Standard Specification for Steel Bars, Carbon and Alloy, Hot-Wrought, General Requirements for[1]

This standard is issued under the fixed designation A 29/A 29M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification[2] covers a group of common requirements which, unless otherwise specified in the purchase order or in an individual specification, shall apply to carbon and alloy steel bars under each of the following ASTM specifications (or under any other ASTM specification which invokes this specification or portions thereof):

Title of Specification	ASTM Designation[A]
Hot-Rolled Carbon Steel Bars:	
Steel Bars, Carbon, Quenched and Tempered	A 321
Steel Bars and Shapes, Carbon Rolled from "T" Rails	A 499
Steel Bars, Carbon, Merchant Quality, M-Grades	A 575
Steel Bars, Carbon, Hot-Wrought, Special Quality	A 576
Steel Bars, Carbon, Merchant Quality, Mechanical Properties	A 663
Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties	A 675
Steel Bars for Springs, Carbon and Alloy	A 689
Cold-Finished Carbon Steel Bars:	
Steel Bars, Carbon, Cold-Finished, Standard Quality	A 108
Stress-Relieved Steel Bars Subject to Mechanical Property Requirements, Cold-Drawn Carbon	A 311/A 311M
Hot-Rolled Alloy Steel Bars:	
Steel Bars, Alloy, Standard Grades	A 322
Steel Bars, Alloy, Subject to End-Quench Hardenability Requirements	A 304
Steel Bars, Alloy, Hot-Wrought or Cold-Finished, Quenched and Tempered	A 434
Steel Bars, Alloy, Hot-Wrought, for Elevated Temperature or Pressure-Containing Parts, or Both	A 739
Cold-Finished Alloy Steel Bars:	
Steel Bars, Alloy, Hot-Rolled or Cold-Finished, Quenched and Tempered	A 434
Steel Bars, Carbon, Hot-Wrought or Cold-Finished, Special Quality, for Pressure Piping Components	A 696

[A] These designations refer to the latest issue of the respective specifications, which appear either in the *Annual Book of ASTM Standards*, Vol 01.05, or as reprints obtainable from ASTM.

1.2 In case of any conflict in requirements, the requirements of the purchase order, the individual material specification, and this general specification shall prevail in the sequence named.

1.3 The values stated in inch-pound units or SI units are to be regarded as the standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.4 For purposes of determining conformance to this specification and the various material specifications referenced in 1.1, dimensional values shall be rounded to the nearest unit in the right-hand place of figures used in expressing the limiting values in accordance with the rounding method of Practice E 29.

NOTE 1—Specification A 29 previously listed dimensional tolerances for cold-finished bars; these are now found in Specification A 108.

2. Referenced Documents

2.1 *ASTM Standards:* [3]

A 108 Specification for Steel Bars, Carbon, Cold-Finished, Standard Quality
A 304 Specification for Carbon and Alloy Steel Bars Subject to End-Quench Hardenability Requirements
A 311 Specification for Cold-Drawn, Stress-Relieved Carbon Steel Bars Subject to Mechanical Property Requirements
A 321 Specification for Steel Bars, Carbon, Quenched and Tempered
A 322 Specfication for Steel Bars, Alloy, Standard Grades
A 331 Specification for Steel Bars, Alloy, Cold-Finished
A 370 Test Methods and Definitions for Mechanical Testing of Steel Products
A 434 Specification for Steel Bars, Alloy, Hot-Wrought or Cold-Finished, Quenched and Tempered
A 499 Specification for Steel Bars and Shapes, Carbon Rolled from "T" Rails
A 575 Specification for Steel Bars, Carbon, Merchant Quality, M-Grade

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-29/SA-29M in Section II of that Code.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard.**

A 576 Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality
A 663 Specification for Steel Bars, Carbon, Merchant Quality, Mechanical Properties
A 675 Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties
A 689 Specification for Carbon and Alloy Steel Bars for Springs
A 695 Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality, for Fluid Power Applications[4]
A 696 Specification for Steel Bars, Carbon, Hot-Wrought or Cold-Finished, Special Quality for Pressure Piping Components
A 700 Practices for Packaging, Marking, and Loading Methods for Steel Products for Domestic Shipment
A 739 Specification for Steel Bars, Alloy, Hot-Wrought, for Elevated Temperature or Pressure-Containing Parts, or Both
A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products
E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E 112 Test Methods for Determining the Average Grain Size

2.2 *Federal Standards:*
Fed. Std. No. 123 Marking for Shipment (Civil Agencies)[5]
Fed. Std. No. 183 Continuous Identification Marking of Iron and Steel Products[5]

2.3 *Military Standard:*
MIL-STD-163 Steel Mill Products—Preparation for Shipment and Storage[5]

2.4 *Other Standards:*
AIAG B-1 Bar Code Symbology Standard for 3-of-9 Bar Codes[6]
AIAGB-5 02.00 Primary Metals Tag Application Standard[6]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *Hot-Wrought Steel Bars*—Steel bars produced by hot forming ingots, blooms, billets, or other semifinished forms to yield straight lengths (or coils, depending upon size, section, and mill equipment) in sections which are uniform throughout their length, and in the following sections and sizes:

3.1.1.1 *Rounds*, 7⁄32 to 10.0 in. [5.5 to 250 mm], inclusive,

3.1.1.2 *Squares*, 7⁄32 to 6.0 in. [6 to 160 mm], inclusive,

3.1.1.3 *Round-Cornered Squares*, 7⁄32 to 8.0 in. [6 to 200 mm], inclusive,

3.1.1.4 *Flats*, 1⁄4 to 8 in. inclusive, in width: 13⁄64 in. in minimum thickness up to 6 in. in width; and 0.230 in. in minimum thickness for over 6 to 8 in. in width, inclusive [over 5 mm in thickness up to 150 mm in width; and over 6 mm in thickness for over 150 mm through 200 mm in width]. Maximum thickness for all widths is 4 in. [100 mm].

3.1.1.5 *Hexagons and Octagons*, 1⁄4 to 4 1⁄16 in. [6 to 103 mm], inclusive, between parallel surfaces,

3.1.1.6 *Bar Size Shapes*—Angles, channels, tees, zees, when their greatest cross-sectional dimension is under 3 in. [75 mm], and

3.1.1.7 *Special Bar Sections*—Half-rounds, ovals, half-ovals, other special bar size sections.

3.1.2 *Cold-Finished Steel Bars*—Steel bars produced by cold finishing previously hot-wrought bars by means of cold drawing, cold forming, turning, grinding, or polishing (singly or in combination) to yield straight lengths or coils in sections which are uniform throughout their length and in the following sections and sizes:

3.1.2.1 *Rounds*, 9 in. [230 mm] and under in diameter,

3.1.2.2 *Squares*, 6 in. [150 mm] and under between parallel surfaces,

3.1.2.3 *Hexagons*, 4 in. [100 mm] and under between parallel surfaces,

3.1.2.4 *Flats*, 1⁄8 in. [3 mm] and over in thickness and not over 12 in. [300 mm] in width, and

3.1.2.5 *Special Bar Sections*.

3.1.3 *Lot*—Unless otherwise specified in the contract or order, a lot shall consist of all bars submitted for inspection at the same time of the same heat, condition, finish, size, or shape. For bars specified in the quenched and tempered condition, when heat treated in batch-type furnaces, a lot shall consist of all bars from the same heat, of the same prior condition, the same size, and subjected to the same heat treatment in one tempering charge. For bars specified in the quenched and tempered condition, when heat treated without interruption in a continuous-type furnace, a lot shall consist of all bars from the same heat, of the same prior condition, of the same size, and subjected to the same heat treatment.

[4] Withdrawn.
[5] Copies of military specifications, military standards, and federal standards required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer, or from the Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.
[6] Available from Automotive Industry Action Group, North Park Plaza, Ste. 830, 17117 W. Nine Mile Rd., Southfield, MI 48075.

TABLE 1 Grade Designations and Chemical Compositions of Carbon Steel Bars

Grade Designation	Heat Chemical Ranges and Limits, %			
	Carbon	Manganese	Phosphorus, max	Sulfur, max[A]
	Nonresulfurized Carbon Steels[B,C,D,E,F]			
1005	0.06 max	0.35 max	0.040	0.050
1006	0.08 max	0.25–0.40	0.040	0.050
1008	0.10 max	0.30–0.50	0.040	0.050
1010	0.08–0.13	0.30–0.60	0.040	0.050
1011	0.08–0.13	0.60–0.90	0.040	0.050

TABLE 1 *Continued*

Grade Designation	Heat Chemical Ranges and Limits, %			
	Carbon	Manganese	Phosphorus, max	Sulfur, max[A]
1012	0.10–0.15	0.30–0.60	0.040	0.050
1013	0.11–0.16	0.50–0.80	0.040	0.050
1015	0.13–0.18	0.30–0.60	0.040	0.050
1016	0.13–0.18	0.60–0.90	0.040	0.050
1017	0.15–0.20	0.30–0.60	0.040	0.050
1018	0.15–0.20	0.60–0.90	0.040	0.050
1019	0.15–0.20	0.70–1.00	0.040	0.050
1020	0.18–0.23	0.30–0.60	0.040	0.050
1021	0.18–0.23	0.60–0.90	0.040	0.050
1022	0.18–0.23	0.70–1.00	0.040	0.050
1023	0.20–0.25	0.30–0.60	0.040	0.050
1025	0.22–0.28	0.30–0.60	0.040	0.050
1026	0.22–0.28	0.60–0.90	0.040	0.050
1029	0.25–0.31	0.60–0.90	0.040	0.050
1030	0.28–0.34	0.60–0.90	0.040	0.050
1034	0.32–0.38	0.50–0.80	0.040	0.050
1035	0.32–0.38	0.60–0.90	0.040	0.050
1037	0.32–0.38	0.70–1.00	0.040	0.050
1038	0.35–0.42	0.60–0.90	0.040	0.050
1039	0.37–0.44	0.70–1.00	0.040	0.050
1040	0.37–0.44	0.60–0.90	0.040	0.050
1042	0.40–0.47	0.60–0.90	0.040	0.050
1043	0.40–0.47	0.70–1.00	0.040	0.050
1044	0.43–0.50	0.30–0.60	0.040	0.050
1045	0.43–0.50	0.60–0.90	0.040	0.050
1046	0.43–0.50	0.70–1.00	0.040	0.050
1049	0.46–0.53	0.60–0.90	0.040	0.050
1050	0.48–0.55	0.60–0.90	0.040	0.050
1053	0.48–0.55	0.70–1.00	0.040	0.050
1055	0.50–0.60	0.60–0.90	0.040	0.050
1059	0.55–0.65	0.50–0.80	0.040	0.050
1060	0.55–0.65	0.60–0.90	0.040	0.050
1064	0.60–0.70	0.50–0.80	0.040	0.050
1065	0.60–0.70	0.60–0.90	0.040	0.050
1069	0.65–0.75	0.40–0.70	0.040	0.050
1070	0.65–0.75	0.60–0.90	0.040	0.050
1071	0.65–0.70	0.75–1.05	0.040	0.050
1074	0.70–0.80	0.50–0.80	0.040	0.050
1075	0.70–0.80	0.40–0.70	0.040	0.050
1078	0.72–0.85	0.30–0.60	0.040	0.050
1080	0.75–0.88	0.60–0.90	0.040	0.050
1084	0.80–0.93	0.60–0.90	0.040	0.050
1086	0.80–0.93	0.30–0.50	0.040	0.050
1090	0.85–0.98	0.60–0.90	0.040	0.050
1095	0.90–1.03	0.30–0.50	0.040	0.050
Resulfurized Carbon Steels[B,D,F]				
1108	0.08–0.13	0.60–0.80	0.040	0.08–0.13
1109	0.08–0.13	0.60–0.90	0.040	0.08–0.13
1110	0.08–0.13	0.30–0.60	0.040	0.08–0.13
1116	0.14–0.20	1.10–1.40	0.040	0.16–0.23
1117	0.14–0.20	1.00–1.30	0.040	0.08–0.13
1118	0.14–0.20	1.30–1.60	0.040	0.08–0.13
1119	0.14–0.20	1.00–1.30	0.040	0.24–0.33
1132	0.27–0.34	1.35–1.65	0.040	0.08–0.13
1137	0.32–0.39	1.35–1.65	0.040	0.08–0.13
1139	0.35–0.43	1.35–1.65	0.040	0.13–0.20
1140	0.37–0.44	0.70–1.00	0.040	0.08–0.13
1141	0.37–0.45	1.35–1.65	0.040	0.08–0.13
1144	0.40–0.48	1.35–1.65	0.040	0.24–0.33
1145	0.42–0.49	0.70–1.00	0.040	0.04–0.07
1146	0.42–0.49	0.70–1.00	0.040	0.08–0.13
1151	0.48–0.55	0.70–1.00	0.040	0.08–0.13

Rephosphorized and Resulfurized Carbon Steels[D,G,F]

Grade Designation	Carbon	Manganese	Phosphorous	Sulfur	Lead
1211	0.13 max	0.60–0.90	0.07–0.12	0.10–0.15	...
1212	0.13 max	0.70–1.00	0.07–0.12	0.16–0.23	...
1213	0.13 max	0.70–1.00	0.07–0.12	0.24–0.33	...
1215	0.09 max	0.75–1.05	0.04–0.09	0.26–0.35	...
12L13	0.13 max	0.70–1.00	0.07–0.12	0.24–0.33	0.15–0.35
12L14	0.15 max	0.85–1.15	0.04–0.09	0.26–0.35	0.15–0.35

TABLE 1 *Continued*

Rephosphorized and Resulfurized Carbon Steels[D,G,F]					
Grade Designation	Carbon	Manganese	Phosphorous	Sulfur	Lead
12L15	0.09 max	0.75–1.05	0.04–0.09	0.26–0.35	0.15–0.35

High-Manganese Carbon Steels[B,C,D,E,F]					
Grade Designation	Former Designation	Carbon	Manganese	Phosphorous, max	Sulfur, max
1513	...	0.10–0.16	1.10–1.40	0.040	0.050
1518	...	0.15–0.21	1.10–1.40	0.040	0.050
1522	...	0.18–0.24	1.10–1.40	0.040	0.050
1524	1024	0.19–0.25	1.35–1.65	0.040	0.050
1525	...	0.23–0.29	0.80–1.10	0.040	0.050
1526	...	0.22–0.29	1.10–1.40	0.040	0.050
1527	1027	0.22–0.29	1.20–1.50	0.040	0.050
1536	1036	0.30–0.37	1.20–1.50	0.040	0.050
1541	1041	0.36–0.44	1.35–1.65	0.040	0.050
1547	...	0.43–0.51	1.35–1.65	0.040	0.050
1548	1048	0.44–0.52	1.10–1.40	0.040	0.050
1551	1051	0.45–0.56	0.85–1.15	0.040	0.050
1552	1052	0.47–0.55	1.20–1.50	0.040	0.050
1561	1061	0.55–0.65	0.75–1.05	0.040	0.050
1566	1066	0.60–0.71	0.85–1.15	0.040	0.050
1572	1072	0.65–0.76	1.00–1.30	0.040	0.050

Heat Chemical Ranges and Limits, percent				
Merchant Quality M Series Carbon Steel Bars				
Grade Designation	Carbon	Manganese[G]	Phosphorous, max	Sulfur, max
M 1008	0.10 max	0.25–0.60	0.04	0.05
M 1010	0.07–0.14	0.25–0.60	0.04	0.05
M 1012	0.09–0.16	0.25–0.60	0.04	0.05
M 1015	0.12–0.19	0.25–0.60	0.04	0.05
M 1017	0.14–0.21	0.25–0.60	0.04	0.05
M 1020	0.17–0.24	0.25–0.60	0.04	0.05
M 1023	0.19–0.27	0.25–0.60	0.04	0.05
M 1025	0.20–0.30	0.25–0.60	0.04	0.05
M 1031	0.26–0.36	0.25–0.60	0.04	0.05
M 1044	0.40–0.50	0.25–0.60	0.04	0.05

[A] Maximum unless otherwise indicated.
[B] When silicon is required, the following ranges and limits are commonly specified: 0.10 %, max, 0.10 % to 0.20 %, 0.15 % to 0.35 %, 0.20 % to 0.40 %, or 0.30 % to 0.60 %.
[C] Copper can be specified when required as 0.20 % minimum.
[D] When lead is required as an added element to a standard steel, a range of 0.15 to 0.35 % inclusive is specified. Such a steel is identified by inserting the letter "L" between the second and third numerals of the grade designation, for example, 10 L 45. A cast or heat analysis is not determinable when lead is added to the ladle stream.
[E] When boron treatment for killed steels is specified, the steels can be expected to contain 0.0005 to 0.003 % boron. If the usual titanium additive is not permitted, the steels can be expected to contain up to 0.005 % boron.
[F] The elements bismuth, calcium, selenium, or tellurium may be added as agreed upon between purchaser and supplier.
[G] Unless prohibited by the purchaser, the manganese content may exceed 0.60 % on heat analysis to a maximum of 0.75 %, provided the carbon range on heat analysis has the minimum and maximum reduced by 0.01 % for each 0.05 % manganese over 0.60 %.

TABLE 2 Grade Designations and Chemical Compositions of Alloy Steel Bars

NOTE 1—Small quantities of certain elements are present in alloy steels which are not specified or required. These elements are considered as incidental and may be present to the following maximum amounts: copper, 0.35 %; nickel, 0.25 %; chromium, 0.20 % and molybdenum, 0.06 %.

NOTE 2—Where minimum and maximum sulfur content is shown it is indicative of resulfurized steel.

NOTE 3—The chemical ranges and limits shown in Table 2 are produced to product analysis tolerances shown in Table 6.

NOTE 4—Standard alloy steels can be produced with a lead range of 0.15–0.35 %. Such steels are identified by inserting the letter "L" between the second and third numerals of the AISI number, for example, 41 L 40. A cast or heat analysis is not determinable when lead is added to the ladle stream.

Grade Designation	Heat Chemical Ranges and Limits, %							
	Carbon	Manganese	Phosphorus, max	Sulfur, max	Silicon[A]	Nickel	Chromium	Molybdenum
1330	0.28–0.33	1.60–1.90	0.035	0.040	0.15 to 0.35	...	...	...
1335	0.33–0.38	1.60–1.90	0.035	0.040	0.15 to 0.35	...	...	...
1340	0.38–0.43	1.60–1.90	0.035	0.040	0.15 to 0.35	...	...	...
1345	0.43–0.48	1.60–1.90	0.035	0.040	0.15 to 0.35			
4012	0.09–0.14	0.75–1.00	0.035	0.040	0.15 to 0.35	...	...	0.15–0.25
4023	0.20–0.25	0.70–0.90	0.035	0.040	0.15 to 0.35	...	...	0.20–0.30
4024	0.20–0.25	0.70–0.90	0.035	0.035–0.050	0.15 to 0.35	...	...	0.20–0.30
4027	0.25–0.30	0.70–0.90	0.035	0.040	0.15 to 0.35	...	...	0.20–0.30

TABLE 2 *Continued*

Grade Designation	Heat Chemical Ranges and Limits, %							
	Carbon	Manganese	Phosphorus, max	Sulfur, max	Silicon[A]	Nickel	Chromium	Molybdenum
4028	0.25–0.30	0.70–0.90	0.035	0.035–0.050	0.15 to 0.35	...	...	0.20–0.30
4032	0.30–0.35	0.70–0.90	0.035	0.040	0.15 to 0.35	...	...	0.20–0.30
4037	0.35–0.40	0.70–0.90	0.035	0.040	0.15 to 0.35	...	...	0.20–0.30
4042	0.40–0.45	0.70–0.90	0.035	0.040	0.15 to 0.35	...	...	0.20–0.30
4047	0.45–0.50	0.70–0.90	0.035	0.040	0.15 to 0.35	...	...	0.20–0.30
4118	0.18–0.23	0.70–0.90	0.035	0.040	0.15 to 0.35	...	0.40–0.60	0.08–0.15
4120	0.18–0.23	0.90–1.20	0.035	0.040	0.15 to 0.35	...	0.40–0.60	0.13–0.20
4121	0.18–0.23	0.75–1.00	0.035	0.040	0.15 to 0.35	...	0.45–0.65	0.20–0.30
4130	0.28–0.33	0.40–0.60	0.035	0.040	0.15 to 0.35	...	0.80–1.10	0.15–0.25
4135	0.33–0.38	0.70–0.90	0.035	0.040	0.15 to 0.35	...	0.80–1.10	0.15–0.25
4137	0.35–0.40	0.70–0.90	0.035	0.040	0.15 to 0.35	...	0.80–1.10	0.15–0.25
4140	0.38–0.43	0.75–1.00	0.035	0.040	0.15 to 0.35	...	0.80–1.10	0.15–0.25
4142	0.40–0.45	0.75–1.00	0.035	0.040	0.15 to 0.35	...	0.80–1.10	0.15–0.25
4145	0.43–0.48	0.75–1.00	0.035	0.040	0.15 to 0.35	...	0.80–1.10	0.15–0.25
4147	0.45–0.50	0.75–1.00	0.035	0.040	0.15 to 0.35	...	0.80–1.10	0.15–0.25
4150	0.48–0.53	0.75–1.00	0.035	0.040	0.15 to 0.35	...	0.80–1.10	0.15–0.25
4161	0.56–0.64	0.75–1.00	0.035	0.040	0.15 to 0.35	...	0.70–0.90	0.25–0.35
4320	0.17–0.22	0.45–0.65	0.035	0.040	0.15 to 0.35	1.65–2.00	0.40–0.60	0.20–0.30
4340	0.38–0.43	0.60–0.80	0.035	0.040	0.15 to 0.35	1.65–2.00	0.70–0.90	0.20–0.30
E4340	0.38–0.43	0.65–0.85	0.025	0.025	0.15 to 0.35	1.65–2.00	0.70–0.90	0.20–0.30
4419	0.18–0.23	0.45–0.65	0.035	0.040	0.15 to 0.35	...	...	0.45–0.60
4422	0.20–0.25	0.70–0.90	0.035	0.040	0.15 to 0.35	...	...	0.35–0.45
4427	0.24–0.29	0.70–0.90	0.035	0.040	0.15 to 0.35	...	...	0.35–0.45
4615	0.13–0.18	0.45–0.65	0.035	0.040	0.15 to 0.35	1.65–2.00	...	0.20–0.30
4620	0.17–0.22	0.45–0.65	0.035	0.040	0.15 to 0.35	1.65–2.00	...	0.20–0.30
4621	0.18–0.23	0.70–0.90	0.035	0.040	0.15 to 0.35	1.65–2.00	...	0.20–0.30
4626	0.24–0.29	0.45–0.65	0.035	0.040	0.15 to 0.35	0.70–1.00	...	0.15–0.25
4715	0.13–0.18	0.70–0.90	0.035	0.040	0.15 to 0.35	0.70–1.00	0.45–0.65	0.45–0.60
4718	0.16–0.21	0.70–0.90	0.035	0.040	0.15 to 0.35	0.90–1.20	0.35–0.55	0.30–0.40
4720	0.17–0.22	0.50–0.70	0.035	0.040	0.15 to 0.35	0.90–1.20	0.35–0.55	0.15–0.25
4815	0.13–0.18	0.40–0.60	0.035	0.040	0.15 to 0.35	3.25–3.75	...	0.20–0.30
4817	0.15–0.20	0.40–0.60	0.035	0.040	0.15 to 0.35	3.25–3.75	...	0.20–0.30
4820	0.18–0.23	0.50–0.70	0.035	0.040	0.15 to 0.35	3.25–3.75	...	0.20–0.30
5015	0.12–0.17	0.30–0.50	0.035	0.040	0.15 to 0.35	...	0.30–0.50	...
5046	0.43–0.48	0.75–1.00	0.035	0.040	0.15 to 0.35	...	0.20–0.35	...
5115	0.13–0.18	0.70–0.90	0.035	0.040	0.15 to 0.35	...	0.70–0.90	...
5120	0.17–0.22	0.70–0.90	0.035	0.040	0.15 to 0.35	...	0.70–0.90	...
5130	0.28–0.33	0.70–0.90	0.035	0.040	0.15 to 0.35	...	0.80–1.10	...
5132	0.30–0.35	0.60–0.80	0.035	0.040	0.15 to 0.35	...	0.75–1.00	...
5135	0.33–0.38	0.60–0.80	0.035	0.040	0.15 to 0.35	...	0.80–1.05	...
5140	0.38–0.43	0.70–0.90	0.035	0.040	0.15 to 0.35	...	0.70–0.90	...
5145	0.43–0.48	0.70–0.90	0.035	0.040	0.15 to 0.35	...	0.70–0.90	...
5147	0.46–0.51	0.70–0.95	0.035	0.040	0.15 to 0.35	...	0.85–1.15	...
5150	0.48–0.53	0.70–0.90	0.035	0.040	0.15 to 0.35	...	0.70–0.90	...
5155	0.51–0.59	0.70–0.90	0.035	0.040	0.15 to 0.35	...	0.70–0.90	...
5160	0.56–0.61	0.75–1.00	0.035	0.040	0.15 to 0.35	...	0.70–0.90	...
E50100	0.98–1.10	0.25–0.45	0.025	0.025	0.15 to 0.35	...	0.40–0.60	...
E51100	0.98–1.10	0.25–0.45	0.025	0.025	0.15 to 0.35	...	0.90–1.15	...
E52100	0.98–1.10	0.25–0.45	0.025	0.025	0.15 to 0.35	...	1.30–1.60	...
52100[B]	0.93–1.05	0.25–0.45	0.025	0.015	0.15 to 0.35	...	1.35–1.60	...
6118	0.16–0.21	0.50–0.70	0.035	0.040	0.15 to 0.35	...	0.50–0.70	(0.10–0.15 V)
6150	0.48–0.53	0.70–0.90	0.035	0.040	0.15 to 0.35	...	0.80–1.10	(0.15 min V)
8115	0.13–0.18	0.70–0.90	0.035	0.040	0.15 to 0.35	0.20–0.40	0.30–0.50	0.08–0.15
8615	0.13–0.18	0.70–0.90	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.15–0.25
8617	0.15–0.20	0.70–0.90	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.15–0.25
8620	0.18–0.23	0.70–0.90	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.15–0.25
8622	0.20–0.25	0.70–0.90	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.15–0.25
8625	0.23–0.28	0.70–0.90	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.15–0.25
8627	0.25–0.30	0.70–0.90	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.15–0.25
8630	0.28–0.33	0.70–0.90	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.15–0.25
8637	0.35–0.40	0.75–1.00	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.15–0.25
8640	0.38–0.43	0.75–1.00	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.15–0.25
8642	0.40–0.45	0.75–1.00	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.15–0.25
8645	0.43–0.48	0.75–1.00	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.15–0.25
8650	0.48–0.53	0.75–1.00	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.15–0.25
8655	0.51–0.59	0.75–1.00	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.15–0.25
8660	0.56–0.64	0.75–1.00	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.15–0.25
8720	0.18–0.23	0.70–0.90	0.035	0.040	0.15 to 0.35	0.40–0.7	0.40–0.60	0.20–0.30
8740	0.38–0.43	0.75–1.00	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.20–0.30
8822	0.20–0.25†	0.75–1.00	0.035	0.040	0.15 to 0.35	0.40–0.70	0.40–0.60	0.30–0.40
9254	0.51–0.59	0.60–0.80	0.035	0.040	1.20–1.60	...	0.60–0.80	...

TABLE 2 *Continued*

Grade Designation	Heat Chemical Ranges and Limits, %							
	Carbon	Manganese	Phosphorus, max	Sulfur, max	Silicon[A]	Nickel	Chromium	Molybdenum
9255	0.51–0.59	0.70–0.95	0.035	0.040	1.80–2.20	...	...	...
9259	0.56–0.64	0.75–1.00	0.035	0.040	0.70–1.10	. . .	0.45–0.65	. . .
9260	0.56–0.64	0.75–1.00	0.035	0.040	1.80–2.20	...	...	...
E9310	0.08–0.13	0.45–0.65	0.025	0.025	0.15 to 0.30	3.00–3.50	1.00–1.40	0.08–0.15
Standard Boron Steels[C]								
50B44	0.43–0.48	0.75–1.00	0.035	0.040	0.15–0.35	. . .	0.20–0.60	. . .
50B46	0.44–0.49	0.75–1.00	0.035	0.040	0.15–0.35	. . .	0.20–0.35	. . .
50B50	0.48–0.53	0.75–1.00	0.035	0.040	0.15–0.35	. . .	0.40–0.60	. . .
50B60	0.56–0.64	0.75–1.00	0.035	0.040	0.15–0.35	. . .	0.40–0.60	. . .
51B60	0.56–0.64	0.75–1.00	0.035	0.040	0.15–0.35	. . .	0.70–0.90	. . .
81B45	0.43–0.48	0.75–1.00	0.035	0.040	0.15–0.35	0.20–0.40	0.35–0.55	0.08–0.15
94B17	0.15–0.20	0.75–1.00	0.035	0.040	0.15–0.35	0.30–0.60	0.30–0.50	0.80–0.15
94B30	0.28–0.33	0.75–1.00	0.035	0.040	0.15–0.35	0.30–0.60	0.30–0.50	0.08–0.15

[A] Silicon may be specified by the purchaser as 0.10% maximum. The need for 0.10% maximum generally relates to severe cold-formed parts.
[B] The purchaser may also require the following maximums: copper 0.30 %; aluminum 0.050 %; oxygen 0.0015 %.
[C] These steels can be expected to contain 0.0005 to 0.003 % boron. If the usual titanium additive is not permitted, the steels can be expected to contain up to 0.005 % boron.
† Editorially corrected.

4. Chemical Composition

4.1 *Limits*:

4.1.1 The chemical composition shall conform to the requirements specified in the purchase order or the individual product specifications. For convenience the grades commonly specified for carbon steel bars are shown in Tables 1 and 2. Bars may be ordered to these grade designations and when so ordered shall conform to the specified limits by heat analysis.

4.1.2 When compositions other than those shown in Tables 1 and 2 are required, the composition limits shall be prepared using the ranges and limits shown in Table 3 for carbon steel and Table 4 for alloy steel.

4.2 *Heat or Cast Analysis*:

4.2.1 The chemical composition of each heat or cast shall be determined by the manufacturer in accordance with Test Methods, Practices, and Terminology A 751.

4.2.2 The heat or cast analysis shall conform to the requirements specified in the product specification or purchase order. These can be the heat chemical range and limit for a grade designated in Tables 1 and 2, or another range and limit in accordance with 4.1.2, or with requirements of the product specification.

NOTE 2—Heat analysis for lead is not determinable since lead is added to the ladle stream while each ingot is poured. When specified as an added element to a standard steel, the percentage of lead is reported as 0.15 to 0.35 incl, which is the range commonly specified for this element.

4.2.3 If requested or required, the heat analysis shall be reported to the purchaser or his representative.

4.2.4 Reporting of significant figures and rounding shall be in accordance with Test Methods, Practices, and Terminology A 751.

4.3 *Product Analysis*:

4.3.1 Merchant quality carbon bar steel is not subject to rejection for product analysis unless misapplication of a heat is clearly indicated.

4.3.2 Analyses may be made by the purchaser from finished bars other than merchant quality representing each heat of open-hearth, basic-oxygen, or electric-furnace steel. The chemical composition thus determined shall not vary from the limits specified in the applicable specification by more than the amounts prescribed in Table 5 and Table 6, but the several determinations of any element, excluding lead, in a heat may not vary both above and below the specified range. Rimmed or capped steel is characterized by a lack of homogeneity in its composition, especially for the elements carbon, phosphorus, and sulfur; therefore, when rimmed or capped steel is specified or required, the limitations for these elements shall not be applicable. Because of the degree to which phosphorus and sulfur segregate, the limitations for these elements shall not be applicable to rephosphorized or resulfurized steels.

4.3.3 Samples for product analysis shall be taken by one of the following methods:

4.3.3.1 Applicable to small sections whose cross-sectional area does not exceed 0.75 in.^{2} [500 mm^2] such as rounds, squares, hexagons, etc. Chips are taken by milling or machining the full cross section of the piece. Drilling is not a feasible method for sampling sizes 0.75 in.^{2} and smaller.

4.3.3.2 Applicable to products where the width of the cross section greatly exceeds the thickness, such as bar size shapes and light flat bars. Chips are taken by drilling entirely through the steel at a point midway between the edge and the middle of the section, or by milling or machining the entire cross section.

4.3.3.3 Applicable to large rounds, squares semifinished, etc. Chips are taken at any point midway between the outside and the center of the piece by drilling parallel to the axis or by milling or machining the full cross section. In cases where these methods are not practicable, the piece may be drilled on the side, but chips are not taken until they represent the portion midway between the outside and the center.

4.3.3.4 When the steel is subject to tension test requirements, the tension test specimen can also be used for product analysis. In that case, chips for product analysis can be taken by drilling entirely through the tension test specimens or by the method described in 4.3.3.1.

TABLE 3 Heat Analysis Chemical Ranges and Limits of Carbon Steel Bars

Element	Chemical Ranges and Limits, %		
	When Maximum of Specified Elements is:	Range	Lowest Maximum
Carbon[A]	...	...	0.06
	to 0.12, incl	...	...
	over 0.12 to 0.25, incl	0.05	...
	over 0.25 to 0.40, incl	0.06	...
	over 0.40 to 0.55, incl	0.07	...
	over 0.55 to 0.80, incl	0.10	...
	over 0.80	0.13	...
Manganese	...	...	0.35
	to 0.40, incl	0.15	...
	over 0.40 to 0.50, incl	0.20	...
	over 0.50 to 1.65, incl	0.30	...
Phosphorus	to 0.040, incl	...	0.040[B]
	over 0.040 to 0.08, incl	0.03	...
	over 0.08 to 0.13, incl	0.05	...
Sulfur	to 0.050, incl	...	0.050[B]
	over 0.050 to 0.09, incl	0.03	...
	over 0.09 to 0.15, incl	0.05	...
	over 0.15 to 0.23, incl	0.07	...
	over 0.23 to 0.50, incl	0.09	...
Silicon[C]	...	...	0.10
	to 0.10, incl	...	...
	over 0.10 to 0.15, incl	0.08	...
	over 0.15 to 0.20, incl	0.10	...
	over 0.20 to 0.30, incl	0.15	...
	over 0.30 to 0.60, incl	0.20	...
Copper	When copper is required 0.20 min is generally used		
Lead[D]	When lead is required, a range of 0.15 to 0.35 is specified		
Bismuth[E]			
Calcium[E]			
Selenium[E]			
Tellurium[E]			

[A] The carbon ranges shown in the column headed "Range" apply when the specified maximum limit for manganese does not exceed 1.10 %. When the maximum manganese limit exceeds 1.10 %, add 0.01 to the carbon ranges shown above.

[B] For steels produced in merchant quality the phosphorus maximum is 0.04 % and the sulfur maximum is 0.05 %.

[C] It is not common practice to produce a rephosphorized and resulfurized carbon steel to specified limits for silicon because of its adverse effect on machinability.

[D] A cast or heat analysis is not determinable when lead is added to the ladle stream.

[E] Element specification range as agreed upon between purchaser and supplier.

4.3.4 When chips are taken by drilling, the diameter of the drill used shall conform to the following:

Area of Sample Cross Section, in.^{2}(cm^2)	Approximate Drill Diameter, in. (mm)
16 [100] or less	½ [12.5]
Over 16 [100]	1 [25.0]

4.3.5 The minimum number of samples to be taken from material representing the same heat or lot before rejection by the purchaser shall be as follows:

	Minimum Number of Samples
15 tons [15 Mg] and under	4
Over 15 tons [15 Mg]	6

4.3.6 In case the number of pieces in a heat is less than the number of samples required, one sample from each piece shall be considered sufficient.

4.3.7 In the event that product analysis determinations are outside the permissible limits as prescribed in 4.3.2, additional samples shall be analyzed and the acceptability of the heat negotiated between the purchaser and the producer.

4.4 *Referee Analysis*—In case a referee analysis is required and agreed upon to resolve a dispute concerning the results of a chemical analysis, the referee analysis shall be performed in accordance with the latest issue of Test Methods, Practices, and Terminology A 751, unless otherwise agreed upon between the manufacturer and the purchaser.

5. Grain Size Requirement

5.1 *Austenitic Grain Size*:

5.1.1 When a coarse austenitic grain size is specified, the steel shall have a grain size number of 1 to 5 exclusive as determined in accordance with Test Methods E 112. Conformance to this grain size of 70 % of the grains in the area examined shall constitute the basis of acceptance. One test per heat shall be made.

5.1.2 When a fine austenitic grain size is specified, the steel shall have a grain size number of 5 or higher as determined in accordance with Test Methods E 112. Conformance to this grain size of 70 % of the area examined shall constitute the basis of acceptance. One test per heat shall be made unless the provisions of 5.1.2.1 or 5.1.2.2 are exercised.

5.1.2.1 When aluminum is used as the grain refining element, the fine austenitic grain size requirement shall be deemed to be fulfilled if, on heat analysis, the aluminum content is not less than 0.020 % total aluminum or, alternately, 0.015 % acid soluble aluminum. The aluminum content shall be reported. The grain size test specified in 5.1.2 shall be the referee test.

5.1.2.2 By agreement between purchaser and supplier, columbium or vanadium or both may be used for grain refining instead of or with aluminum. When columbium or vanadium is used as a grain refining element, the fine austenitic grain size requirement shall be deemed to be fulfilled if, on heat analysis, the columbium or vanadium content is as follows (the content of the elements shall be reported with the heat analysis):

Steels having 0.25 % carbon or less:	
Cb	0.025 min
V	0.05 min
Steels having over 0.25 % carbon:	
Cb	0.015 min
V	0.02 min
The maximum contents shall be:	
Cb	0.05 max
V	0.08 max
Cb + V	0.06 max

5.1.2.3 When provisions of 5.1.2.1 or 5.1.2.2 are exercised, a grain size test is not required unless specified by the purchaser. Unless otherwise specified, fine austenitic grain size shall be certified using the analysis of grain refining element(s).

5.1.2.4 *Referee Test*—In the event that the chemical analysis of columbium or vanadium does not meet the requirements of 5.1.2.2, the grain size test shown in 5.1.2 shall be the referee test unless an alternative test method is agreed upon between the manufacturer and the purchaser.

TABLE 4 Heat Analysis Chemical Ranges and Limits of Alloy Steel Bars

NOTE 1—Boron steels can be expected to have 0.0005 % minimum boron content.

NOTE 2—Alloy steels can be produced with a lead range of 0.15–0.35 %. A cast or heat analysis is not determinable when lead is added to the ladle stream.

Element	Chemical Ranges and Limits, %			
	When Maximum of Specified Element is:	Open-Hearth or Basic-Oxygen Steel	Electric Furnace Steel	Maximum Limit, %[A]
Carbon	To 0.55, incl	0.05	0.05	
	Over 0.55–0.70, incl	0.08	0.07	
	Over 0.70 to 0.80, incl	0.10	0.09	
	Over 0.80–0.95, incl	0.12	0.11	
	Over 0.95–1.35, incl	0.13	0.12	
Manganese	To 0.60, incl	0.20	0.15	
	Over 0.60–0.90, incl	0.20	0.20	
	Over 0.90–1.05, incl	0.25	0.25	
	Over 1.05–1.90, incl	0.30	0.30	
	Over 1.90–2.10, incl	0.40	0.35	
Phosphorus	Basic open-hearth or basic-oxygen steel			0.035
	Acid open-hearth steel			0.050
	Basic electric-furnace steel			0.025
	Acid electric-furnace steel			0.050
Sulfur	To 0.050, incl	0.015	0.015	
	Over 0.050–0.07, incl	0.02	0.02	
	Over 0.07–0.10, incl	0.04	0.04	
	Over 0.10–0.14, incl	0.05	0.05	
	Basic open-hearth or basic-oxygen steel			0.040
	Acid open-hearth steel			0.050
	Basic electric-furnace steel			0.025
	Acid electric-furnace steel			0.050
Silicon	To 0.20, incl	0.08	0.08	
	Over 0.20–0.30, incl	0.15	0.15	
	Over 0.30–0.60, incl	0.20	0.20	
	Over 0.60–1.00, incl	0.30	0.30	
	Over 1.00–2.20, incl	0.40	0.35	
	Acid steels[B]			
Nickel	To 0.50, incl	0.20	0.20	
	Over 0.50–1.50, incl	0.30	0.30	
	Over 1.50–2.00, incl	0.35	0.35	
	Over 2.00–3.00, incl	0.40	0.40	
	Over 3.00–5.30, incl	0.50	0.50	
	Over 5.30–10.00, incl	1.00	1.00	
Chromium	To 0.40, incl	0.15	0.15	
	Over 0.40–0.90, incl	0.20	0.20	
	Over 0.90–1.05, incl	0.25	0.25	
	Over 1.05–1.60, incl	0.30	0.30	
	Over 1.60–1.75, incl	[C]	0.35	
	Over 1.75–2.10, incl	[C]	0.40	
	Over 2.10–3.99, incl	[C]	0.50	
Molybdenum	To 0.10, incl	0.05	0.05	
	Over 0.10–0.20, incl	0.07	0.07	
	Over 0.20–0.50, incl	0.10	0.10	
	Over 0.50–0.80, incl	0.15	0.15	
	Over 0.80–1.15, incl	0.20	0.20	
Tungsten	To 0.50, incl	0.20	0.20	
	Over 0.50–1.00, incl	0.30	0.30	
	Over 1.00–2.00, incl	0.50	0.50	
	Over 2.00–4.00, incl	0.60	0.60	
Vanadium	To 0.25, incl	0.05	0.05	
	Over 0.25–0.50, incl	0.10	0.10	
Aluminum	Up to 0.10, incl	0.05	0.05	
	Over 0.10–0.20, incl	0.10	0.10	
	Over 0.20–0.30, incl	0.15	0.15	
	Over 0.30–0.80, incl	0.25	0.25	
	Over 0.80–1.30, incl	0.35	0.35	
	Over 1.30–1.80, incl	0.45	0.45	
Copper	To 0.60, incl	0.20	0.20	
	Over 0.60–1.50, incl	0.30	0.30	
	Over 1.50–2.00, incl	0.35	0.35	

[A] Applies to only nonrephosphorized and nonresulfurized steels.
[B] Minimum silicon limit for acid open-hearth or acid electric-furnace alloy steels is 0.15 %.
[C] Not normally produced in open-hearth.

TABLE 5 Permissible Variations for Product Analysis of Carbon Steel

Element	Limit, or Maximum of Specified Range, %	Over Maximum Limit, %	Under Minimum Limit, %
Carbon[A]	0.25 and under	0.02	0.02
	over 0.25 to 0.55, incl	0.03	0.03
	over 0.55	0.04	0.04
Manganese	0.90 and under	0.03	0.03
	over 0.90 to 1.65, incl	0.06	0.06
Phosphorus[A,B]	basic steels	0.008	...
	acid bessemer steel	0.01	0.01
Sulfur[A,B]		0.008	...
Silicon	0.35 and under	0.02	0.02
	over 0.35 to 0.60, incl	0.05	0.05
Copper	under minimum only	...	0.02
Lead[C]	0.15 to 0.35, incl	0.03	0.03

[A] Rimmed and capped steels are not subject to rejection on product analysis unless misapplication is clearly indicated.
[B] Resulfurized or rephosphorized steels are not subject to rejection on product analysis for these elements unless misapplication is clearly indicated.
[C] Product analysis tolerance for lead applies both over and under to a specified range of 0.15 to 0.35 %.

TABLE 6 Permissible Variations for Product Analysis of Alloy Steel

Elements	Limit, or Maximum of Specified Range, %	Permissible Variations Over Maximum Limit or Under Minimum Limit, %
Carbon	0.30 and under	0.01
	over 0.30 to 0.75, incl	0.02
	over 0.75	0.03
Manganese	0.90 and under	0.03
	over 0.90 to 2.10, incl	0.04
Phosphorus	over maximum only	0.005
Sulfur	0.060 and under	0.005
Silicon	0.40 and under	0.02
	over 0.40 to 2.20, incl	0.05
Nickel	1.00 and under	0.03
	over 1.00 to 2.00, incl	0.05
	over 2.00 to 5.30, incl	0.07
	over 5.30 to 10.00, incl	0.10
Chromium	0.90 and under	0.03
	over 0.90 to 2.10, incl	0.05
	over 2.10 to 3.99, incl	0.10
Molybdenum	0.20 and under	0.01
	over 0.20 to 0.40, incl	0.02
	over 0.40 to 1.15, incl	0.03
Vanadium	0.10 and under	0.01
	over 0.10 to 0.25, incl	0.02
	over 0.25 to 0.50, incl	0.03
	minimum value specified, under minimum limit only	0.01
Tungsten	1.00 and under	0.04
	over 1.00 to 4.00, incl	0.08
Aluminum	0.10 and under	0.03
	over 0.10 to 0.20, incl	0.04
	over 0.20 to 0.30, incl	0.05
	over 0.30 to 0.80, incl	0.07
	over 0.80 to 1.80, incl	0.10
Lead[A]	0.15 to 0.35, incl	0.03
Copper	to 1.00 incl	0.03
	over 1.00 to 2.00, incl	0.05

[A] Product analysis tolerance for lead applies both over and under to a specified range of 0.15 to 0.35 %.

6. Mechanical Property Requirements

6.1 *Test Specimens*:

6.1.1 *Selection*—Test specimens shall be selected in accordance with the requirements of the applicable product specification or in accordance with Supplement I of the latest issue of Test Methods and Definitions A 370, in the sequence named.

6.1.2 *Preparation*—Unless otherwise specified in the applicable product specification, test specimens shall be prepared in accordance with the latest issue of Test Methods and Definitions A 370, and especially Supplement I thereof.

6.2 *Methods of Mechanical Testing*— All mechanical tests shall be conducted in accordance with the latest issue of Test Methods and Definitions A 370, and especially Supplement I thereof, on steel bar products.

6.3 *Retests*:

6.3.1 If any test specimen shows defective machining or develops flaws, the specimen may be discarded and another substituted.

6.3.2 If the percentage elongation of any tension specimen is less than that specified and any part of the fracture is more than ¾ in. [20 mm] from the center of a 2-in. [50-mm] specimen, or is outside the middle half of the gage length of an 8-in. [200-mm] specimen as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

6.3.3 For "as-wrought" material, if the results for any original tension specimen are within 2000 psi [14 MPa] of the required tensile strength, within 1000 psi [7 MPa] of the required yield point, or within 2 % of the required elongation, retesting shall be permitted. If the original testing required only one test, the retest shall consist of two random tests from the heat or lot involved. If the original testing required two tests of which one failed by the amounts listed in this paragraph, the retest shall be made on one random test from the heat or lot. If the results on the retest specimen or specimens meet the specified requirements, the heat or test lot will be accepted. If the results of one retest specimen do not meet the specified requirements, the material is subject to rejection.

6.3.4 For thermally treated bars, if the results of the mechanical tests do not conform to the requirements specified, two more tests may be selected for each bar failing, and each of these retests shall conform to the requirements of the product specification.

6.3.5 If a bend specimen fails, due to conditions of bending more severe than required by the specification, a retest shall be permitted from the heat or test lot involved for which one random specimen for each original specimen showing failure shall be used. If the results on the retest specimen meet the requirements of the specification, the heat or test lot will be accepted.

7. Dimensions, Mass, and Permissible Variations

7.1 *Hot-Wrought Bars*—The permissible variations for dimensions of hot-wrought carbon and alloy steel bars shall not exceed the applicable limits stated in Annex A1 for inch-pound values and Annex A2 for metric values.

8. Workmanship, Finish, and Appearance

8.1 The material shall be free of injurious defects and shall have a workmanlike finish.

9. Rework and Retreatment

9.1 For thermally treated bars only, the manufacturer may retreat a lot one or more times, and retests shall be made in the same manner as the original tests. Each such retest shall conform to the requirements specified.

10. Inspection

10.1 The inspector representing the purchaser shall have entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests (except product analysis) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

10.2 All required tests and inspection shall be made by the manufacturer prior to shipment.

11. Rejection

11.1 Unless otherwise specified, any rejection because of noncompliance to the requirements of the specification shall be reported by the purchaser to the manufacturer within 30 working days after receipt of samples.

11.2 Material that shows imperfections capable of adversely affecting processibility subsequent to its acceptance at the purchaser's works will be rejected, and the manufacturer shall be notified.

12. Rehearing

12.1 Samples that represent rejected material shall be preserved for two weeks from the date rejection is reported to the manufacturer. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

13. Product Marking

13.1 *Civilian Procurement*—Bars of all sizes, when loaded for shipment, shall be properly identified with the name or brand of manufacturer, purchaser's name and order number, the ASTM designation (year date is not required), grade number where appropriate, size and length, weight of lift, and the heat number for identification. Unless otherwise specified, the method of marking is at the manufacturer's option and may be made by hot stamping, cold stamping, painting, or marking tags attached to the lifts of bars.

13.1.1 Bar code marking may be used as an auxiliary method of identification. Such bar-code markings shall be of the 3-of-9 type and shall conform to AIAG B1. When barcoded tags are used, they shall conform to AIAG B5.

13.2 *Government Procurement*:

13.2.1 Marking for shipment shall be in accordance with the requirements specified in the contract or order and shall be in accordance with MIL-STD-163 for military agencies and in accordance with Fed. Std. No. 123 for civil agencies.

13.2.2 For government procurement by the Defense Supply Agency, the bars shall be continuously marked for identification in accordance with Fed. Std. No. 183.

14. Packaging

14.1 *Civilian Procurement*—Unless otherwise specified, the bars shall be packaged and loaded in accordance with Practices A 700.

14.2 *Government Procurement*—MIL-STD-163 shall apply when packaging is specified in the contract or order, or when Level A for preservation, packaging, and packing is specified for direct procurement by or direct shipment to the government.

15. Keywords

15.1 alloy steel bars; carbon steel bars; cold finished steel bars; general delivery requirements; hot wrought steel bars; steel bars

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the contract or order.

S1. Flat Bar Thickness Tolerances

S1.1 When flat bars are specified in metric units to a thickness under tolerance of 0.3 mm, the thickness tolerance of Table S1.1 shall apply.

TABLE S1.1 Thickness and Width Tolerances for Hot-Wrought Square-Edge and Round-Edge Flat Bars Ordered to 0.3 mm Under Tolerance[A]

NOTE—Tolerance under specified thickness 0.3 mm.

Specified Width, mm	Tolerances over Specified Thickness for Thickness Given, mm					Tolerance from Specified Width, mm	
	Over 6 to 12, incl	Over 12 to 25, incl	Over 25 to 50, incl	Over 50 to 75, incl	Over 75	Over	Under
To 25, incl	. . .	. . .	. . .	. . .	. . .	0.5	0.5
Over 25 to 50, incl	. . .	0.5	1.3	. . .	. . .	1.0	1.0
Over 50 to 100, incl	0.5	0.7	1.3	2.1	2.1	1.5	1.0
Over 100 to 150, incl	0.5	0.7	1.3	2.1	2.1	2.5	1.5
Over 150 to 200, incl	0.5	1.0	1.3	2.1	2.9	3.0	2.5

[A] When a square is held against a face and an edge of a square-edge flat bar, the edge shall not deviate by more than 3° or 5 % of the thickness.

ANNEXES

(Mandatory Information)

A1. PERMISSIBLE VARIATIONS IN DIMENSIONS, ETC.—INCH-POUND UNITS

A1.1 Listed below are permissible variations in dimensions expressed in inch-pound units of measurement.

TABLE A1.1 Permissible Variations in Cross Section for Hot-Wrought Round, Square, and Round-Cornered Square Bars of Steel

Specified Size, in.	Permissible Variation from Specified Size, in.[A]		Out-of-Round or Out-of-Square, in.[B]
	Over	Under	
To 5⁄16 , incl	0.005	0.005	0.008
Over 5⁄16 to 7⁄16 , incl	0.006	0.006	0.009
Over 7⁄16 to 5⁄8 , incl	0.007	0.007	0.010
Over 5⁄8 to 7⁄8 , incl	0.008	0.008	0.012
Over 7⁄8 to 1, incl	0.009	0.009	0.013
Over 1 to 1 1⁄8 , incl	0.010	0.010	0.015
Over 1 1⁄8 to 1 1⁄4 , incl	0.011	0.011	0.016
Over 1 1⁄4 to 1 3⁄8 , incl	0.012	0.012	0.018
Over 1 3⁄8 to 1 1⁄2 , incl	0.014	0.014	0.021
Over 1 1⁄2 to 2, incl	1⁄64	1⁄64	0.023
Over 2 to 2 1⁄2 , incl	1⁄32	0	0.023
Over 2 1⁄2 to 3 1⁄2 , incl	3⁄64	0	0.035
Over 3 1⁄2 to 4 1⁄2 , incl	1⁄16	0	0.046
Over 4 1⁄2 to 5 1⁄2 , incl	5⁄64	0	0.058
Over 5 1⁄2 to 6 1⁄2 , incl	1⁄8	0	0.070
Over 6 1⁄2 to 8 1⁄4 , incl	5⁄32	0	0.085
Over 8 1⁄4 to 9 1⁄2 , incl	3⁄16	0	0.100
Over 9 1⁄2 to 10, incl	1⁄4	0	0.120

[A] Steel bars are regularly cut to length by shearing or hot sawing, which can cause end distortion resulting in those portions of the bar being outside the applicable size tolerance. When this end condition is objectionable, a machine cut end should be considered.

[B] Out-of-round is the difference between the maximum and minimum diameters of the bar, measured at the same cross section. Out-of-square is the difference in the two dimensions at the same cross section of a square bar between opposite faces.

TABLE A1.2 Permissible Variations in Cross Section for Hot-Wrought Hexagonal Bars of Steel

Specified Sizes Between Opposite Sides, in.	Permissible Variations from Specified Size, in.[A]		Out-of-Hexagon (Carbon Steel and Alloy Steel) or Out-of-Octagon (Alloy Steel), in.[B]
	Over	Under	
To 1⁄2 , incl	0.007	0.007	0.011
Over 1⁄2 to 1, incl	0.010	0.010	0.015
Over 1 to 1 1⁄2 , incl	0.021	0.013	0.025
Over 1 1⁄2 to 2, incl	1⁄32	1⁄64	1⁄32
Over 2 to 2 1⁄2 , incl	3⁄64	1⁄64	3⁄64
Over 2 1⁄2 to 3 1⁄2 , incl	1⁄16	1⁄64	1⁄16
Over 3 1⁄2 to 4 1⁄16 , incl	5⁄64	1⁄64	5⁄64

[A] Steel bars are regularly cut to length by shearing or hot sawing, which can cause end distortion resulting in those portions of the bar being outside the applicable size tolerance. When this end condition is objectionable, a machine cut end should be considered.

[B] Out-of-hexagon or out-of-octagon is the greatest difference between any two dimensions at the same cross section between opposite faces.

TABLE A1.3 Permissible Variations in Thickness and Width for Hot-Wrought Square Edge and Round Edge Flat Bars[A]

Specified Width, in.	Permissible Variations in Thickness, for Thickness Given, Over and Under, in.[B]							Permissible Variations in Width, in.	
	0.203 to 0.230, excl	0.230 to 1⁄4 , excl	1⁄4 to 1⁄2 , incl	Over 1⁄2 to 1, incl	Over 1 to 2, incl	Over 2 to 3, incl	Over 3	Over	Under
To 1, incl	0.007	0.007	0.008	0.010	...	...	...	1⁄64	1⁄64
Over 1 to 2, incl	0.007	0.007	0.012	0.015	1⁄32	...	...	1⁄32	1⁄32
Over 2 to 4, incl	0.008	0.008	0.015	0.020	1⁄32	3⁄64	3⁄64	1⁄16	1⁄32
Over 4 to 6, incl	0.009	0.009	0.015	0.020	1⁄32	3⁄64	3⁄64	3⁄32	1⁄16
Over 6 to 8, incl	[C]	0.015	0.016	0.025	1⁄32	3⁄64	1⁄16	1⁄8	3⁄32

[A] When a square is held against a face and an edge of a square edge flat bar, the edge shall not deviate by more than 3° or 5 % of the thickness.

[B] Steel bars are regularly cut to length by shearing or hot sawing, which can cause end distortion resulting in those portions of the bar being outside the applicable size tolerance. When this end condition is objectionable, a machine cut end should be considered.

[C] Flats over 6 to 8 in., incl, in width, are not available as hot-wrought steel bars in thickness under 0.230 in.

TABLE A1.4 Permissible Variations in Thickness, Length, and Out-of-Square for Hot-Wrought Bar Size Angles of Carbon Steel

Specified Length of Leg, in.[A]	Permissible Variations in Thickness, for Thicknesses Given, Over and Under, in.			Permissible Variations for Length of Leg, Over and Under, in.
	To 3⁄16, incl	Over 3⁄16 to 3⁄8, incl	Over 3⁄8	
To 1, incl	0.008	0.010	...	1⁄32
Over 1 to 2, incl	0.010	0.010	0.012	3⁄64
Over 2 to 3, excl	0.012	0.015	0.015	1⁄16

[A] The longer leg of an unequal angle determines the size for tolerance. The out-of-square tolerance in either direction is 1½ °.

TABLE A1.5 Permissible Variations in Dimensions for Hot-Wrought Bar Size Channels of Carbon Steel

Specified Size of Channel, in.	Permissible Variations in Size, Over and Under, in.				Out-of-Square[A] if Either Flange, in./in. of Flange Width
	Depth of Section[B]	Width of Flanges[B]	Thickness of Web for Thickness Given		
			To 3⁄16, incl	Over 3⁄16	
To 1½, incl	1⁄32	1⁄32	0.010	0.015	1⁄32
Over 1½ to 3, excl	1⁄16	1⁄16	0.015	0.020	1⁄32

[A] For channels 5⁄8 in. and under in depth, the out-of-square tolerance is 3⁄64 in./in. of depth.
[B] Measurements for depth of section and width of flanges are overall.

TABLE A1.6 Permissible Variations in Dimensions for Hot-Wrought Bar Size Tees of Carbon Steel

Specified Size of Tee, in.[A]	Permissible Variations in Size, in.						Stem out-of-Square[C]
	Width or Depth[B]		Thickness of Flange		Thickness of Stem		
	Over	Under	Over	Under	Over	Under	
To 1¼, incl	3⁄64	3⁄64	0.010	0.010	0.005	0.020	1⁄32
Over 1¼ to 2, incl	1⁄16	1⁄16	0.012	0.012	0.010	0.020	1⁄16
Over 2 to 3, excl	3⁄32	3⁄32	0.015	0.015	0.015	0.020	3⁄32

[A] The longer member of the unequal tee determines the size for tolerances.
[B] Measurements for both width and depth are overall.
[C] Stem out-of-square is the variation from its true position of the center line of the stem measured at the point.

TABLE A1.7 Permissible Variations in Dimensions for Half-Rounds, Ovals, Half-Ovals, and Other Special Bar Size Sections

Due to mill facilities, tolerances on half-rounds, ovals, half-ovals, and other special bar size sections vary among the manufacturers and such tolerances should be negotiated between the manufacturer and the purchaser.

TABLE A1.8 Permissible Variations in Length for Hot-Wrought Rounds, Squares, Hexagons, Flats, and Bar Size Sections of Steel

Specified Size of Rounds, Squares, and Hexagons, in.	Specified Size of Flats, in.		Permissible Variations Over Specified Length, in.[A]				
	Thickness	Width	5 to 10 ft, excl	10 to 20 ft, excl	20 to 30 ft, excl	30 to 40 ft, excl	40 to 60 ft, excl
			Mill Shearing				
To 1, incl	to 1, incl	to 3, incl	½	¾	1¼	1¾	2¼
Over 1 to 2, incl	over 1	to 3, incl	⅝	1	1½	2	2½
	to 1, incl	over 3 to 6, incl	⅝	1	1½	2	2½
Over 2 to 5, incl	over 1	over 3 to 6, incl	1	1½	1¾	2¼	2¾
Over 5 to 10, incl	...	...	2	2½	2¾	3	3¼
	0.230 to 1, incl	over 6 to 8, incl	¾	1¼	1¾	3½	4
	over 1 to 3, incl	over 6 to 8, incl	1¼	1¾	2	3½	4
Bar Size Sections	...	...	⅝	1	1½	2	2½
			Hot Sawing				
2 to 5, incl	1 and over	3 and over	[B]	1½	1¾	2¼	2¾
Over 5 to 10, incl	...	...	[B]	2½	2¾	3	3¼

[A] No permissible variations under.
[B] Smaller sizes and shorter lengths are not hot sawed.

TABLE A1.9 Permissible Variations in Length for Recutting of Bars Meeting Special Straightness Tolerances

Sizes of Rounds, Squares, Hexagons, Width of Flats and Maximum Dimension of Other Sections, in.[A]	Tolerances Over Specified Length, in.[A]	
	To 12 ft, incl	Over 12 ft
To 3, incl	¼	5⁄16
Over 3 to 6, incl	5⁄16	7⁄16
Over 6 to 8, incl	7⁄16	9⁄16
Rounds over 8 to 10, incl.	9⁄16	11⁄16

[A] No tolerance under.

TABLE A1.10 Permissible Variations in Straightness for Hot-Wrought Bars and Bar Size Sections of Steel[A]

Standard tolerances	¼ in. in any 5 ft and (¼ in. × length in ft)/5
Special tolerances	⅛ in. in any 5 ft and (⅛ in. × length in ft)/5

[A] Because of warpage, straightness tolerances do not apply to bars if any subsequent heating operation or controlled cooling has been performed.

A2. DIMENSIONAL TOLERANCES—SI UNITS

A2.1 Listed below are permissible variations in dimensions expressed in SI units of measurement.

TABLE A2.1 Tolerances in Sectional Dimensions for Round and Square Bars and Round-Cornered Square Bars

Size, mm	Tolerance from Specified Size, Over and Under, mm or %[A]	Out-of-Round, or Out-of-Square Section,[B] mm or %[A]
To 7, incl	0.13 mm	0.20 mm
Over 7 to 11, incl	0.15 mm	0.22 mm
Over 11 to 15, incl	0.18 mm	0.27 mm
Over 15 to 19, incl	0.20 mm	0.30 mm
Over 19 to 250, incl	1 %	1.5 %

[A] The tolerance shall be rounded to the nearest tenth of a millimetre after calculation.
[B] Out-of-round is the difference between the maximum and the minimum diameters of the bar, measured at the same cross section. Out-of-square is the difference in the two dimensions at the same cross section of a square bar between opposite faces.

TABLE A2.2 Tolerances in Cross Section for Hot-Wrought Hexagonal and Octagonal Steel Bars

Specified Size Between Opposite Sides, mm	Tolerance from Specified Size, mm		Out of Hexagon or Out of Octagon, mm[A]
	Over	Under	
To 13, incl	0.18	0.18	0.3
Over 13 to 25, incl	0.25	0.25	0.4
Over 25 to 40, incl	0.55	0.35	0.6
Over 40 to 50, incl	0.8	0.40	0.8
Over 50 to 65, incl	1.2	0.40	1.2
Over 65 to 80, incl	1.6	0.40	1.6
Over 80 to 100, incl	2.0	0.40	2.0

[A] Out of hexagon or out of octagon is the greatest difference between any two dimensions at the cross section between opposite faces.

TABLE A2.3 Thickness and Width Tolerances for Hot-Wrought Square-Edge and Round-Edge Flat Bars[A,B]

Specified Width, mm	Tolerances from Specified Thickness for Thickness Given Over and Under, mm						Tolerances from Specified Width, mm	
	Over 5 to 6, incl	Over 6 to 12, incl	Over 12, to 25, incl	Over 25 to 50, incl	Over 50 to 75	Over 75	Over	Under
To 25, incl	0.18	0.20	0.25	. . .	. . .	. . .	0.5	0.5
Over 25 to 50, incl	0.18	0.30	0.40	0.8	. . .	. . .	1.0	1.0
Over 50 to 100, incl	0.20	0.40	0.50	0.8	1.2	1.2	1.5	1.0
Over 100 to 150, incl	0.25	0.40	0.50	0.8	1.2	1.2	2.5	1.5
Over 150 to 200, incl	[A]	0.40	0.65	0.8	1.2	1.6	3.0	2.5

[A] When a square is held against a face and an edge of a square edge flat bar, the edge shall not deviate by more than 3° or 5 % of the thickness.
[B] Flats over 150 to 200 mm, incl in width are not available as hot-wrought bars in thickness 6 mm and under.

TABLE A2.4 Thickness, Length, and Out-of-Square Tolerances for Hot-Wrought Bar Size Angles

Specified Length of Leg, mm[A,B]	Tolerances in Thickness for Thickness Given, Over and Under, mm			Tolerances for Length of Leg Over and Under, mm
	To 5, incl	Over 5 to 10, incl	Over 10	
To 50, incl	0.2	0.2	0.3	1
Over 50 to 75, excl	0.3	0.4	0.4	2

[A] The longer leg of an unequal angle determines the size for tolerance.
[B] Out of square tolerances in either direction is 1½ ° = 0.026 mm/mm.

TABLE A2.5 Dimensional Tolerances for Hot-Wrought Bar Size Channels

Specified Size of Channel, mm	Tolerances in Size, Over and Under, mm				
	Depth of Section[A]	Width of Flanges[A]	Thickness of Web		Out of Square of Either Flange per mm of Flange Width,[B] mm
			To 5, incl	Over 5	
To 40, incl	1	1	0.2	0.4	0.03
Over 40 to 75, excl	2	2	0.4	0.5	0.03

[A] Measurements for depth of section and width of flanges are overall.
[B] For channels 16 mm and under in depth, out of square tolerance is 0.05 mm/mm.

TABLE A2.6 Dimensional Tolerances for Hot-Wrought Bar Size Tees

Specified Size of Tee,[A] mm	Tolerances in Size, mm						
	Width or Depth,[B]		Thickness of Flange		Thickness of Stem		Stem Out of Square[C]
	Over	Under	Over	Under	Over	Under	
To 30, incl	1	1	0.2	0.2	0.1	0.5	1
Over 30 to 50, incl	2	2	0.3	0.3	0.2	0.5	2
Over 50 to 75, excl	2	2	0.4	0.4	0.4	0.5	2

[A] The longer member of the unequal tee determines the size for tolerances.
[B] Measurements for width and depth are over all.
[C] Stem out of square is the tolerance from its true position of the center line of the stem measured at the point.

TABLE A2.7 Permissible Variations in Dimensions for Half-Rounds, Ovals, Half-Ovals, and Other Special Bar Size Sections

Due to mill facilities, tolerances on half-rounds, ovals, and other special bar size sections vary among the manufacturers and such tolerances should be negotiated between the manufacturer and the purchaser.

TABLE A2.8 Length Tolerances for Hot-Wrought Rounds, Squares, Hexagons, Octagons, Flats, and Bar Size Sections

Specified Size of Rounds, Squares, Hexagons and Octagons, mm	Specified Size of Flats, mm		Tolerances over Specified Length, mm[A]				
	Thickness	Width	1500 to 3000, excl	3000 to 6000, excl	6000 to 9000, excl	9000 to 12 000, excl	12 000 to 18 000, excl
		Hot Shearing					
To 25, incl	to 25, incl	to 75, incl	15	20	35	45	60
Over 25 to 50, incl	over 25	to 75, incl	15	25	40	50	65
	to 25, incl	over 75 to 150, incl	15	25	40	50	65
Over 50 to 125, incl	over 25	over 75 to 150, incl	25	40	45	60	70
Over 125 to 250, incl	. . .	. . .	50	65	70	75	85
Bar Size Sections	over 6 to 25, incl	over 150 to 200, incl	20	30	45	90	100
	over 25 to 75, incl	over 150 to 200, incl	30	45	50	90	100
	. . .	. . .	15	25	40	50	65
		Hot Sawing					
50 to 125, incl	25 and over	75 and over	[B]	40	45	60	70
Over 125 to 250, incl	. . .	. . .	[B]	65	70	75	85

[A] No tolerance under.
[B] Smaller sizes and shorter lengths are not hot sawed.

TABLE A2.9 Length Tolerances for Recutting of Bars Meeting Special Straightness Tolerances

Sizes of Rounds, Squares, Hexagons, Octagons, Widths of Flats and Maximum Dimensions of Other Sections, mm	Tolerances over Specified Length, mm[A]	
	To 3700 mm, incl	Over 3700 mm
To 75, incl	6	8
Over 75 to 150, incl	8	11
Over 150 to 200, incl	11	14
Rounds over 200 to 250, incl	14	18

[A] No tolerance under.

TABLE A2.10 Straightness Tolerances for Hot-Wrought Bars and Bar Size Sections[A]

Standard Tolerances	6 mm in any 1500 mm and (length in mm/250)[B]
Special Tolerances	3 mm in any 1500 mm and (length in mm/500)[B]

[A] Because of warpage, straightness tolerances do not apply to bars if any subsequent heating operation or controlled cooling has been performed.
[B] Round to the nearest whole millimetre.

SUMMARY OF CHANGES

Committee C12 has identified the location of selected changes since A 29/A 29M-03 that may impact the use of this standard. (Approved March 1, 2004.)

1 Removed ″and Cold-Finished″ from Title
2 Removed A331 and A695 (dropped) from list of specifications in Scope
3 Added Note to end of Scope.
4 Removed 7.2
5 Removed Tables A1.11, 12, 13, 14 and A2.11, 12, 13, 14
6 Corrected Cr on grade 52100 in Table 2

Committee C12 has identified the location of selected changes since A 29/A 29M-99 that may impact the use of this standard. (Approved Sept. 10, 2003.)

(1) Changed Tables A1.10 and A2.10.
(2) Added Grade 52100 to Table 2 and added Footnote B.

Designation: A 108 – 03

Standard Specification for Steel Bar, Carbon and Alloy, Cold-Finished[1]

This standard is issued under the fixed designation A 108; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers cold-finished carbon and alloy steel bars produced in straight length and coil to chemical compositions. Cold-finished bars are suitable for heat treatment, for machining into components, or for use in the as-finished condition as shafting, or in constructional applications, or for other similar purposes (Note 1). Grades of steel are identified by grade numbers or by chemical composition.

NOTE 1—A guide for the selection of steel bars is contained in Practice A 400.

1.2 Some end uses may require one or more of the available designations shown under Supplementary Requirements. Supplementary requirements shall apply only when specified individually by the purchaser.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought. General Requirements for

A 304 Specification for Carbon and Alloy Steel Bars Subject to End-Quench Hardenability Requirements

A 322 Specification for Steel Bars, Alloy, Standard Grades

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 400 Practice for Steel Bars, Selection Guide, Composition, and Mechanical Properties

A 510 Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel

A 576 Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality

A 700 Specification for Packaging, Marking, and Loading Methods for Steel Products for Domestic Shipment

E 45 Test Methods for Determining the Inclusion Content of Steel

E 112 Test Methods for Determining the Average Grain Size

E 381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings

E 527 Practice for Numbering Metals and Alloys (UNS)

E 1077 Test Method for Estimating the Depth of Decarburization of Steel Specimens

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.2 *Other Documents:*

SAE Handbook and SAE J1086 Recommended Practice for Numbering Metals and Alloys (UNS)[3]

Federal Standard 66 C Steel, Chemical Composition and Hardenability[4]

ISS Steel Bar Product Guideline for Bar Steel[5]

3. Terminology

3.1 *Definition:*

3.1.1 *product tolerance levels*—cold-finished steel bar is produced with up to four (4) increasingly tight tolerance levels, for the individual product characteristics, dependent on the method of manufacture necessary to meet purchaser-ordered specification requirements. (Product Tolerance Level 1 is selected, unless otherwise specified by purchaser.)

4. Ordering Information

4.1 Orders for cold-finished steel bar to this specification should include the following items to adequately describe the material:

4.1.1 Name of material,

4.1.2 ASTM specification number and date of issue,

4.1.3 Chemical composition, grade designation or limits,

4.1.4 Silicon level, if required,

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

Current edition approved Nov. 1, 2003. Published December 2003. Originally approved in 1926. Last previous edition approved in 1999 as A 108 – 99.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001.

[4] Available from the Standardization Documents Order Desk, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094 Attn: NPODS.

[5] Available from American Iron and Steel Institute (AISI), 1101 17th St., NW, Suite 1300, Washington, DC 20036.

4.1.5 Additional machinability-enhancing elements (see Footnote F to Table 1 of Specification A 29A 29M),

4.1.6 Condition (Surface Roughness tolerances listed in Table A1.7),

4.1.7 Tolerance Levels (Reference tolerances listed in Table A1.1 through Table A1.9),

4.1.8 Shape (round, hexagon, square, flat, etc.), size, and length,

4.1.9 Report of heat analysis, if required,

4.1.10 End use,

4.1.11 Additions to the specification and special or supplementary requirements, if required, and

4.1.12 For coiled product, the coil weights, inside diameter, outside diameter, and coil height limitations, when required.

NOTE 2—A typical ordering description is as follows: Steel Bar; ASTM A 108, dated _____; SAE 1117; Coarse Grain; Cold Drawn; 1.500-in. (38.10 mm) diameter round; 12 ft (3657.61 mm) long; Heat Analysis Required; Precision Machined Parts.

NOTE 3—A more complex ordering description is as follows: Steel Bar; ASTM A 108, dated ____; SAE 1045; Fine Grain; Cold Drawn, Turned, Ground and Polished; chamfer both ends; Mechanical Property Test Results; Hardness test; Inspect for Residual Magnetism; 2.000-in. (50.80 mm) diameter round; 12 ft (3657.61 mm) long; Heat Analysis Required; Precision Machined Parts. Product codes allow you to abbreviate, yet identify a complex ordering description in the following simplified description: Steel Bar: ASTM A 108, dated ____; SAE 1045; Fine Grain; 2.000-in. (50.80 mm) diameter round; 12 ft (3657.61 mm) long; Heat Analysis Required; Precision Machined Parts.

5. General Requirements

5.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 29/A 29M.

6. Materials and Manufacture

6.1 *Feedstock*—Cold-finished steel bar shall be produced from hot-wrought carbon or alloy steel bar (Specification A 29/A 29M), or from hot-wrought rod designated for cold-finished bar (Specification A 510).

6.2 *Condition*—The product shall be furnished in one of the following conditions as specified by the purchaser.

6.2.1 *Rounds*:

6.2.1.1 Cold drawn,

6.2.1.2 Cold drawn, turned, and polished,

6.2.1.3 Cold drawn, ground, and polished,

6.2.1.4 Cold drawn, turned, ground, and polished,

6.2.1.5 Cold drawn, turned, and ground,

6.2.1.6 Hot wrought, turned, and polished,

6.2.1.7 Hot wrought, turned, ground and polished,

6.2.1.8 Hot wrought, turned, and ground, and

6.2.1.9 Hot wrought, rough turned.

6.2.2 *Squares, Hexagons*:

6.2.2.1 Cold drawn, and

6.2.2.2 Cold rolled.

6.2.3 *Flats*:

6.2.3.1 Cold drawn, and

6.2.3.2 Cold rolled.

6.2.4 *Special Bar Sections*:

6.2.4.1 Cold Drawn, and

6.2.4.2 Cold Rolled.

6.3 *Heat Treatment*:

6.3.1 Unless otherwise specified, the bars shall be furnished as cold-finished. Plain Carbon Steels with a maximum carbon over 0.55 % and Alloy Steels with a maximum carbon over 0.38 % shall be annealed prior to cold finishing.

6.3.2 The following heat-treatment processes may be performed singularly or in combination:

6.3.2.1 Annealed,

6.3.2.2 Normalized,

6.3.2.3 Stress relieved, and

6.3.2.4 Quench and tempered.

7. Chemical Composition

7.1 *Chemical Composition*:

7.1.1 The chemical analysis of the steel shall conform to that specified in Specification A 29/A 29M for the steel grade ordered, or to such other limits as may be specified using the standard ranges in Specification A 29/A 29M.

7.1.2 Steels may be selected from: Specifications A 29/A 29M, A 304, A 322, A 510, and A 576; Federal Standard 66 C; the SAE Handbook; or the ISS Steel Bar Product Guideline for Bar Steel.

7.1.3 When a steel's composition cannot be identified by a standard grade number in accordance with 7.1.1 and 7.1.2, the limits for each required element may be specified using the chemical ranges shown in the table (Heat Analysis Chemical Ranges and Limits of Carbon Steel Bars) of Specification A 29/A 29M.

8. Tolerance Levels

8.1 *Cold-Finished Bars*—The permissible dimensional variations for cold-finished carbon and alloy steel bar shall not exceed the applicable tolerance levels or limits stated in Annex A1 for inch-pound values.

9. Workmanship, Finish, and Product Presentation

9.1 *Workmanship*:

9.1.1 Within the limits of good manufacturing and inspection practices, the bars shall be free of injurious seams, laps, segregation, or other imperfections which, due to their nature, degree, or extent, will interfere with the use of the material in machining or fabrication of suitable parts. (Reference Table A1.8)

9.2 *Finish*:

9.2.1 Unless otherwise specified, the bars shall have a commercial bright smooth surface finish, obtained by conventional cold-finishing operations such as cold drawing or cold rolling.

9.2.2 When a superior bar surface finish is required, bars may be obtained as; turned and polish, ground and polished, or turned, ground, and polished. (Reference Table A1.7)

9.2.3 Bars that are thermally treated after cold finishing may exhibit a discolored or oxidized surface.

9.3 *Product Presentation*:

9.3.1 The bars shall be given a surface coating of oil or other rust inhibitor to protect against corrosion during shipment.

9.3.2 The bar bundles shall be identified, packaged and loaded to preserve the physical appearance, product tolerance and identity of the cold-finished product, as agreed upon between the purchaser and supplier.

10. Certification

10.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the test results shall be furnished at the time of shipment.

11. Keywords

11.1 alloy steel; carbon steel; cold-finished; steel bar

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall be applied only when specified by the purchaser in the inquiry, contract, or order. Details of these supplementary requirements shall be agreed upon in writing, by the manufacturer and the purchaser. Supplementary requirements shall in no way negate any requirement of the specification itself.

S1. Hot Rolling Reduction Ratio

S1.1 When required, purchaser may require the supplier to report the reduction ratio of the initial Bloom/Billet cross sectional area to finished hot rolled cross sectional area.

S2. Steel Melting Process

S2.1 When required, purchaser may require the supplier to report the steel melting process (Basic Oxygen Furnace, Electric Arc Furnace, etc.) for each initial heat/lot number supplied to the purchaser.

S3. Steel Refinement Process

S3.1 When required, purchaser may require the supplier to report the steel refinement processes performed after melting and before casting (Vacuumed Degassed, etc.) on the heat/lot number supplied to the purchaser.

S4. Continuous Casting Process

S4.1 When required, purchaser may require the supplier to report the casting process (Bloom, Billet, etc.) for each heat/lot number supplied to the purchaser.

S5. Country or Countries of Origin

S5.1 When required, purchaser may require the supplier to report the country of origin where the steel was melted for each heat/lot number supplied to the purchaser.

S5.2 When required, purchaser may require the supplier to report the country of origin where the steel was hot rolled for each heat/lot number supplied to the purchaser.

S5.3 When required, purchaser may require the supplier to report the country of origin where the steel was cold finished for each heat/lot number supplied to the purchaser.

S6. Mechanical Properties

S6.1 When required, purchaser may require the supplier to report the cold-finished steel bar mechanical properties for each heat/lot number supplied to the purchaser. Mechanical properties shall be evaluated in accordance with Test Methods and Definitions in Test Methods A 370.

S7. Surface Inspection

S7.1 When required, purchaser may require the supplier to inspect the cold finish steel bar surface within an electromagnetic surface inspection process to detect and sort surface discontinuities that exceed the maximum allowed depth tolerances listed in Table A1.8 or other tolerances agreed upon between the purchaser and supplier.

S8. Bar Marking

S8.1 When required, bar marking specification requirements shall be agreed upon between the purchaser and supplier.

ANNEX

(Mandatory Information)

A1. PERMISSIBLE VARIATIONS IN QUALITY CHARACTERISTICS—INCH-POUND AND METRIC UNITS

TABLE A1.1 Size Tolerances for Level One Cold-Finished Carbon Steel Bars, Cold Drawn or Turned and Polished

Size, in. (mm)[A]	Maximum of Carbon Range 0.28 % or less	Maximum of Carbon Range over 0.28 % to 0.55 % incl	Maximum of Carbon Range to 0.55 % incl, Stress Relieved or Annealed after Cold Finishing	Maximum of Carbon Range over 0.55 % or All Grades Quenched and Tempered or Normalized and Tempered before Cold Finishing
	All tolerances are in inches (mm) and are minus[B]			
Rounds—Cold Drawn[C] to 6 in.(152.4 mm) or Turned and Polished				
To 1½ (38.1) incl, in coils, or cut lengths	0.002 (.051)	0.003 (.076)	0.004 (.102)	0.005 (.127)
Over 1½ (38.10) to 2½ (63.50) incl	0.003 (.076)	0.004 (.102)	0.005 (.127)	0.006 (.152)
Over 2½ (63.50) to 4 (101.60) incl	0.004 (.102)	0.005 (.127)	0.006 (.152)	0.007 (.178)
Over 4 (101.60) to 6 (152.40) incl	0.005 (.127)	0.006 (.152)	0.007 (.178)	0.008 (.203)
Over 6 (152.40) to 8 (203.20) incl	0.006 (.152)	0.007 (.178)	0.008 (.203)	0.009 (.229)
Over 8 (203.20) to 9 (228.60) incl	0.007 (.178)	0.008 (.203)	0.009 (.229)	0.010 (.254)
Hexagons				
To ¾ (19.05) incl	0.002 (.051)	0.003 (.076)	0.004 (.102)	0.006 (.152)
Over ¾ (19.05) to 1½ (38.10) incl	0.003 (.076)	0.004 (.102)	0.005 (.127)	0.007 (.178)
Over 1½ (38.10) to 2½ (63.50) incl	0.004 (.102)	0.005 (.127)	0.006 (.152)	0.008 (.203)
Over 2½ (63.50) to 3⅛ (79.38) incl	0.005 (.127)	0.006 (.152)	0.007 (.178)	0.009 (.229)
Over 3⅛ (79.38) to 4 (101.60) incl	0.005 (.127)	0.006 (.152)	. . .	. . .
Squares				
To ¾ (19.05) incl	0.002 (.051)	0.004 (.102)	0.005 (.127)	0.007 (.178)
Over ¾ (19.05) to 1½ (38.10) incl	0.003 (.076)	0.005 (.127)	0.006 (.152)	0.008 (.203)
Over 1½ (38.10) to 2½ (63.50) incl	0.004 (.102)	0.006 (.152)	0.007 (.178)	0.009 (.229)
Over 2½ (63.50) to 4 (101.60) incl	0.006 (.152)	0.008 (.203)	0.009 (.229)	0.011 (.279)
Over 4 (101.60) to 5 (127.00) incl	0.010 (.254)	. . .	. . .	. . .
Over 5 (127.00) to 6 (152.4) incl	0.014 (.356)	. . .	. . .	. . .
Flats[D]				
Width:				
To ¾ (19.05) incl	0.003 (.076)	0.004 (.102)	0.006 (.152)	0.008 (.203)
Over ¾ (19.05) to 1 ½ (38.10) incl	0.004 (.102)	0.005 (.127)	0.008 (.203)	0.010 (.254)
Over 1½ (38.10) to 3 (76.2) incl	0.005 (.127)	0.006 (.152)	0.010 (.254)	0.012 (.305)
Over 3 (76.2) to 4 (101.60) incl	0.006 (.152)	0.008 (.203)	0.011 (.279)	0.016 (.410)
Over 4 (101.60) to 6 (152.40) incl	0.008 (.203)	0.010 (.254)	0.012 (.305)	0.020 (.508)
Over 6 (152.40)	0.013 (.330)	0.015 (.381)	. . .	. . .

[A] Standard manufacturing practice is shear cut for cold drawn bars (size limits vary by producer) which can cause end distortion resulting in those portions of the bar being outside the applicable size tolerance. When this end condition is undesirable, a saw cut end to remove end distortion should be considered.

[B] While size tolerances are usually specified as minus, tolerances may be ordered all plus, or distributed plus and minus, with the sum being equivalent to the tolerances listed.

[C] Maximum allowable deviation in roundness around the circumference of the same cross-section of a round cold drawn bar is ½ the size tolerance range.

[D] Width governs the tolerances for both width and thickness of flats. For example, when the maximum of carbon range is 0.28 % or less, for a flat 2 in. (50.80 mm) wide and 1 in. (25.40 mm) thick, the width tolerance is 0.005 in. (.127 mm) and the thickness tolerance is the same, namely, 0.005 in. (.127 mm).

TABLE A1.2 Size Tolerance for Level One Cold-Finished Alloy Steel Bars, Cold Drawn, or Turned and Polished

Size, in. (mm)[A]	Maximum of Carbon Range 0.28 % or less	Maximum of Carbon Range over 0.28 % to 0.55 % incl	Maximum of Carbon Range to 0.55 % incl, Stress Relieved or Annealed after Cold Finishing	Maximum of Carbon Range over 0.55 % with or without stress relieving or annealing after cold finishing. Also, all carbons, quenched and tempered (heat treated), or normalized and tempered, before Cold Finishing
	All tolerances are in inches (mm) and are minus[B]			
Rounds-Cold Drawn[C] to 6 in. (152.40 mm) or Turned and Polished				
To 1 (25.4) incl, in coils	0.002 (.051)	0.003 (.076)	0.004 (.102)	0.005 (.127)
Cut Lengths:				
To 1½ (38.10) incl	0.003 (.076)	0.004 (.102)	0.005 (.127)	0.006 (.152)
Over 1½ (38.10) to 2½ (63.50) incl	0.004 (.102)	0.005 (.127)	0.006 (.152)	0.007 (.178)
Over 2½ (63.50) to 4 (101.60) incl	0.005 (.127)	0.006 (.152)	0.007 (.178)	0.008 (.203)
Over 4 (101.60) to 6 (152.40) incl	0.006 (.152)	0.007 (.178)	0.008 (.203)	0.009 (.229)
Over 6 (152.40) to 8 (203.20) incl	0.007 (.178)	0.008 (.203)	0.009 (.229)	0.010 (.254)
Over 8 (203.20) to 9 (228.60) incl	0.008 (.203)	0.009 (.229)	0.010 (.254)	0.011 (.279)
Hexagons				
To ¾ (19.05) incl	0.003 (.076)	0.004 (.102)	0.005 (.127)	0.007 (.178)
Over ¾ (19.05) to 1½ 38.10) incl	0.004 (.102)	0.005 (.127)	0.006 (.152)	0.008 (.203)
Over 1½ (38.10) to 2½ (63.50) incl	0.005 (.127)	0.006 (.152)	0.007 (.178)	0.009 (.229)
Over 2½ (63.50) to 3⅛ (79.38) incl	0.006 (.152)	0.007 (.178)	0.008 (.203)	0.010 (.254)
Over 3⅛ (79.38) to 4 (101.60) incl	0.006 (.152)	...	...	...
Squares				
To ¾ (19.05) incl	0.003 (.076)	0.005 (.127)	0.006 (.152)	0.008 (.203)
Over ¾ (19.05) to 1½ (38.10) incl	0.004 (.102)	0.006 (.152)	0.007 (.178)	0.009 (.229)
Over 1½ (38.10) to 2½ (63.50) incl	0.005 (.127)	0.007 (.178)	0.008 (.203)	0.010 (.254)
Over 2½ (63.50) to 4 (101.60) incl	0.007 (.178)	0.009 (.229)	0.010 (.254)	0.012 (.305)
Over 4 (101.60) to 5 (127.00) incl	0.011 (.279)	...	...	...
Flats[D]				
To ¾ (19.05) incl	0.004 (.102)	0.005 (.127)	0.007 (.178)	0.009 (.229)
Over ¾ (19.05) to 1½ (38.10) incl	0.005 (.127)	0.006 (.152)	0.009 (.229)	0.011 (.279)
Over 1½ (38.10) to 3 (76.2) incl	0.006 (.152)	0.007 (.178)	0.011 (.279)	0.013 (.330)
Over 3 (76.2) to 4 (101.60) incl	0.007 (.178)	0.009 (.229)	0.012 (.305)	0.017 (.432)
Over 4 (101.60) to 6 (152.40) incl	0.009 (.229)	0.011 (.279)	0.013 (.330)	0.021 (.533)
Over 6 (152.40)	0.014 (.356)	...	...	...

[A] Standard manufacturing practice is shear cut for cold drawn bars (size limits vary by producer) which can cause end distortion resulting in those portions of the bar being outside the applicable size tolerance. When this end condition is undesirable, a saw cut end to remove end distortion should be considered.

[B] While size tolerances are usually specified as minus, tolerances may be ordered all plus, or distributed plus and minus, with the sum being equivalent to the tolerances listed.

[C] Maximum allowable deviation in roundness around the circumference of the same cross-section of a round cold drawn bar is ½ the size tolerance range.

[D] Width governs the tolerances for both width and thickness of flats. For example, when the maximum of carbon range is 0.28 % or less, for a flat 2 in. (50.80 mm) wide and 1 in. (25.40 mm) thick, the width tolerance is 0.006 in. (.152 mm) and the thickness tolerance is the same, namely, 0.006 in. (.152mm).

TABLE A1.3 Size Tolerances for Level Two and Level Three Cold Finished Round Bars Cold Drawn, Ground and Polished, or Turned, Ground and Polished

Size, in. (mm) Cold Drawn, Ground and Polished[A]	Size, in. (mm) Turned, Ground and Polished[A]	Tolerances from Specified Size, Minus Only, in. (mm)	
		Level 2	Level 3
To 1½ (38.10) incl	To 1½ (38.10) incl	0.001 (.0254)	0.0008 (.0203)
Over 1½ (38.10) to 2½ (63.50) excl	Over 1½ (38.10) to 2½ (63.50) excl	0.0015 (.0381)	0.0013 (.033)
2½ (63.50) to 3 (76.20) incl	2½ (63.50) to 3 (76.20) incl	0.002 (.0508)	0.001 5(.0381)
Over 3 (76.20) to 4 (101.60) incl	Over 3 (76.20) to 4 (101.60) incl	0.003 (.0762)	0.0025 (.0635)
. . .	Over 4 (101.60) to 6 (152.40) incl	0.004 (.1016)[B]	0.003 (.0762)[B]
. . .	Over 6 (152.40)	0.005 (.127)[B]	0.004 (.1016)[B]

[A] Maximum allowable deviation of roundness or ovality tolerances are agreed upon between purchaser and supplier.

[B] For nonresulfurized steels (steels specified to maximum sulfur limits under 0.08 %), or for steels thermally treated, the tolerance is increased by 0.001 in. (.025 mm).

TABLE A1.4 Straightness Tolerances for Level One Cold Finished Bars[A,B]

NOTE—All grades quenched and tempered or normalized and tempered to Brinell 302 max before cold finishing; and all grades stress relieved or annealed after cold finishing. Straightness tolerances are not applicable to bars having Brinell hardness exceeding 302.

Size, in. (mm)	Length, ft (mm)	Straightness Tolerances, in. (mm) (Maximum Deviation) from Straightness in any 10-ft Portion of the Bar			
		Maximum of Carbon Range, 0.28 % or Less		Maximum of Carbon Range, over 0.28 % and All Grades Thermally Treated	
		Rounds	Squares, Hexagons, and Octagons	Rounds	Squares, Hexagons, and Octagons
Less than ⅝ (15.88)	Less than 15 (4572)	⅛ (3.17)	3⁄16 (4.76)	3⁄16 (4.76)	¼ (6.35)
Less than ⅝ (15.88)	15 (4572) and over	⅛ (3.17)	5⁄16 (7.94)	5⁄16 (7.94)	⅜ (9.53)
⅝ (15.88) and over	Less than 15 (4572)	1⁄16 (1.59)	⅛ (3.17)	⅛ (3.17)	3⁄16 (4.76)
⅝ (15.88) and over	15 (4572) and over	⅛ (3.17)	3⁄16 (4.76)	3⁄16 (4.76)	¼ (6.35)

[A] The foregoing tolerances are based on the following method of measuring straightness: Departure from straightness is measured by placing the bar on a level table so that the arc or departure from straightness is horizontal, and the depth of the arc is measured with a feeler gage and a straightedge.

[B] It should be recognized that straightness is a perishable quality and may be altered by mishandling. The preservation of straightness in cold-finished bars requires the utmost care in subsequent handling. Specific straightness tolerances are sometimes required for carbon and alloy steels in which case the purchaser should inform the manufacturer of the straightness tolerances and the methods to be used in checking the straightness.

TABLE A1.5 Length Tolerances for Cold Finished Steel Bar

Product Tolerance Level	Tolerances, inches (mm) Plus Allowable Deviation above Specified Uniform Length		
	Cutting Process	Minimum	Maximum
Level 1	Shear Cut	0.000	2.000 (50.80)
Level 2	In-Line Saw Cut	0.000	1.000 (25.40)
Level 3	Off-Line Saw Cut	0.000	0.500 (12.70)

TABLE A1.6 Across-Corner Tolerances for Hexagon and Square Cold Drawn Steel Bar[A]

Product Tolerance Level	Tolerance Range Applied to Across Corner Calculations	
	Hexagon, Inches (mm), Minus	Square, Inches (mm), Minus
Level 1	0.025 (.64)	0.030 (.76)
Level 2	0.020 (.51)	0.025 (.64)
Level 3	0.015 (.38)	0.020 (.51)
	Sharp Corner Hexagon Calculation = $(1.1547 \times D)$	Sharp Corner Square Calculation = $(1.4142 \times D)$
	Round Corner Hexagon Calculation = $[(1.1547) \times (D - 2r)] + 2r$	Round Corner Square Calculation = $[(1.4142) \times (D - 2r)] + 2r$

[A] When required, type of corner must be specified at time of order inquiry.

TABLE A1.7 Surface Roughness Average[A] (Ra) Tolerances for Cold-Finished Steel Bar

Product Tolerance Level	Allowable Maximum Deviation of Surface Roughness Average (Ra) Measurement	
	Turned and Polished Maximum, (µin.) (Ra)	Ground and Polished Maximum, (µin.) (Ra)
Level 1	Not Required	40
Level 2[B]	60	30
Level 3[B]	40	20

[A] RMS (root mean square calculation) is no longer applied to measure surface roughness. Roughness average (Ra) is current technology measurement output data.

[B] Special surface Ra restrictions must be agreed upon at time of order inquiry, between purchaser and supplier. Lower Ra values are available with additional bar passes and/or special processing conditions.

TABLE A1.8 Surface Discontinuity Tolerances for Cold-Finished Steel Bar[A]

Product Tolerance Level	Maximum Allowable Surface Discontinuity Depth					
	Carbon and Alloy Non-resulfurized		Carbon and Alloy Resulfurized (0.08 thru 0.19 % Sulfur)		Carbon and Alloy Resulfurized (0.20 thru 0.35 % Sulfur)	
	Maximum Depth ¼ (6.35 mm) thru ⅝ (15.88 mm) ma. inches (mm)	Maximum Depth (% of Size) over ⅝ (15.88 mm) thru 6 (152.40 mm) (max. percentage)	Maximum Depth ¼ (6.35 mm) thru ⅝ (15.88 mm) max. inches (mm)	Maximum Depth (% of Size) over ⅝ (15.88 mm) thru 6 (152.40 mm) max. percentage)	Maximum Depth ¼ (6.35 mm) thru ⅝ (15.88 mm) max. inches (mm)	Maximum Depth (% of Size) ⅝ (15.88 mm) thru 6 (152.40 mm) (max., percentage)
Level 1	0.008 in. (.20)	1.6 %	0.010 in. (.25)	2.0 %	0.012 in. (.30)	2.4 %
Level 2	0.006 in. (.15)	1.0 %	0.008 in.(.20)	1.3 %	0.010 in. (.25)	1.6 %
Level 3	0.006 in. (.15)	0.75 %	0.006 in. (.15)	1.0 %	0.008 in. (.20)	1.3 %
Level 4[B]	Nil	Nil	Nil	Nil	Nil	Nil

[A] The information in the chart is the expected maximum surface discontinuity depth within the limits of good manufacturing practice. Occasional bars in a shipment may have surface discontinuity that exceed these limits. For critical applications, the purchaser may require the cold finish steel bar supplier to eddy current test the bars prior to shipment.

[B] Level 4 requires metal removal by turning or multiple grinding passes for small bars.

TABLE A1.9 Surface Decarburization Tolerances for Cold-Finished Steel Bar

Product Tolerance Level	Maximum Affected Depth All Carbon or Alloy Steel Grades	
	Maximum Inches of Decarburization per Side of Bar ¼ (6.35 mm) thru ⅝ (15.88 mm) Sizes, All Shapes, Max. inches (mm)	Maximum Percentage of Decarburization per Side Based on Percentage of Size over ⅝ (15.88 mm) thru 6 (152.40 mm) Sizes, All Shapes, (max., %)
Level 1	0.010 in.(.25)	1.6 %
Level 2	0.006 in.(.15)	1.0 %
Level 3[A]	Nil	Nil

[A] Level 3 requires metal removal by turning or multiple grinding for small bars.

Designation: A 125 – 96 (Reapproved 2001)

Standard Specification for Steel Springs, Helical, Heat-Treated[1]

This standard is issued under the fixed designation A 125; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers hot-coiled, heat-treated helical compression springs with tapered, closed, squared and ground ends made of hot-wrought round steel bars ⅜ in. (9.5 mm) and larger in diameter.

1.2 This specification also serves to inform the user of practical manufacturing limits, mechanical tests, and inspection requirements applicable to the type of spring described in 1.1.

1.3 Supplementary Requirements S1 to S8 inclusive of an optional nature are provided. They shall apply only when specified by the purchaser. Details of these supplementary requirements shall be agreed upon by the manufacturer and purchaser.

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only).

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 689 Specification for Carbon and Alloy Steel Bars for Springs[2]

E 10 Test Method for Brinell Hardness of Metallic Materials[3]

E 112 Test Methods for Determining Average Grain Size[3]

E 709 Guide for Magnetic Particle Examination[4]

3. Ordering Information

3.1 Orders for springs under this specification shall include the following information:

3.1.1 Quantity,

3.1.2 Name of material,

3.1.3 A drawing or list showing required dimensions and loads, and part number,

3.1.4 Packaging, marking and loading, and

3.1.5 End use.

NOTE 1—A typical ordering description is: 500 springs Drawing 3303 Rev. A. to ASTM A 125, 1095 steel, for cyclical machine operation. Palletize, maximum weight 4000 lb.

4. Materials and Manufacture

4.1 *Material*:

4.1.1 Unless otherwise specified, the springs shall be made of carbon steel bars conforming to the requirements of Specification A 689. Due to hardenability limitations of carbon steel, it is suggested that the bar diameter be limited to 1⅝ in. (41.8 mm) max in order to withstand the maximum test stress requirements of this specification.

4.1.2 If alloy steel is specified, the springs shall be made from alloy steel bars conforming to Specification A 689. Any of the alloy steel grades referred to may be used at the option of the spring manufacturer, providing that a minimum as-quenched hardness of Rockwell HRC-50 will be achieved at the center of the bar section representing the spring when quenched in the same media and manner as the spring.

4.1.3 *Springs Made from Bars Over 2 in. (50.8 mm)*—Note that the bias tolerance (reference Specification A29/A 29M, Table A1.1 on Permissible Variations in Cross Section for Hot-Wrought Round, Square, and Round-Cornered Square Bars of Steel) of the bar diameter shall be taken into consideration when designing and calculating the solid height, spring rate, solid stress, and solid capacity.

4.2 *Hardness*:

4.2.1 The springs must be quenched and tempered to a sufficiently high hardness (strength) to withstand the stresses developed in testing the finished spring. The maximum hardness shall not exceed 477 Brinell numbers (2.80 mm indentation diameter).

4.2.2 When hardness limits are specified, the total range or spread may not be less than 0.15 mm difference in indentation diameters. The specified or indicated minimum hardness must

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] *Annual Book of ASTM Standards*, Vol 03.03.

be sufficient to develop the required strength to withstand the solid stresses of the spring design involved.

4.2.3 Hardness shall be read on a prepared flat surface in an area not detrimental to the life of the spring at a full section after removal of the decarburized layer. A tungsten-carbide 10-mm ball shall be applied under a 3000-kg load and the indentation diameter converted to Brinell numbers by using Table 1. The values for Table 1 have been taken from Specification E 10.

4.3 *Metallurgical Requirements*:

4.3.1 The total depth of decarburization, partial plus complete as measured on the finished spring in the quenched and tempered condition, shall not exceed 0.006 in. (0.15 mm) plus 1 % of the bar diameter. The decarburization shall be examined at 100× on a test specimen suitably etched and cut from a full cross section of the test spring showing at least one lineal inch of original bar circumference.

4.3.2 The structure of the finished spring shall have an average ASTM Grain Size No. 5 or finer as determined by the latest revision of Test Methods E 112.

4.4 *End Construction*:

4.4.1 *End Construction-Tapered Squared and Ground*—The end bearing surfaces of the spring shall be ground to produce a firm bearing. The end bearing surfaces shall have a minimum bearing surface of two thirds of the mean coil circumference and a minimum width of two thirds of the hot-tapered surface of the bar. The tip ends of the bar shall be in approximate contact with the adjacent coil, and shall not protrude beyond the maximum permissible outside diameters of the spring as established by Table 2.

4.4.1.1 *End Construction Coil Blunt Squared and Ground (Optional)*—The end bearing surfaces of the spring shall be ground to produce a firm bearing. The end bearing surfaces shall have a minimum ground bearing surface of two thirds of the mean coil circumference and a minimum width of two thirds of the bar diameter. The tip ends of the bar shall be in approximate contact with the adjacent coil and shall not protrude beyond the maximum permissible outside diameters of the spring as established by Table 2.

4.4.2 Springs with ground ends having a free height-to-mean diameter ratio of not less than 1 or more than 5 shall not deviate from the perpendicular more than the number of degrees prescribed in Table 3, as determined by standing the spring on its end and measuring the angular deviation of a straightedge along the outer helix from a perpendicular to the plate on which the spring is standing.

4.4.3 The ends of springs shall be parallel within a tolerance of twice that specified for the squareness of ends as determined by standing the spring on its end and measuring the maximum angular deviation of the other end from a plane parellel to the plate on which the spring is standing.

TABLE 2 Brinell Hardness

Indentation Diameter, mm	Brinell Hardness Numbers
2.75	495
2.80	477
2.85	461
2.90	444
2.95	429
3.00	415
3.05	401
3.10	388
3.15	375

5. Physical Requirements

5.1 *Measurements*:

5.1.1 *Solid Height*—The solid height is the perpendicular distance between the plates of the testing machine when the

TABLE 1 Permissible Out-of-Squareness, Springs with Ground Ends

Total Travel, in. (mm)	Mean Diameter, in. (mm)									
	2 (51) and under	Over 2 to 4 (51 to 102), incl	Over 4 to 6 (102 to 152), incl	Over 6 to 8 (152 to 203), incl	Over 8 to 10 (203 to 254), incl	Over 10 to 12 (254 to 305), incl	Over 12 to 14 (305 to 356), incl	Over 14 to 16 (356 to 406), incl	Over 16 to 18 (406 to 457), incl	Over 18 to 20 (457 to 508), incl
	Degree									
2 (51) and under	1¼	1¼	1	1	1	1	. . .	. . .	. . .	. . .
Over 2 to 4 (51 to 102), incl	1¾	1½	1¼	1¼	1	1	1	. . .	. . .	. . .
Over 4 to 6 (102 to 152), incl	2¼	1¾	1½	1¼	1¼	1	1	. . .	. . .	. . .
Over 6 to 8 (152 to 203), incl	2½	2¼	1¾	1½	1¼	1¼	1	1	. . .	. . .
Over 8 to 10 (203 to 254), incl	2¾	2½	2	1½	1½	1¼	1¼	1	. . .	. . .
Over 10 to 12 (254 to 305), incl	3	2¾	2¼	1¾	1½	1½	1¼	1¼	1	. . .
Over 12 to 14 (305 to 356), incl	. . .	3	2½	2	1¾	1¾	1½	1½	1¼	1¼
Over 14 to 16 (356 to 406), incl	. . .	. . .	2¾	2¼	2	2	1¾	1¾	1½	1½
Over 16 to 18 (406 to 457), incl	. . .	. . .	3	2½	2¼	2	2	1¾	1¾	1½
Over 18 to 20 (457 to 508), incl	. . .	. . .	3	2¾	2½	2¼	2¼	2	2	1¾
Over 20 to 22 (508 to 559), incl	. . .	. . .	. . .	3	2¾	2¼	2¼	2	2	1¾
Over 22 to 24 (559 to 610), incl	. . .	. . .	. . .	. . .	3	2¼	2¼	2	2	1¾
Over 24 to 26 (610 to 660), incl	. . .	. . .	. . .	. . .	. . .	2½	2½	2¼	2¼	2
Over 26 to 28 (660 to 701), incl	. . .	. . .	. . .	. . .	. . .	2½	2½	2¼	2¼	2
Over 28 to 30 (702 to 762), incl	. . .	. . .	. . .	. . .	. . .	2¾	2½	2¼	2¼	2
Over 30 to 32 (762 to 813), incl	. . .	. . .	. . .	. . .	. . .	2¾	2¾	2½	2½	. . .
Over 32 to 34 (813 to 864), incl	. . .	. . .	. . .	. . .	. . .	2¾	2¾	2½	2½	. . .
Over 34 to 38 (864 to 914), incl	. . .	. . .	. . .	. . .	. . .	3	2¾	2¾	2¾	. . .
Over 36 to 38 (914 to 965), incl	. . .	. . .	. . .	. . .	. . .	. . .	3	2¾	2¾	. . .
Over 38 to 42 (965 to 1016), incl	. . .	. . .	. . .	. . .	. . .	. . .	. . .	3	3	. . .

TABLE 3 Permissible Variations in Outside Diameter of Helix
(For springs with *D/d* ratio not exceeding 8)

NOTE 1— (for design information) These permissible variations, exclusives of manufacturing taper, should be used as a guide in the design of concentrically-nested helical-spring units for free assembly. The diametrical clearance desired is 1/16 in. (1.59 mm) less than the sum of the applicable tolerances of the nested spring units, but in no case shoulds it be less than 1/8 in. (3.17 mm).

NOTE 2—In cases where radical clearance on existing concentrically-nested helical-spring units will not accommodate these tolerances, the nominal inside diameters shall be adhered to as closely as practicable, with plus variation on the outer springs and minus variation on the inner springs to guarantee free assembly. Drawings must show reference to the complete nested spring units.

NOTE 3— (For springs with *D/d* ratio not exceeding 8) For *D/d* ratio greater than 8, increase tolerance 50 %.

Nominal Outside Diameter, in. (mm)	Nominal Free Height or Length of Spring, in. (mm)					
	Up to 10 (254) incl, ±	Over 10 to 18 (254 to 457), incl, ±	Over 18 to 26 (457 to 661), incl, ±	Over 26 to 34 (661 to 874), incl, ±	Over 34 to 42 (874 to 1067), incl, ±	Over 42 to 60 (1067 to 1524), incl, ±
Up to 6 (152), incl	1/16 (1.59)	3/32 (2.38)	1/8 (3.17)	5/32 (3.97)	3/16 (4.76)	. . .
Over 6 to 8 (152 to 203), incl	3/32 (2.38)	1/8 (3.17)	3/16 (4.76)	1/4 (6.35)	1/4 (6.35)	. . .
Over 8 to 12 (203 to 305), incl	1/8 (3.17)	3/16 (4.76)	1/4 (6.35)	1/4 (6.35)	1/4 (6.35)	. . .
Over 12 to 16 (305 to 406), incl	. . .	1/4 (6.35)	1/4 (6.35)	1/4 (6.35)	1/4 (6.35)	5/16 (7.94)
Over 16 to 20 (406 to 508), incl	. . .	. . .	5/16 (7.94)	5/16 (7.94)	5/16 (7.94)	3/8 (9.53)
Over 20 to 24 (508 to 610), incl	. . .	. . .	3/8 (9.53)	3/8 (9.53)	3/8 (9.53)	7/16 (11.00)
Over 24 to 28 (610 to 701), incl	. . .	. . .	7/16	7/16	7/16	1/2
Over 28 (701), incl	. . .	. . .	1/2	1/2	1/2	1/2

spring is compressed solid with the load specified in 7.3. The solid height thus measured may be less, but shall not exceed the specified nominal solid height by more than the limits given in Table 4.

5.1.2 *Free Height*—The free height is the height of the spring after the load specified in 7.3 has been released, and is determined by placing a straightedge across the top of the spring and measuring the perpendicular distance from the plate on which the spring stands to the bottom of the straightedge at the approximate center of the spring. Tolerances are shown in Table 5.

5.1.3 *Loaded Height*—The loaded height is the perpendicular distance between the plates of the testing machine when the specified working load has been applied in compression. Tolerances are shown in Table 5.

5.1.4 *Permanent Set*—After determining the free height as specified in 5.1.2, the permanent set is the difference between this free height and the height after the spring has been compressed solid three additional times under the test load specified in 7.3, measured at the same point and in the same manner. Tolerances are shown in Table 5.

TABLE 4 Permissible Variations in Solid Height

Nominal Solid Height, in. (mm)	Deviation Above Nominal Solid Height, max, in.[A] (mm)
Up to 7 (178), incl	1/16 (1.59)
Over 7 to 10 (178 to 254), incl	3/32 (2.38)
Over 10 to 13 (254 to 330), incl	1/8 (3.17)
Over 13 to 16 (330 to 406), incl	5/32 (3.97)
Over 16 to 19 (406 to 483), incl	3/16 (4.76)
Over 19 to 22 (483 to 559), incl	7/32 (5.56)
Over 22 to 25 (559 to 635), incl	1/4 (6.35)
Over 25 to 28 (635 to 711), incl	9/32 (7.14)
Over 28 to 31 (711 to 787), incl	5/16 (7.94)

[A] For additional 3-in. (76-mm) increase in solid height, the deviation shown should be increased by 1/32 in. (0.79 mm).

TABLE 5 Permissible Variations in Free Height, Loaded Height and Permanent Set

Nominal Total Deflection, in. (mm)	Deviation From Nominal Free Height, max, in. (mm), ±	Deviation From Nominal Loaded Height,[A] max, in. (mm), ±	Permanent Set, max, in. (mm)
Up to 3 (76.2), incl	5/32 (3.97)	4/32 (3.17)	3/64 (1.19)
Over 3 to 4 (76.2 to 102), incl	8/32 (6.35)	5/32 (3.97)	4/64 (1.59)
Over 4 to 5 (102 to 127), incl	8/32 (6.35)	6/32 (4.76)	4/64 (1.59)
Over 5 to 6 (127 to 152), incl	11/32 (8.73)	7/32 (5.56)	5/64 (1.99)
Over 6 to 7 (152 to 179), incl	11/32 (8.73)	8/32 (6.35)	5/64 (1.99)
Over 7 to 8 (179 to 203), incl	14/32 (11.0)	9/32 (7.14)	6/64 (2.38)
Over 8 to 9 (203 to 228), incl	14/32 (11.0)	10/32 (7.94)	6/64 (2.38)
Over 9 to 10 (228 to 254), incl	17/32 (13.49)	11/32 (8.73)	7/64 (2.78)
Over 10 to 11 (254 to 279), incl	17/32 (13.49)	12/32 (9.53)	7/64 (2.78)
Over 11 to 12 (279 to 305), incl	20/32 (15.87)	13/32 (10.32)	8/64 (3.17)
Over 12 to 13 (305 to 330), incl	20/32 (15.87)	14/32 (11.00)	8/64 (3.17)
Over 13 to 14 (330 to 356), incl	23/32 (18.25)	15/32 (11.91)	8/64 (3.17)
Over 14 to 15 (356 to 381), incl	23/32 (18.25)	16/32 (12.70)	9/64 (3.57)
Over 15 to 16 (381 to 406), incl	26/32 (20.64)	17/32 (13.49)	9/64 (3.57)
Over 16 to 17 (406 to 431), incl	26/32 (20.64)	18/32 (14.28)	10/36 (3.97)
Over 17 to 18 (431 to 457), incl	29/32 (23.01)	19/32 (15.08)	10/64 (3.97)
Over 18 to 19 (457 to 483), incl	29/32 (23.01)	20/32 (15.87)	11/64 (4.37)
Over 19 to 20 (483 to 508), incl	1 (25.40)	21/32 (16.67)	11/64 (4.37)
Over 20 to 21 (508 to 533), incl	1 (25.40)	22/32 (17.46)	12/64 (4.76)
Over 21 to 22 (533 to 559), incl	1 3/32 (27.78)	23/32 (18.25)	12/64 (4.76)
Over 22 to 23 (559 to 584), incl	1 3/32 (27.78)	24/32 (19.05)	13/64 (5.16)
Over 23 to 24 (584 to 610), incl	1 6/32 (30.16)	25/32 (19.84)	13/64 (5.16)
Over 24 to 25 (610 to 635), incl	1 6/32 (30.16)	26/32 (20.64)	14/64 (5.56)
Over 25 to 26 (635 to 661), incl	1 9/32 (32.54)	27/32 (21.43)	14/64 (5.56)
Over 26 to 27 (661 to 685), incl	1 9/32 (32.54)	28/32 (22.22)	15/64 (5.96)
Over 27 to 28 (685 to 711), incl	1 12/32 (34.93)	29/32 (23.01)	15/64 (5.96)
Over 28 to 29 (711 to 746), incl	1 12/32 (34.93)	30/32 (23.81)	16/64 (6.35)
Over 29 to 30 (746 to 772), incl	1 15/32 (37.19)	31/32 (24.61)	16/64 (6.35)

[A] If two loads are specified, no tolerance shall apply to the free height.

5.1.5 *Uniformity of Pitch*—The pitch of the coils shall be sufficiently uniform so that when the spring is compressed without lateral support to a height representing a deflection of 85 % of the nominal total travel, none of the coils shall be in contact with one another, excluding the inactive end coils.

Under 85 % deflection, the maximum spacing between any two adjacent active coils shall not exceed 40 % of the nominal free coil spacing. The nominal free coil spacing is equivalent to the specified total travel divided by the number of active turns. When the design is such that it cannot be compressed to solid height without lateral support, these requirements do not apply.

5.1.6 *Outside Diameter*—The outside diameter shall be measured on a spring in the free condition and across any full turn excluding the end turns and must be taken approximately perpendicular to the helix axis. The tolerances are shown in Table 2.

5.1.7 *Calculations for Testing Loads and Stresses*:

5.1.7.1 *Solid Capacity*—Calculate the solid capacity of the spring as follows:

$$P = Gd^4F/8\,ND^3 \quad (1)$$

where:

G = 11×10^6 psi = effective torsional modulus of elasticity,
d = nominal bar diameter, in.,
D = mean coil or helix diameter, in.,
F = spring deflection = free to solid, in.,
N = active turns = (solid height)/bar diameter) − 1.5, and
P = solid capacity, lb.

5.1.7.2 *Uncorrected Solid Stress*—Calculate the uncorrected solid stress as follows: (**Warning**—Bar nominal diameter may not be the same as the specified diameter, due to biased tolerances on hot-rolled bars 2 in. (50.8 mm) and over.)

$$S = 8PD/3.1416\,d^3 \quad (2)$$

6. Workmanship, Finish, and Appearance

6.1 *Finish*:

6.1.1 The surface of the spring shall be as furnished in the quenched and tempered condition.

6.1.2 The surface of the springs shall be free of injurious defects within the normal limitation of hot-coiled springs.

7. Sampling and Conduct of Tests for Lot Inspection

7.1 The springs shall be submitted singly or grouped as shown by the drawings and shall conform to the drawings within the permissible variations shown in 5.1.1 through 5.1.6 and 4.4.1 through 4.4.3.

7.2 The physical tests specified in 5.1.1 through 5.1.7.2 shall be conducted in the order specified. When lateral support during the test is not required, the springs shall not be rapped or otherwise disturbed during the tests.

7.3 The test load to be used in 5.1.1, 5.1.2, and 5.1.4 shall be determined as follows:

7.3.1 If the uncorrected solid stress (see 5.1.7.2) is not more than 100 000 psi (690 MPa) for carbon steel and 115 000 psi (795 MPa) for alloy steel, the test load shall be that load which is sufficient to bring all coils in contact. In no case, however, shall this load exceed by more than 50 % the solid capacity as calculated (see 5.1.7.1).

7.3.2 If the uncorrected solid stress (see 5.1.7.2) exceeds 100 000 psi for carbon steel or 115 000 psi for alloy steel, the springs shall not be subject to solid compression, and requirements for solid height (5.1.1) and permanent set (5.1.4) do not apply.

7.4 The stresses specified in 7.3 are limiting stresses not to be exceeded in testing and are not intended as a guide in the design of springs. The proper working and solid stresses will depend upon the class of spring, bar size, spring index, and type of service for which it is intended.

8. Inspection

8.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Source inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspections shall be made at the place of manufacture unless otherwise agreed to.

8.2 The purchaser may make tests to govern the acceptance or rejection in his own laboratory or elsewhere. Such tests, however, shall be made at the expense of the purchaser.

9. Rejection and Rehearing

9.1 *Rejection*:

9.1.1 Unless otherwise specified, any rejection based on tests made in accordance with this specification shall be reported to the manufacturer within 30 working days of receipt of the springs by the purchaser.

9.1.2 Individual springs that show injurious defects subsequent to inspection at the manufacturer's plant or elsewhere will be rejected and shall be replaced by the manufacturer.

9.2 *Rehearing*:

9.2.1 Samples that represent rejected material shall be preserved for 2 weeks from the date of the test report. In case of dissatisfaction with the results of these tests, the manufacturer may make claim for a rehearing within that time.

9.3 *Reworking*:

9.3.1 Material that fails to conform to the requirements as to dimensions or mechanical tests may be again submitted after being reworked.

10. Marking

10.1 The name or brand of the manufacturer and the month and year of manufacture shall be legibly stamped on each spring on bar sizes $^{11}/_{16}$ in. (17.4 mm) and larger at a place not detrimental to the life or service of the spring.

11. Keywords

11.1 steel springs

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when individually specified by the purchaser. When details of these requirements are not covered herein, they are subject to agreement between the manufacturer and purchaser.

S1. Tapered and Squared Ends (Not Ground)

S1.1 The ends of the bar shall be properly tapered to give the finished spring a reasonably firm bearing. The points of the bar shall be in approximate contact with the adjacent coil, and shall not protrude beyond the maximum permissible outside diameter of the spring, as established by Table 3.

S1.2 All springs with ends not ground having a mean diameter-to-bar diameter ratio of 3.5 or over and having a free height-to-mean diameter ratio of not less than 1 nor more than 4 shall not deviate from perpendicular more than shown in Table S1.1. This is determined by standing the spring on its end and measuring the angular deviation of a straightedge along the outer helix from a perpendicular to the plate on which the spring is standing.

S2. Magnetic Particle Inspection

S2.1 When specified, magnetic particle inspection shall be employed for locating surface cracks and defects such as seams and similar irregularities. The methods and procedures for such inspection shall be in accordance with Guide E 709. Acceptable depth of defects shall be a matter of agreement between the manufacturer and purchaser.

S3. Shotpeening

S3.1 When specified, shotpeening may be employed to increase the fatigue strength of the springs.

S3.2 The minimum requirement for intensity and coverage shall be 0.006 in. (0.15 mm) and 90 % visual coverage as measured on an Almen C strip (Note S1). A test strip is to be located on the inside of a suitable test spring.

NOTE S1—The Almen C test strip is a hardened steel strip 0.0938 in. (2.38 mm) thick made to close dimensional, flatness, and hardness limits. This strip is mounted on a special holder exposing one side of the test strip to the steel shotpeening blast while protecting the other side from the shotpeening. The strip curvature, caused by the peening of one side only, is measured by means of a special micrometer dial gage (Almen No. 2). The depth of curvature so measured, is designated as the intensity. The coverage is determined by visual examination of the peened surface of the test strip at 10× magnification. Coverage is defined as the percentage of uniform denting or obliteration of the original surface of the test strip.

S3.3 Because of the wide scope of spring sizes, bar diameters, and spring applications, higher intensities and coverage may be desirable, in which case the intensities and coverage are subject to agreement between purchaser and manufacturer.

TABLE S1.1 Permissible Out-of-Squareness, Springs with Unground Ends

Mean Diameter, in. (mm)	Deviation, deg
Up to 2 (51), incl	3½
Over 2 to 4 (51 to 102), incl	3
Over 4 to 6 (102 to 152), incl	2½
Over 6 to 8 (152 to 203), incl	2½
Over 8 to 10 (203 to 254), incl	2¼
Over 10 to 12 (254 to 305), incl	2¼
Over 12 to 14 (305 to 356), incl	2¼
Over 14 to 16 (356 to 406), incl	2¼

S4. Special Surface Finishes

S4.1 For closer control over spring characteristics and increased fatigue strength, the use of material with special surface finish may be specified, subject to special agreement between purchaser and manufacturer.

S5. Protective Finishes

S5.1 When specified, the springs will be coated with a good grade of corrosion preventative, suitable for temporary outdoor storage. The application of special coatings, plating, etc. for protection in environmental conditions shall be a matter of agreement between the manufacturer and purchaser.

S6. Load Rate

S6.1 The average load rate shall be determined by dividing the difference in recorded loads at 20 % and 60 % of the nominal total travel by the measured deflection between these two points. The average load rate is not subject to checking unless a tolerance is specified. When a tolerance is specified, it shall be ±10 % on springs with 5 or more total turns and a matter of agreement on springs with fewer than 5 coils.

S7. Special Load Requirements

S7.1 With respect to loaded heights, if the tolerance is placed on the load rather than the height dimension, it shall be between 20 % and 80 % of calculated solid capacity and be no less than ±5 % of the calculated solid capacity of the spring.

S7.2 Only two of the following parameters: solid height, free height, load rate, load at a height, or a different load at a height, may be specified and the remaining parameters will be considered reference.

S8. Additional Tests

S8.1 Any testing in addition to that prescribed in Section 5, including the results of Paragraphs 4.2, 4.3, and 4.4, shall be a matter of agreement between the manufacturer and purchaser.

Standard Test Methods for Determining Hardenability of Steel[1]

This standard is issued under the fixed designation A255; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 These test methods cover the identification and description of test methods for determining the hardenability of steels. The two test methods include the quantitative end-quench or Jominy Test and a method for calculating the hardenability of steel from the chemical composition based on the original work by M. A. Grossman.

1.2 The selection of the test method to be used for determining the hardenability of a given steel shall be agreed upon between the supplier and user. The Certified Material Test Report shall state the method of hardenability determination.

1.3 The calculation method described in these test methods is applicable only to the range of chemical compositions that follow:

Element	Range, %
Carbon	0.10–0.70
Manganese	0.50–1.65
Silicon	0.15–0.60
Nickel	1.50 max
Chromium	1.35 max
Molybdenum	0.55 max
Copper	0.35 max
Vanadium	0.20 max

1.4 Hardenability is a measure of the depth to which steel will harden when quenched from its austenitizing temperature (Table 1). It is measured quantitatively, usually by noting the extent or depth of hardening of a standard size and shape of test specimen in a standardized quench. In the end-quench test the depth of hardening is the distance along the specimen from the quenched end which correlates to a given hardness level.

1.5 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E18 Test Methods for Rockwell Hardness of Metallic Materials

E112 Test Methods for Determining Average Grain Size

2.2 *ASTM Adjuncts:*

ASTM Hardenability Chart[3]

END-QUENCH OR JOMINY TEST

3. Description

3.1 This test method covers the procedure for determining the hardenability of steel by the end-quench or Jominy test. The test consists of water quenching one end of a cylindrical test specimen 1.0 in. in diameter and measuring the hardening response as a function of the distance from the quenched end.

4. Apparatus

4.1 *Support for Test Specimen*—A fixture for supporting the test specimen vertically so that the lower end of the specimen is a distance of 0.5 in. (12.7 mm) above the orifice of the water-quenching device. A satisfactory type of support for the standard 1.0-in. (25.4-mm) specimen is shown in Fig. 1.

NOTE 1—A suitable support for other sizes and shapes of specimens is shown in Fig. X1.1.

4.2 *Water-Quenching Device*—A water-quenching device of suitable capacity to provide a vertical stream of water that can be controlled to a height of 2.5 in. (63.5 mm) when passing through an orifice 0.5 in. (12.7 mm) in diameter. A tank of sufficient capacity to maintain the water temperature requirements of 6.3 with a small pump and control valves will be

[1] These test methods are under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and are the direct responsibility of Subcommittee A01.15 on Bars.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Standard ASTM Hardenability Charts (8½ by 11 in. pads of 50 charts) are available from ASTM International Headquarters. Order Adjunct No. ADJA0255. Original adjunct produced in 1945.

TABLE 1 Normalizing and Austenitizing Temperatures[A]

Steel Series	Ordered Carbon Content, max, %	Normalizing Temperature, °F (°C)	Austenitizing Temperature, °F (°C)
1000, 1300, 1500, 3100, 4000, 4100	0.25 and under	1700 (925)	1700 (925)
4300, 4400, 4500, 4600, 4700, 5000, 5100, 6100,[B] 8100, 8600, 8700, 8800, 9400, 9700, 9800	0.26 to 0.36, incl	1650 (900)	1600 (870)
	0.37 and over	1600 (870)	1550 (845)
2300, 2500, 3300, 4800, 9300	0.25 and under	1700 (925)	1550 (845)
	0.26 to 0.36, incl	1650 (900)	1500 (815)
	0.37 and over	1600 (870)	1475 (800)
9200	0.50 and over	1650 (900)	1600 (870)

[A] A variation of ±10°F (6°C) from the temperatures in this table is permissible.
[B] Normalizing and austenitizing temperatures are 50°F (30°C) higher for the 6100 series.

found satisfactory. The water-supply line shall also be provided with a quick opening valve.

5. Test Specimens

5.1 *Wrought Specimens*—End-quench specimens shall be prepared from rolled or forged stock and shall represent the full cross section of the product. If negotiated between the supplier and the user, the end-quench specimen may be prepared from a given location in a forged or rolled product or from a continuous cast billet. The test specimen shall be 1.0 in. (25.4 mm) in diameter by 4.0 in. (101.6 mm) in length, with means for hanging it in a vertical position for end quenching. Dimensions of the preferred specimen and of an optional specimen (Note 2) are given in Figs. 2 and 3. The specimen shall be machined from a bar previously normalized in accordance with 6.1 and of such size as to permit the removal of all decarburization in machining to 1.0 in. round. The end of the specimen to be water cooled shall have a reasonably smooth finish, preferably produced by grinding. Normalizing may be waived by agreement between the supplier and the user. The previous thermal history of the specimen tested shall always be recorded.

5.2 *Cast Specimens*—A separately cast end-quench specimen may be used for non-boron steels. Cast specimens are not suitable for boron steel grades due to erratic results. A graphite or metal mold may be used to form an overlength specimen 1.0 in. (25.4 mm) in diameter which shall be cut to the standard specimen size. The mold may also be used to form a 1.25-in. (31.8-mm) diameter specimen which shall be machined to the final specimen size. Cast tests need not be normalized.

NOTE 2—Other sizes and shapes of test specimens are described in Appendix X1.

6. Procedure

6.1 *Normalizing*—The wrought product from which the specimen is to be prepared shall be normalized to ensure proper hardening characteristics. The sample shall be held at the temperature listed in Table 1 for 1 h and cooled in air. Tempering of the normalized sample to improve machinability is permitted.

6.2 *Heating*—Place the specimen in a furnace that is at the specified austenitizing temperature (Table 1) and hold at this temperature for 30 min. In production testing slightly longer times up to 35 min may be used without appreciably affecting results. It is important to heat the specimen in such an atmosphere that practically no scaling and a minimum of decarburization takes place. This may be accomplished by heating the specimen in a vertical position in a container with an easily removable cover containing a layer of cast-iron chips with the bottom face of the specimen resting on the chips.

6.2.1 Other methods consist of placing the specimen in an appropriately sized hole in a graphite block or placing the specimen in an upright tube attached to a flat base, both of a heat-resistant metal, with the collar projecting for a tong hold. Place a disk of graphite or carbon, or a layer of carbonaceous material such as charcoal, in the bottom of the tube to prevent scaling.

6.2.2 For a particular fixture and furnace, determine the time required to heat the specimen to the austenitizing temperature by inserting a thermocouple into a hole drilled axially in the top of the specimen. Repeat this procedure periodically, for example once a month, for each combination of fixture and furnace.

6.3 *Quenching*—Adjust the water-quenching device so that the stream of water rises to a free height of 2.5 in. (63.5 mm) above the 0.5-in. (12.7-mm) orifice, without the specimen in position. The support for the specimen shall be dry at the beginning of each test. Then place the heated specimen in the support so that its bottom face is 0.5 in. above the orifice, and turn on the water by means of the quick-opening valve. The time between removal of the specimen from the furnace and the beginning of the quench should not be more than 5 s. Direct the stream of water, at a temperature of 40 to 85°F (5 to 30°C), against the bottom face of the specimen for not less than 10 min. Maintain a condition of still air around the specimen during cooling. If the specimen is not cold when removed from the fixture, immediately quench it in water.

6.4 *Hardness Measurement*—Two flats 180° apart shall be ground to a minimum depth of 0.015 in. (0.38 mm) along the entire length of the bar and Rockwell C hardness measurements made along the length of the bar. Shallower ground depths can affect reproducibility of results, and correlation with cooling rates in quenched bars.

6.4.1 The preparation of the two flats must be carried out with considerable care. They should be mutually parallel and the grinding done in such a manner that no change of the quenched structure takes place. Very light cuts with water cooling and a coarse, soft-grinding wheel are recommended to avoid heating the specimen. In order to detect tempering due to grinding, the flat may be etched with one of the following etchant solutions:

NOTE 3—5 % nitric acid (concentrated) and 95 % water by volume.

NOTE 4—50 % hydrochloric acid (concentrated) and 50 % water by volume.

Wash the sample in hot water. Etch in solution No. 1 until black. Wash in hot water. Immerse in solution No. 2 for 3 s and wash in hot water. Dry in air blast.

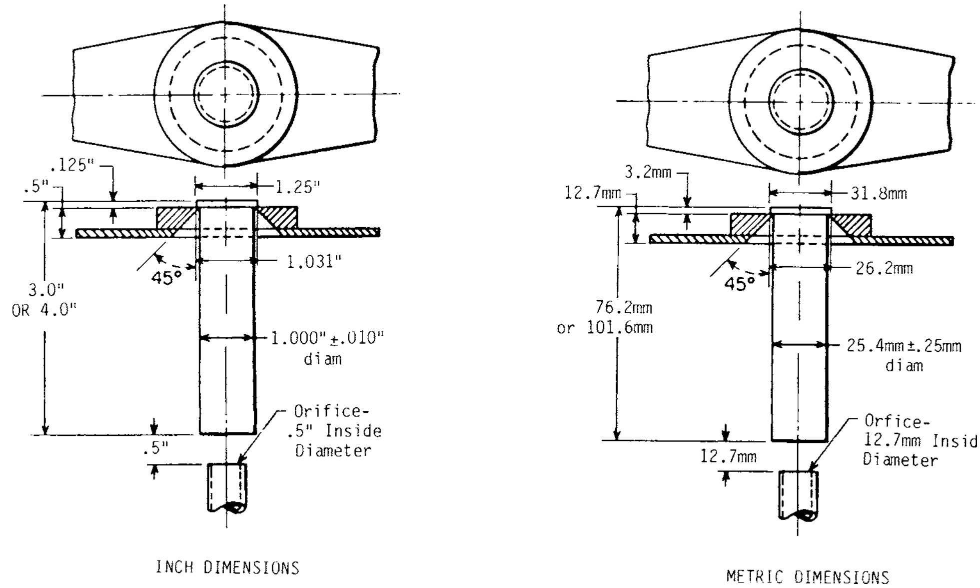

FIG. 1 Test Specimen in Support for Water Quenching

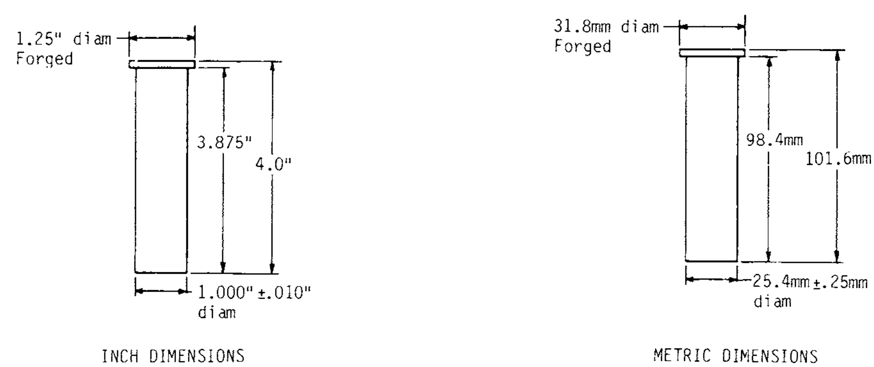

FIG. 2 Preferred Test Specimen

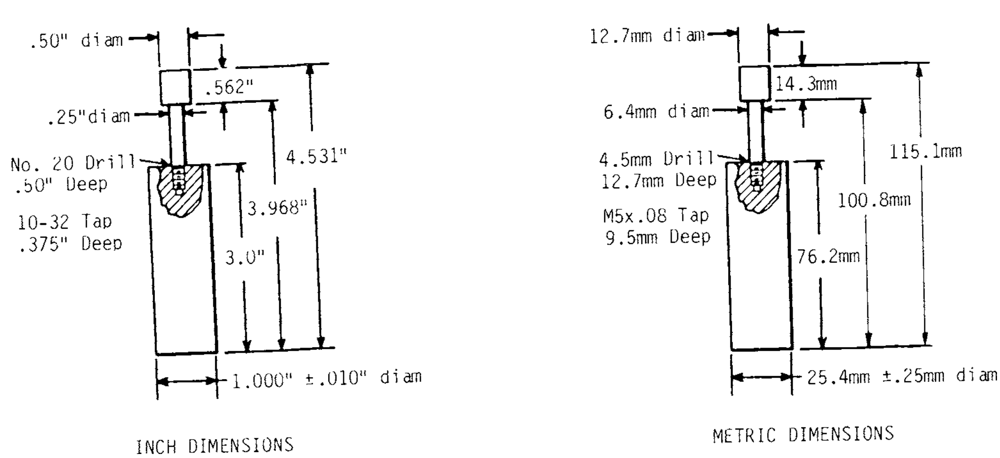

FIG. 3 Optional Test Specimen

6.4.1.1 The presence of lighter or darker areas indicates that hardness and structure have been altered in grinding. If such changes caused by grinding are indicated, new flats may be prepared.

6.4.2 When hardness tests are made, the test specimen rests on one of its flats on an anvil firmly attached to the hardness machine. It is important that no vertical movement be allowed when the major load is applied. The anvil must be constructed to move the test specimen past the penetrator in accurate steps of 1⁄16 in. (1.5 mm). Resting the specimen in a V-block is not permitted.

6.4.2.1 The Rockwell tester should periodically be checked against standard test blocks. It is recommended that a test block be interposed between the specimen and the indenter to check the seating of the indenter and the specimen simultaneously. For general statements regarding the use of test blocks and surface conditions, reference should be made to 4.7 and 5.2, respectively, of Test Methods E18.

6.4.3 Exercise care in registering the point of the indenter in relationship to the quenched end of the specimen as well as providing for accurate spacing between indentations. A low-power measuring microscope is suitable for use in determining the distance from the quenched end to the center of the first impression and in checking the distance from center to center of the succeeding impressions. It has been found that with reasonable operating care and a well-built fixture, it is practical to locate the center of the first impression 0.0625 ± 0.004 in. (1.5 ± 0.10 mm) from the quenched end. The variations between spacings should be even smaller. Obviously, it is more important to position the indenter accurately when testing low-hardenability steels than when testing high-hardenability steels. The positioning of the indenter should be checked with sufficient frequency to provide assurance that accuracy requirements are being met. In cases of lack of reproducibility or of differences between laboratories, indenter spacing should be measured immediately.

6.4.4 Readings shall be taken in steps of 1⁄16 in. (1.6 mm) for the first 16 sixteenths (25.4 mm), then 18, 20, 22, 24, 28, and 32 sixteenths of an inch. Values below 20 HRC are not recorded because such values are not accurate. When a flat on which readings have been made is used as a base, the burrs around the indentation shall be removed by grinding unless a fixture is used which has been relieved to accommodate the irregularities due to the indentations.

6.4.4.1 Hardness readings should preferably be made on two flats 180° apart. Testing on two flats will assist in the detection of errors in specimen preparation and hardness measurement. If the two probes on opposite sides differ by more than 4 HRC points at any one position, the test should be repeated on new flats, 90° from the first two flats. If the retest also has greater than 4 HRC points spread, a new specimen should be tested.

6.4.4.2 For reporting purposes, hardness readings should be recorded to the nearest integer, with 0.5 HRC values rounded to the next higher integer.

7. Plotting Test Results

7.1 Test results should be plotted on a standard hardenability chart prepared for this purpose, in which the ordinates represent HRC values and the abscissae represent the distance from the quenched end of the specimen at which the hardness determinations were made. When hardness readings are taken on two or more flats, the values at the same distance should be averaged and that value used for plotting. A facsimile of the standard ASTM hardenability chart[3] on which typical hardenability curves have been plotted is shown in Fig. 4.

8. Index of Hardenability

8.1 The hardenability of a steel can be designated by a specific HRC hardness value or HRC hardness value range at a given Jominy ("J") distance. Examples of this method are J 4⁄16 in. (6.4 mm) = 47 HRC min, J 7⁄16 in. (11.1 mm) = 50 HRC max, and J 5⁄16 in. (7.9 mm) = 38–49 HRC.

9. Report

9.1 Report the following information that may be recorded on the ASTM hardenability chart:

9.1.1 Previous thermal history of the specimen tested, including the temperature of normalizing and austenitizing,

9.1.2 Chemical Composition,

9.1.3 ASTM grain size (McQuaid-Ehn) as determined by Test Methods E112, unless otherwise indicated, and

9.1.4 A prominent notation on the standard hardenability chart if any of the test specimens listed in Appendix X1 are used.

CALCULATION OF HARDENABILITY

10. Introduction

10.1 This method of Jominy Hardenability calculation from the chemical ideal diameter (DI) on a steel is based on the original work of M. A. Grossman and provides increased accuracy by refinement of the carbon multiplying factors and the correlation of a boron factor (B.F.) with carbon and alloy content. These refinements were based on analysis of thousands of heats of boron and non-boron 1500, 4100, 5000, and 8600 series steels encompassing a range of compositions as follows and a range of DI as contained in Tables 2-5. The accuracy of this test method and the techniques used to develop it have been documented. For comparison of this test method to others, or for steel compositions outside the mentioned grades, the user should refer to other articles concerned with calculating hardenability.

Element	Range, %
Carbon	0.10–0.70
Manganese	0.50–1.65
Silicon	0.15–0.60
Nickel	1.50 max
Chromium	1.35 max
Molybdenum	0.55 max
Copper	0.35 max
Vanadium	0.20 max

10.1.1 Calculated DI and Jominy hardenability curves are valid only within the chemical ranges stated above. However, to facilitate melting process control for higher alloy steels, Hardenability Multiplying Factors have been included for calculating the DI within the following chemical composition ranges:

Element	Range, %
Carbon	0.01–0.90
Manganese	0.01–1.95
Silicon	0.01–2.00
Nickel	0.01–3.50
Chromium	0.01–2.50
Molybdenum	0.01–0.55
Copper	0.01–0.55
Vanadium	0.01–0.20
Zirconium	0.01–0.25

10.2 Tables 2-18 are to be used to calculate hardenability from the chemical ideal diameter for the grades shown in 10.1. Hardenability results are to be reported for the first 10 sixteenth (16 mm), the 12, 14, 16, 18, 20, 24, 28, and 32 sixteenths of an inch.

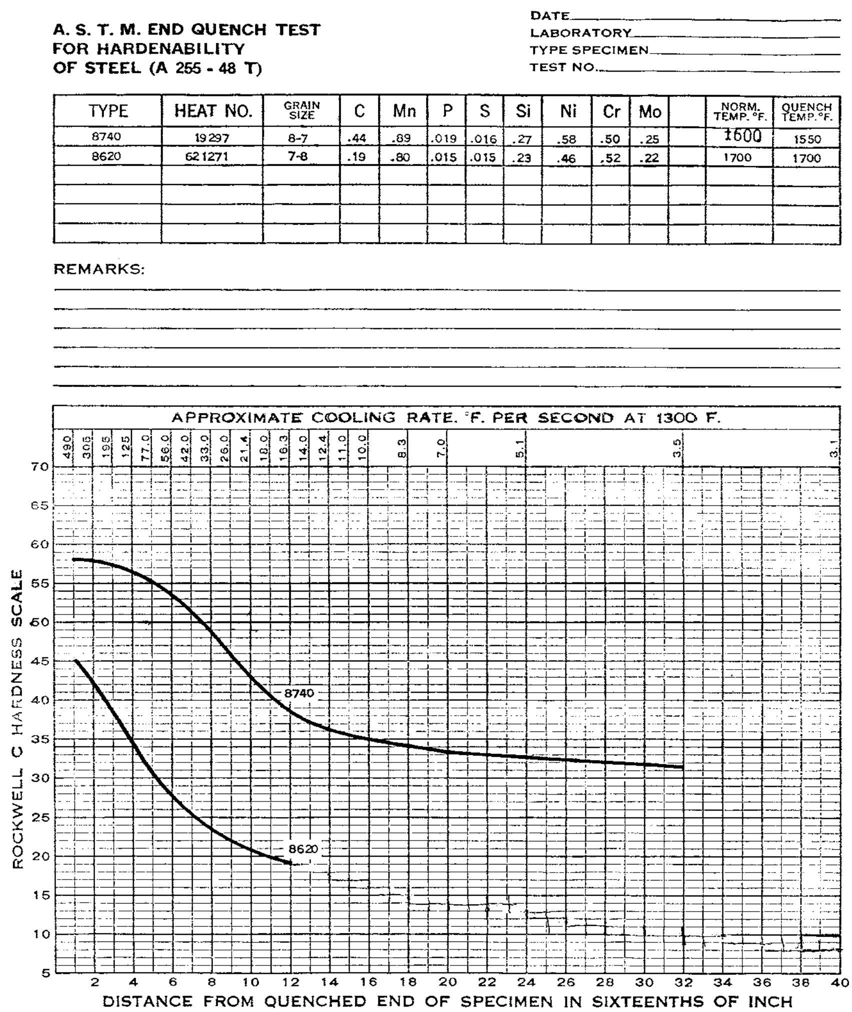

FIG. 4 Facsimile of Standard ASTM Hardenability Chart, Showing Typical Hardenability Curves [Chart Size: 8½ by 11 in. (216 by 279 mm)]

NOTE 5—The reporting of hardenability using the calculated method differs from the procedure as shown in 6.4.4.

10.3 *DI Calculation for Non-Boron Steels*—This calculation relies on a series of hardenability factors (Table 6) for each alloying element in the composition which, when multiplied together, gives a DI value. (For simplicity, only multiplying factors for DI in inch-pound units are given. For DI in millimetres, use the metric value table.) The effects of phosphorous and sulfur are not considered since they tend to cancel one another. A No. 7 austenitic grain size is assumed since most steels with hardenability control are melted to a fine-grain practice where experience has demonstrated that a high percentage of heats conform to this grain size. An example DI calculation is given as follows for an SAE 4118 modified steel:

Element	%	Multiplying Factor
Carbon	0.22	0.119
Manganese	0.80	3.667
Silicon	0.18	1.126
Nickel	0.10	1.036
Chromium	0.43	1.929
Molybdenum	0.25	1.75
Copper	0.10	1.04
Vanadium	0.05	1.09

where:

$$DI = 0.119 \times 3.667 \times 1.126 \times 1.036 \times 1.929 \times 1.75 \times 1.04 \times 1.09 = 1.95 \text{ in.}$$

10.4 *DI Calculation for Boron Steels*—With an effective steel making process, the boron factor (signifying the contribution for boron to increased hardenability) is an inverse function of the carbon and alloy content. The higher the carbon or alloy content, or both, the lower the boron factor.

10.4.1 The actual boron factor is expressed by the following relationship:

$$B.F. = \frac{\text{measured DI (from Jominy data and carbon content)}}{\text{calculated DI (from composition excluding boron)}} \quad (1)$$

10.4.2 An example of actual boron factor determination is given as follows for an SAE 15B30 modified steel:

Composition, %	C	Mn	Si	Ni	Cr	Mo	Cu	B	Calculated DI (boron excluded)
	0.29	1.25	0.20	0.13	0.07	0.03	0.24	0.0015	1.35 in.

End-Quench Test Results, in.

"J" Position (⅛ in.)	1	2	3	4	5	6	7
Hardness, HRC	50	50	49	48	47	45	41
"J" Position (⅛ in.)	8	9	10	12	14	16	
Hardness, HRC	38	33	28	25	22	20	

10.4.3 Using Table 7, determine the nearest location on the end-quench curve where hardness corresponding to 50% martensite occurs for the actual carbon content. For the example heat with 0.29 carbon, this hardness is 37 HRC occurring at a "J" distance of 8⁄16 in. from the quenched end (interpolation required).

10.4.4 From Table 8 (in.), a "J" distance of 8⁄16 in. equates to a measured DI of 2.97 in. (interpolation required).

$$\text{Boron Factor} = \frac{2.97\text{ in.}}{1.35\text{ in.}} = 2.2\text{ boron factor} \tag{2}$$

10.4.5 *Calculation of DI with Boron (DI_B)*:

10.4.5.1 Calculate the DI without boron. For the example in 10.4.4, this DI is 1.35 in.

10.4.5.2 Calculate the alloy factor (the product of all the multiplying factors from Table 6 excluding carbon). For the example in 10.4.4:

$$\text{Alloy Factor} = \frac{\text{Calculated DI (without boron)}}{\text{Carbon multiplying factor}} = \frac{1.35\text{ in.}}{0.157\text{ in.}} = 8.6 \tag{3}$$

10.4.5.3 Determine the boron multiplying factor from Table 10. For this example with 0.29% carbon and an alloy factor of 8.6, the boron multiplying factor is 2.31 (interpolation required).

10.4.6 Calculate the DI with boron as follows:

where:

DI_B = DI (without boron) × boron factor
DI_B = 1.35 in. × 2.31
DI_B = 3.12 in.

10.5 *Hardenability Curves from Composition*—With a predetermined DI (DI_B for boron steel), the end-quench hardenability curve can be computed by the following procedure:

10.5.1 The initial hardness (IH) at the J = 1⁄16 in. position is a function of carbon content and independent of hardenability and is selected from Table 7. For the example non-boron SAE 4118 modified heat containing 0.22 % carbon, the initial hardness is 45 HRC.

10.5.2 The hardness at other positions along the end-quench specimen (termed distance hardness) is determined by dividing the initial hardness by the appropriate factor from Table 2 (in.) or Table 3 (mm) for non-boron steels or from Table 4 (in.) or Table 5 (mm) for boron steels.

10.6 For the example non-boron heat with an IH = 45 HRC and a calculated DI of 1.95 in., the hardness at the respective end-quench positions can be calculated by dividing 45 by the appropriate dividing factor listed in Table 2 (in.) for non-boron steels. (For simplicity, the DI should be rounded to the nearest 0.1 in.).

10.7 Distance Dividing Hardness Factors in Tables 2-5 are calculated from the equations in Tables 15-18. Multiplying Factors in Table 6 are calculated from the equations in Table 11. Jominy Distance for 50 % Martensite versus DI in Tables 8 and 9 are calculated from the equations in Table 13. Boron Factor versus % Carbon and Alloy Factor in Table 10 are calculated from the equations in Table 14. Equations representing a least squares polynomial fit of the data contained in Table 7 is listed in Table 12. The use of these equations to plot curves may result in random inflection points due to the characteristics of polynomial equations. These inflections will be minor, however, and should be disregarded.

11. Keywords

11.1 end-quench hardenability; hardenability

TABLE 2 Distance Hardness Dividing Factors for Non-Boron Steels, in.

Ideal Diameter (DI), in.	Jominy End-Quench Distance (1⁄16 in.)																
	2	3	4	5	6	7	8	9	10	12	14	16	18	20	24	28	32
1	1.15	1.50	2.14	2.46	2.72	2.81	2.92	3.07	3.22	3.49							
1.1	1.12	1.42	1.99	2.32	2.60	2.70	2.80	2.94	3.07	3.34							
1.2	1.10	1.35	1.85	2.20	2.48	2.59	2.69	2.81	2.94	3.20	3.32	3.44					
1.3	1.08	1.29	1.74	2.09	2.38	2.48	2.58	2.69	2.81	3.07	3.19	3.30	3.53				
1.4	1.07	1.24	1.64	1.99	2.27	2.38	2.47	2.58	2.69	2.95	3.06	3.17	3.37	3.50	3.79		
1.5	1.05	1.19	1.56	1.89	2.18	2.28	2.37	2.47	2.58	2.83	2.94	3.05	3.22	3.35	3.61		
1.6	1.04	1.16	1.49	1.81	2.09	2.19	2.28	2.37	2.47	2.73	2.83	2.94	3.09	3.21	3.45	3.67	3.77
1.7	1.03	1.13	1.43	1.73	2.00	2.10	2.19	2.28	2.38	2.62	2.73	2.83	2.96	3.07	3.30	3.51	3.63
1.8	1.02	1.11	1.37	1.66	1.92	2.02	2.11	2.19	2.29	2.53	2.63	2.73	2.85	2.95	3.17	3.37	3.49
1.9	1.02	1.09	1.33	1.60	1.85	1.94	2.03	2.11	2.20	2.44	2.54	2.64	2.74	2.84	3.04	3.24	3.36
2	1.01	1.08	1.29	1.54	1.78	1.87	1.95	2.03	2.12	2.35	2.45	2.55	2.65	2.74	2.93	3.12	3.24
2.1	1.01	1.07	1.26	1.48	1.72	1.80	1.89	1.96	2.05	2.27	2.37	2.47	2.56	2.65	2.83	3.00	3.13
2.2	1.00	1.07	1.23	1.44	1.65	1.74	1.82	1.90	1.98	2.20	2.30	2.39	2.47	2.56	2.74	2.90	3.03
2.3	1.00	1.06	1.21	1.39	1.60	1.68	1.76	1.83	1.91	2.13	2.22	2.32	2.40	2.48	2.65	2.81	2.93
2.4	1.00	1.06	1.18	1.35	1.55	1.62	1.70	1.77	1.85	2.06	2.16	2.25	2.32	2.41	2.57	2.72	2.84
2.5	1.00	1.05	1.17	1.32	1.50	1.57	1.65	1.72	1.80	2.00	2.09	2.19	2.26	2.34	2.50	2.64	2.76
2.6	1.00	1.05	1.15	1.29	1.45	1.52	1.60	1.67	1.74	1.94	2.03	2.13	2.19	2.27	2.43	2.57	2.68
2.7	1.00	1.04	1.13	1.26	1.41	1.48	1.56	1.62	1.69	1.88	1.97	2.07	2.14	2.21	2.37	2.50	2.61
2.8	1.00	1.04	1.12	1.23	1.37	1.44	1.52	1.58	1.65	1.83	1.92	2.02	2.08	2.16	2.31	2.43	2.54
2.9	1.00	1.03	1.11	1.21	1.34	1.40	1.48	1.54	1.61	1.78	1.87	1.97	2.03	2.10	2.25	2.37	2.48
3	1.00	1.02	1.10	1.19	1.31	1.37	1.44	1.50	1.56	1.73	1.82	1.92	1.98	2.05	2.20	2.31	2.41
3.1	1.00	1.01	1.09	1.17	1.28	1.34	1.41	1.47	1.53	1.68	1.77	1.87	1.94	2.01	2.15	2.26	2.36
3.2	1.00	1.00	1.08	1.15	1.25	1.31	1.38	1.43	1.49	1.64	1.73	1.83	1.89	1.96	2.10	2.21	2.30
3.3	1.00	1.00	1.07	1.13	1.23	1.28	1.35	1.40	1.46	1.60	1.69	1.79	1.85	1.92	2.05	2.16	2.25
3.4	1.00	1.00	1.06	1.12	1.20	1.26	1.32	1.37	1.43	1.56	1.65	1.75	1.81	1.87	2.01	2.11	2.20
3.5	1.00	1.00	1.05	1.10	1.18	1.24	1.30	1.35	1.40	1.53	1.61	1.71	1.77	1.83	1.96	2.07	2.15
3.6	1.00	1.00	1.05	1.09	1.17	1.22	1.28	1.32	1.37	1.49	1.58	1.68	1.73	1.79	1.92	2.02	2.10
3.7	1.00	1.00	1.04	1.08	1.15	1.20	1.26	1.30	1.35	1.46	1.54	1.64	1.70	1.76	1.87	1.98	2.06
3.8	1.00	1.00	1.04	1.07	1.14	1.18	1.24	1.28	1.32	1.43	1.51	1.61	1.66	1.72	1.83	1.94	2.01
3.9	1.00	1.00	1.03	1.06	1.12	1.17	1.22	1.25	1.30	1.40	1.48	1.58	1.63	1.68	1.79	1.90	1.97
4	1.00	1.00	1.02	1.05	1.11	1.15	1.20	1.24	1.28	1.37	1.45	1.55	1.60	1.65	1.75	1.86	1.93
4.1	1.00	1.00	1.01	1.04	1.10	1.14	1.18	1.22	1.26	1.35	1.42	1.52	1.57	1.62	1.71	1.82	1.89
4.2	1.00	1.00	1.00	1.03	1.09	1.13	1.17	1.20	1.24	1.32	1.39	1.49	1.54	1.58	1.68	1.78	1.85
4.3	1.00	1.00	1.00	1.02	1.08	1.12	1.15	1.18	1.22	1.30	1.37	1.46	1.51	1.55	1.64	1.75	1.82
4.4	1.00	1.00	1.00	1.01	1.07	1.10	1.14	1.17	1.21	1.28	1.35	1.44	1.48	1.52	1.60	1.71	1.78
4.5	1.00	1.00	1.00	1.00	1.06	1.09	1.13	1.15	1.19	1.26	1.32	1.41	1.45	1.49	1.57	1.67	1.75
4.6	1.00	1.00	1.00	1.00	1.05	1.08	1.11	1.14	1.18	1.24	1.30	1.39	1.42	1.46	1.54	1.64	1.71
4.7	1.00	1.00	1.00	1.00	1.04	1.07	1.10	1.13	1.16	1.22	1.28	1.36	1.40	1.43	1.50	1.60	1.68
4.8	1.00	1.00	1.00	1.00	1.03	1.06	1.09	1.11	1.15	1.21	1.26	1.34	1.37	1.40	1.47	1.57	1.65
4.9	1.00	1.00	1.00	1.00	1.02	1.05	1.08	1.10	1.13	1.19	1.24	1.32	1.35	1.37	1.44	1.54	1.62
5	1.00	1.00	1.00	1.00	1.01	1.04	1.07	1.09	1.12	1.18	1.23	1.30	1.32	1.35	1.41	1.51	1.59
5.1	1.00	1.00	1.00	1.00	1.00	1.03	1.06	1.08	1.11	1.17	1.21	1.28	1.30	1.32	1.39	1.48	1.56
5.2	1.00	1.00	1.00	1.00	1.00	1.02	1.05	1.07	1.10	1.15	1.20	1.26	1.28	1.30	1.36	1.45	1.53
5.3	1.00	1.00	1.00	1.00	1.00	1.01	1.04	1.06	1.09	1.14	1.18	1.24	1.26	1.28	1.34	1.42	1.50
5.4	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.05	1.08	1.13	1.17	1.22	1.24	1.25	1.32	1.39	1.48
5.5	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.04	1.07	1.12	1.16	1.21	1.22	1.23	1.30	1.37	1.45
5.6	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.06	1.11	1.15	1.19	1.20	1.22	1.28	1.34	1.43
5.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.05	1.10	1.14	1.18	1.19	1.20	1.26	1.32	1.41
5.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.04	1.09	1.13	1.16	1.17	1.18	1.25	1.30	1.38
5.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.08	1.12	1.15	1.16	1.17	1.23	1.28	1.36
6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.07	1.11	1.13	1.14	1.15	1.22	1.26	1.34
6.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.06	1.10	1.12	1.13	1.14	1.21	1.24	1.32
6.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.05	1.09	1.11	1.12	1.13	1.20	1.22	1.30
6.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.04	1.08	1.10	1.11	1.12	1.19	1.21	1.28
6.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.07	1.09	1.10	1.11	1.18	1.20	1.26
6.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.06	1.08	1.09	1.10	1.17	1.18	1.25
6.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.05	1.07	1.08	1.09	1.15	1.17	1.23
6.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.04	1.06	1.07	1.08	1.14	1.16	1.21
6.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.05	1.06	1.07	1.12	1.15	1.19
6.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.04	1.05	1.06	1.11	1.14	1.17
7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.04	1.05	1.08	1.13	1.15

TABLE 3 Distance Hardness Dividing Factors for Non-Boron Steels, mm

Ideal Diameter (DI), mm	Jominy End-Quench Distance (mm)													
	3	5	7	9	11	13	15	20	25	30	35	40	45	50
25	1.13	1.62	2.11	2.62	2.82	2.96	3.15	3.52						
27.5	1.11	1.54	1.99	2.50	2.70	2.84	3.01	3.37						
30	1.09	1.47	1.88	2.38	2.58	2.72	2.89	3.24	3.48					
32.5	1.07	1.41	1.78	2.27	2.48	2.61	2.76	3.11	3.34	3.58				
35	1.06	1.35	1.69	2.17	2.37	2.51	2.65	2.99	3.20	3.43				
37.5	1.05	1.30	1.61	2.07	2.28	2.41	2.54	2.88	3.08	3.28	3.52			
40	1.04	1.26	1.54	1.99	2.19	2.31	2.44	2.77	2.96	3.15	3.37	3.56		
42.5	1.03	1.22	1.48	1.91	2.10	2.22	2.35	2.67	2.85	3.03	3.23	3.41	3.55	
45	1.02	1.19	1.42	1.83	2.02	2.14	2.26	2.57	2.75	2.92	3.10	3.27	3.41	3.54
47.5	1.02	1.16	1.37	1.76	1.95	2.06	2.17	2.48	2.66	2.81	2.98	3.14	3.28	3.41
50	1.01	1.13	1.33	1.70	1.87	1.99	2.10	2.40	2.57	2.71	2.87	3.03	3.16	3.29
52.5	1.01	1.11	1.29	1.64	1.81	1.92	2.02	2.32	2.48	2.62	2.77	2.92	3.05	3.18
55	1.00	1.10	1.26	1.58	1.75	1.85	1.95	2.24	2.40	2.54	2.68	2.82	2.95	3.07
57.5	1.00	1.08	1.23	1.53	1.69	1.79	1.89	2.17	2.33	2.46	2.60	2.73	2.85	2.97
60	1.00	1.07	1.21	1.48	1.63	1.74	1.83	2.10	2.26	2.39	2.52	2.65	2.76	2.88
62.5	1.00	1.06	1.18	1.44	1.58	1.68	1.77	2.04	2.19	2.32	2.45	2.57	2.68	2.79
65	1.00	1.05	1.16	1.40	1.54	1.63	1.72	1.98	2.13	2.26	2.38	2.50	2.60	2.70
67.5	1.00	1.04	1.15	1.36	1.49	1.59	1.67	1.92	2.08	2.20	2.32	2.43	2.53	2.62
70	1.00	1.04	1.13	1.33	1.45	1.54	1.63	1.87	2.02	2.14	2.26	2.37	2.46	2.55
72.5	1.00	1.03	1.12	1.30	1.41	1.50	1.58	1.82	1.97	2.09	2.20	2.31	2.40	2.48
75	1.00	1.03	1.11	1.27	1.38	1.46	1.54	1.77	1.92	2.04	2.15	2.25	2.34	2.41
77.5	1.00	1.03	1.10	1.24	1.35	1.43	1.51	1.72	1.87	1.99	2.10	2.20	2.28	2.35
80	1.00	1.02	1.09	1.22	1.32	1.40	1.47	1.68	1.83	1.95	2.06	2.15	2.22	2.29
82.5	1.00	1.02	1.08	1.20	1.29	1.37	1.44	1.64	1.79	1.90	2.01	2.10	2.17	2.23
85	1.00	1.02	1.07	1.18	1.26	1.34	1.41	1.60	1.75	1.86	1.97	2.05	2.12	2.17
87.5	1.00	1.02	1.07	1.16	1.24	1.31	1.38	1.57	1.71	1.82	1.92	2.01	2.07	2.12
90	1.00	1.02	1.06	1.14	1.22	1.29	1.35	1.53	1.67	1.78	1.88	1.96	2.03	2.07
92.5	1.00	1.01	1.05	1.13	1.20	1.27	1.33	1.50	1.64	1.75	1.84	1.92	1.98	2.02
95	1.00	1.01	1.05	1.11	1.18	1.24	1.31	1.47	1.60	1.71	1.81	1.88	1.94	1.98
97.5	1.00	1.01	1.04	1.10	1.16	1.22	1.28	1.44	1.57	1.67	1.77	1.84	1.90	1.93
100	1.00	1.01	1.04	1.09	1.15	1.21	1.26	1.41	1.54	1.64	1.73	1.80	1.86	1.89
102.5	1.00	1.01	1.03	1.08	1.13	1.19	1.24	1.39	1.51	1.61	1.70	1.76	1.82	1.85
105	1.00	1.01	1.03	1.07	1.12	1.17	1.23	1.36	1.48	1.58	1.66	1.73	1.78	1.81
107.5	1.00	1.00	1.02	1.06	1.11	1.16	1.21	1.34	1.46	1.55	1.63	1.69	1.74	1.77
110	1.00	1.00	1.02	1.05	1.10	1.15	1.19	1.32	1.43	1.51	1.59	1.65	1.71	1.73
112.5	1.00	1.00	1.02	1.04	1.08	1.13	1.18	1.29	1.41	1.49	1.56	1.62	1.67	1.70
115	1.00	1.00	1.01	1.04	1.07	1.12	1.16	1.27	1.38	1.46	1.53	1.59	1.64	1.67
117.5	1.00	1.00	1.01	1.03	1.07	1.11	1.15	1.26	1.36	1.43	1.50	1.55	1.61	1.63
120	1.00	1.00	1.01	1.03	1.06	1.10	1.14	1.24	1.34	1.40	1.47	1.52	1.58	1.60
122.5	1.00	1.00	1.01	1.02	1.05	1.09	1.12	1.22	1.31	1.38	1.44	1.49	1.55	1.57
125	1.00	1.00	1.00	1.02	1.04	1.08	1.11	1.21	1.29	1.35	1.41	1.46	1.52	1.54
127.5	1.00	1.00	1.00	1.01	1.04	1.07	1.10	1.19	1.27	1.33	1.39	1.43	1.49	1.52
130	1.00	1.00	1.00	1.01	1.03	1.06	1.09	1.18	1.25	1.31	1.36	1.41	1.46	1.49
132.5	1.00	1.00	1.00	1.01	1.02	1.05	1.08	1.16	1.24	1.28	1.34	1.38	1.44	1.47
135	1.00	1.00	1.00	1.01	1.02	1.04	1.07	1.15	1.22	1.26	1.32	1.36	1.42	1.44
137.5	1.00	1.00	1.00	1.00	1.01	1.04	1.06	1.14	1.20	1.24	1.30	1.34	1.39	1.42
140	1.00	1.00	1.00	1.00	1.01	1.03	1.05	1.13	1.19	1.22	1.28	1.32	1.37	1.40
142.5	1.00	1.00	1.00	1.00	1.00	1.02	1.04	1.12	1.17	1.21	1.26	1.30	1.35	1.38
145	1.00	1.00	1.00	1.00	1.00	1.02	1.03	1.11	1.16	1.19	1.24	1.28	1.33	1.36
147.5	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.10	1.14	1.17	1.23	1.26	1.32	1.34
150	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.09	1.13	1.16	1.21	1.25	1.30	1.33
152.5	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.08	1.12	1.15	1.20	1.23	1.29	1.31
155	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.07	1.10	1.13	1.19	1.22	1.27	1.30
157.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.06	1.09	1.12	1.18	1.21	1.26	1.28
160	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.05	1.08	1.11	1.17	1.20	1.24	1.27
162.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.05	1.07	1.10	1.16	1.19	1.23	1.26
165	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.04	1.06	1.09	1.15	1.17	1.22	1.25
167.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.05	1.08	1.14	1.16	1.21	1.24
170	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.04	1.07	1.13	1.15	1.20	1.23
172.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.06	1.12	1.14	1.18	1.22
175	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.05	1.11	1.12	1.17	1.21
177.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.04	1.10	1.10	1.15	1.20

TABLE 4 Distance Hardness Dividing Factors for Boron Steels, in.

Ideal Diameter (DI), in.	Jominy End-Quench Distance (1⁄16 in.)																
	2	3	4	5	6	7	8	9	10	12	14	16	18	20	24	28	32
1.5	1.10	1.14	1.88	2.52	2.91	3.23											
1.6	1.08	1.12	1.65	2.20	2.70	3.02											
1.7	1.07	1.10	1.47	1.95	2.50	2.82	2.99										
1.8	1.06	1.09	1.34	1.74	2.31	2.63	2.83	3.00									
1.9	1.05	1.08	1.25	1.58	2.13	2.45	2.67	2.84	3.08								
2	1.04	1.07	1.19	1.46	1.97	2.28	2.51	2.68	2.88	3.33							
2.1	1.03	1.06	1.14	1.36	1.83	2.12	2.36	2.53	2.70	3.15	3.69						
2.2	1.02	1.05	1.11	1.29	1.70	1.98	2.21	2.38	2.53	2.98	3.48	3.86					
2.3	1.02	1.04	1.09	1.24	1.58	1.84	2.08	2.24	2.38	2.82	3.29	3.65					
2.4	1.02	1.04	1.08	1.20	1.48	1.72	1.95	2.11	2.24	2.67	3.11	3.45	3.63				
2.5	1.01	1.03	1.07	1.17	1.40	1.61	1.83	1.99	2.12	2.54	2.95	3.27	3.45	3.62	4.05		
2.6	1.00	1.03	1.06	1.15	1.32	1.52	1.72	1.87	2.00	2.41	2.79	3.09	3.28	3.46	3.86	4.23	
2.7	1.00	1.03	1.05	1.14	1.26	1.43	1.62	1.77	1.90	2.29	2.65	2.93	3.12	3.30	3.67	4.00	
2.8	1.00	1.02	1.05	1.13	1.21	1.36	1.53	1.67	1.80	2.18	2.52	2.78	2.97	3.15	3.50	3.78	4.27
2.9	1.00	1.01	1.04	1.12	1.17	1.30	1.44	1.59	1.72	2.08	2.40	2.65	2.83	3.01	3.34	3.59	4.01
3	1.00	1.00	1.04	1.11	1.13	1.25	1.37	1.51	1.64	1.99	2.29	2.52	2.70	2.88	3.19	3.41	3.78
3.1	1.00	1.00	1.03	1.10	1.11	1.20	1.31	1.44	1.57	1.90	2.19	2.40	2.57	2.75	3.04	3.25	3.57
3.2	1.00	1.00	1.03	1.09	1.09	1.17	1.26	1.38	1.50	1.82	2.09	2.29	2.46	2.63	2.91	3.10	3.39
3.3	1.00	1.00	1.02	1.08	1.08	1.14	1.21	1.33	1.45	1.75	2.01	2.19	2.35	2.51	2.78	2.97	3.22
3.4	1.00	1.00	1.02	1.07	1.07	1.11	1.17	1.28	1.40	1.68	1.93	2.10	2.25	2.40	2.66	2.84	3.07
3.5	1.00	1.00	1.01	1.06	1.06	1.10	1.14	1.24	1.35	1.62	1.85	2.01	2.16	2.30	2.55	2.73	2.94
3.6	1.00	1.00	1.00	1.05	1.06	1.08	1.12	1.21	1.31	1.56	1.78	1.93	2.07	2.21	2.45	2.63	2.82
3.7	1.00	1.00	1.00	1.04	1.06	1.08	1.10	1.18	1.27	1.51	1.72	1.86	1.99	2.12	2.35	2.53	2.71
3.8	1.00	1.00	1.00	1.04	1.06	1.07	1.09	1.16	1.24	1.46	1.66	1.80	1.92	2.04	2.26	2.44	2.61
3.9	1.00	1.00	1.00	1.03	1.05	1.06	1.08	1.14	1.21	1.42	1.60	1.74	1.85	1.96	2.18	2.36	2.52
4	1.00	1.00	1.00	1.02	1.05	1.06	1.07	1.13	1.19	1.38	1.55	1.68	1.79	1.89	2.11	2.29	2.44
4.1	1.00	1.00	1.00	1.02	1.05	1.06	1.07	1.12	1.17	1.35	1.50	1.63	1.73	1.82	2.03	2.22	2.37
4.2	1.00	1.00	1.00	1.01	1.04	1.06	1.06	1.11	1.15	1.31	1.46	1.58	1.68	1.76	1.97	2.15	2.30
4.3	1.00	1.00	1.00	1.01	1.03	1.05	1.06	1.10	1.13	1.28	1.42	1.54	1.63	1.71	1.91	2.09	2.23
4.4	1.00	1.00	1.00	1.01	1.03	1.05	1.06	1.09	1.11	1.25	1.38	1.50	1.58	1.66	1.85	2.03	2.17
4.5	1.00	1.00	1.00	1.00	1.02	1.04	1.06	1.09	1.10	1.23	1.35	1.47	1.54	1.61	1.80	1.98	2.11
4.6	1.00	1.00	1.00	1.00	1.01	1.04	1.06	1.08	1.09	1.21	1.32	1.43	1.51	1.57	1.75	1.93	2.06
4.7	1.00	1.00	1.00	1.00	1.01	1.03	1.05	1.08	1.08	1.19	1.29	1.40	1.47	1.53	1.71	1.88	2.01
4.8	1.00	1.00	1.00	1.00	1.01	1.03	1.05	1.07	1.07	1.17	1.26	1.37	1.44	1.50	1.67	1.83	1.96
4.9	1.00	1.00	1.00	1.00	1.02	1.02	1.04	1.06	1.06	1.15	1.24	1.35	1.41	1.47	1.63	1.79	1.91
5	1.00	1.00	1.00	1.00	1.00	1.02	1.04	1.06	1.06	1.14	1.21	1.32	1.38	1.44	1.59	1.75	1.87
5.1	1.00	1.00	1.00	1.00	1.00	1.02	1.03	1.05	1.05	1.12	1.19	1.30	1.36	1.41	1.56	1.71	1.82
5.2	1.00	1.00	1.00	1.00	1.00	1.02	1.02	1.04	1.05	1.11	1.17	1.28	1.33	1.39	1.52	1.67	1.78
5.3	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.03	1.04	1.10	1.16	1.26	1.31	1.36	1.49	1.64	1.74
5.4	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.04	1.09	1.14	1.24	1.29	1.34	1.46	1.60	1.70
5.5	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.02	1.04	1.08	1.13	1.22	1.27	1.32	1.44	1.57	1.67
5.6	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.02	1.03	1.07	1.12	1.20	1.25	1.30	1.41	1.54	1.63
5.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.03	1.06	1.11	1.19	1.23	1.28	1.38	1.51	1.60
5.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.02	1.05	1.10	1.17	1.22	1.26	1.36	1.48	1.56
5.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.04	1.09	1.16	1.20	1.24	1.33	1.46	1.53
6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.04	1.08	1.14	1.18	1.23	1.31	1.43	1.50
6.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.07	1.13	1.17	1.21	1.28	1.41	1.47
6.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.07	1.12	1.15	1.19	1.26	1.38	1.44
6.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.06	1.10	1.14	1.17	1.23	1.35	1.41
6.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.05	1.09	1.12	1.15	1.21	1.33	1.38
6.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.04	1.08	1.11	1.13	1.18	1.30	1.35
6.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.07	1.09	1.12	1.16	1.27	1.32
6.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.06	1.08	1.10	1.14	1.25	1.29
6.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.05	1.07	1.08	1.11	1.21	1.25
6.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.05	1.06	1.07	1.09	1.18	1.21
7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.04	1.05	1.05	1.07	1.14	1.17

TABLE 5 Distance Hardness Dividing Factors for Boron Steels, mm

Ideal Diameter (DI), mm	Jominy End-Quench Distance (mm)													
	3	5	7	9	11	13	15	20	25	30	35	40	45	50
40	1.07	1.25	1.92	2.56										
42.5	1.06	1.21	1.73	2.34										
45	1.05	1.18	1.57	2.14	2.64									
47.5	1.04	1.14	1.45	1.97	2.44									
50	1.03	1.12	1.35	1.83	2.26	2.57								
52.5	1.03	1.09	1.28	1.70	2.10	2.40								
55	1.03	1.08	1.22	1.59	1.96	2.24	2.52							
57.5	1.02	1.06	1.17	1.49	1.83	2.10	2.37							
60	1.02	1.05	1.14	1.41	1.71	1.97	2.23							
62.5	1.01	1.04	1.11	1.35	1.61	1.86	2.10							
65	1.01	1.03	1.09	1.29	1.53	1.75	1.99	2.56						
67.5	1.00	1.03	1.08	1.24	1.45	1.66	1.88	2.43						
70	1.00	1.02	1.07	1.20	1.38	1.57	1.78	2.32						
72.5	1.00	1.02	1.06	1.17	1.32	1.50	1.70	2.21						
75	1.00	1.01	1.06	1.14	1.27	1.43	1.62	2.11	2.53					
77.5	1.00	1.01	1.05	1.12	1.23	1.37	1.55	2.01	2.42	2.71				
80	1.00	1.00	1.05	1.11	1.19	1.32	1.48	1.93	2.31	2.59	2.82			
82.5	1.00	1.00	1.05	1.10	1.16	1.27	1.43	1.85	2.21	2.47	2.70	2.89	3.06	3.26
85	1.00	1.00	1.04	1.09	1.13	1.23	1.38	1.78	2.11	2.37	2.59	2.77	2.92	3.11
87.5	1.00	1.00	1.04	1.08	1.11	1.20	1.33	1.71	2.03	2.27	2.48	2.66	2.80	2.98
90	1.00	1.00	1.03	1.07	1.09	1.17	1.29	1.65	1.95	2.18	2.38	2.55	2.69	2.86
92.5	1.00	1.00	1.03	1.07	1.08	1.15	1.26	1.59	1.87	2.09	2.29	2.46	2.59	2.75
95	1.00	1.00	1.02	1.06	1.07	1.13	1.23	1.54	1.81	2.01	2.20	2.37	2.50	2.65
97.5	1.00	1.00	1.01	1.06	1.06	1.11	1.20	1.49	1.74	1.94	2.12	2.28	2.42	2.56
100	1.00	1.00	1.00	1.06	1.05	1.09	1.18	1.45	1.69	1.87	2.05	2.21	2.34	2.48
102.5	1.00	1.00	1.00	1.05	1.04	1.08	1.16	1.41	1.63	1.81	1.98	2.13	2.27	2.41
105	1.00	1.00	1.00	1.05	1.04	1.07	1.14	1.37	1.58	1.75	1.91	2.07	2.21	2.34
107.5	1.00	1.00	1.00	1.05	1.04	1.06	1.13	1.34	1.54	1.70	1.86	2.01	2.15	2.27
110	1.00	1.00	1.00	1.04	1.03	1.06	1.12	1.31	1.50	1.65	1.80	1.95	2.09	2.21
112.5	1.00	1.00	1.00	1.04	1.03	1.05	1.11	1.28	1.46	1.61	1.75	1.89	2.03	2.16
115	1.00	1.00	1.00	1.03	1.03	1.05	1.10	1.25	1.43	1.56	1.70	1.84	1.98	2.10
117.5	1.00	1.00	1.00	1.03	1.03	1.05	1.09	1.23	1.39	1.53	1.66	1.80	1.93	2.05
120	1.00	1.00	1.00	1.03	1.03	1.04	1.08	1.21	1.36	1.49	1.62	1.75	1.88	2.01
122.5	1.00	1.00	1.00	1.02	1.02	1.04	1.08	1.19	1.34	1.46	1.58	1.71	1.84	1.96
125	1.00	1.00	1.00	1.02	1.02	1.04	1.07	1.17	1.31	1.43	1.55	1.67	1.80	1.91
127.5	1.00	1.00	1.00	1.01	1.02	1.04	1.07	1.15	1.29	1.40	1.52	1.64	1.75	1.87
130	1.00	1.00	1.00	1.01	1.02	1.03	1.06	1.14	1.27	1.38	1.49	1.60	1.72	1.83
132.5	1.00	1.00	1.00	1.00	1.02	1.03	1.05	1.13	1.25	1.35	1.46	1.57	1.68	1.79
135	1.00	1.00	1.00	1.00	1.02	1.03	1.05	1.11	1.23	1.33	1.44	1.54	1.64	1.75
137.5	1.00	1.00	1.00	1.00	1.01	1.02	1.04	1.10	1.21	1.31	1.41	1.51	1.61	1.72
140	1.00	1.00	1.00	1.00	1.01	1.02	1.04	1.09	1.19	1.29	1.39	1.48	1.58	1.68
142.5	1.00	1.00	1.00	1.00	1.01	1.02	1.03	1.08	1.18	1.27	1.37	1.45	1.55	1.65
145	1.00	1.00	1.00	1.00	1.01	1.01	1.03	1.07	1.16	1.25	1.34	1.43	1.52	1.62
147.5	1.00	1.00	1.00	1.00	1.00	1.01	1.02	1.06	1.15	1.24	1.32	1.41	1.49	1.59
150	1.00	1.00	1.00	1.00	1.00	1.01	1.02	1.05	1.14	1.22	1.30	1.38	1.47	1.56
152.5	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.05	1.12	1.20	1.28	1.36	1.44	1.53
155	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.04	1.11	1.18	1.26	1.34	1.42	1.51
157.5	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.10	1.17	1.24	1.31	1.40	1.48
160	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.09	1.15	1.22	1.29	1.37	1.45
162.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.07	1.13	1.20	1.27	1.35	1.43
165	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.06	1.12	1.18	1.25	1.33	1.40
167.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.05	1.10	1.16	1.22	1.30	1.37
170	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.04	1.08	1.14	1.20	1.27	1.33
172.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.07	1.12	1.17	1.23	1.29
175	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.05	1.10	1.14	1.19	1.25
177.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.04	1.08	1.11	1.14	1.20

TABLE 6 Multiplying Factors, in.

% Alloy	Carbon-Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V	Zr
0.01	0.005	1.033	1.007	1.004	1.022	1.03	1.00	1.02	1.02
0.02	0.011	1.067	1.014	1.007	1.043	1.06	1.01	1.03	1.05
0.03	0.016	1.100	1.021	1.011	1.065	1.09	1.01	1.05	1.07
0.04	0.022	1.133	1.028	1.015	1.086	1.12	1.01	1.07	1.10
0.05	0.027	1.167	1.035	1.018	1.108	1.15	1.02	1.09	1.12
0.06	0.032	1.200	1.042	1.022	1.130	1.18	1.02	1.10	1.15
0.07	0.038	1.233	1.049	1.025	1.151	1.21	1.03	1.12	1.17
0.08	0.043	1.267	1.056	1.029	1.173	1.24	1.03	1.14	1.20
0.09	0.049	1.300	1.063	1.033	1.194	1.27	1.03	1.16	1.22
0.10	0.054	1.333	1.070	1.036	1.216	1.30	1.04	1.17	1.25
0.11	0.059	1.367	1.077	1.040	1.238	1.33	1.04	1.19	1.27
0.12	0.065	1.400	1.084	1.044	1.259	1.36	1.04	1.21	1.30
0.13	0.070	1.433	1.091	1.047	1.281	1.39	1.05	1.22	1.32
0.14	0.076	1.467	1.098	1.051	1.302	1.42	1.05	1.24	1.35
0.15	0.081	1.500	1.105	1.054	1.324	1.45	1.05	1.26	1.37
0.16	0.086	1.533	1.112	1.058	1.346	1.48	1.06	1.28	1.40
0.17	0.092	1.567	1.119	1.062	1.367	1.51	1.06	1.29	1.42
0.18	0.097	1.600	1.126	1.065	1.389	1.54	1.07	1.31	1.45
0.19	0.103	1.633	1.133	1.069	1.410	1.57	1.07	1.33	1.47
0.20	0.108	1.667	1.140	1.073	1.432	1.60	1.07	1.35	1.50
0.21	0.113	1.700	1.147	1.076	1.454	1.63	1.08	. . .	1.52
0.22	0.119	1.733	1.154	1.080	1.475	1.66	1.08	. . .	1.55
0.23	0.124	1.767	1.161	1.083	1.497	1.69	1.08	. . .	1.57
0.24	0.130	1.800	1.168	1.087	1.518	1.72	1.09	. . .	1.60
0.25	0.135	1.833	1.175	1.091	1.540	1.75	1.09	. . .	1.62
0.26	0.140	1.867	1.182	1.094	1.562	1.78	1.09	. . .	
0.27	0.146	1.900	1.189	1.098	1.583	1.81	1.10	. . .	. . .
0.28	0.151	1.933	1.196	1.102	1.605	1.84	1.10	. . .	. . .
0.29	0.157	1.967	1.203	1.105	1.626	1.87	1.11	. . .	. . .
0.30	0.162	2.000	1.210	1.109	1.648	1.90	1.11	. . .	. . .
0.31	0.167	2.033	1.217	1.113	1.670	1.93	1.11	. . .	. . .
0.32	0.173	2.067	1.224	1.117	1.691	1.96	1.12	. . .	. . .
0.33	0.178	2.100	1.231	1.120	1.713	1.99	1.12	. . .	. . .
0.34	0.184	2.133	1.238	1.123	1.734	2.02	1.12	. . .	. . .
0.35	0.189	2.167	1.245	1.127	1.756	2.05	1.13	. . .	. . .
0.36	0.194	2.200	1.252	1.131	1.778	2.08	1.13	. . .	. . .
0.37	0.200	2.233	1.259	1.134	1.799	2.11	1.14	. . .	. . .
0.38	0.205	2.267	1.266	1.138	1.821	2.14	1.14	. . .	. . .
0.39	0.211	2.300	1.273	1.142	1.842	2.17	1.14	. . .	. . .
0.40	0.214	2.333	1.280	1.145	1.864	2.20	1.15	. . .	. . .
0.41	0.216	2.367	1.287	1.149	1.886	2.23	1.15	. . .	. . .
0.42	0.218	2.400	1.294	1.152	1.907	2.26	1.15	. . .	. . .
0.43	0.220	2.433	1.301	1.156	1.929	2.29	1.16	. . .	. . .
0.44	0.223	2.467	1.308	1.160	1.950	2.32	1.16	. . .	. . .
0.45	0.225	2.500	1.315	1.163	1.972	2.35	1.16	. . .	. . .
0.46	0.228	2.533	1.322	1.167	1.994	2.38	1.17	. . .	. . .
0.47	0.230	2.567	1.329	1.171	2.015	2.41	1.17	. . .	. . .
0.48	0.233	2.600	1.336	1.174	2.037	2.44	1.18	. . .	. . .
0.49	0.235	2.633	1.343	1.178	2.058	2.47	1.18	. . .	. . .
0.50	0.238	2.667	1.350	1.182	2.080	2.50	1.18	. . .	. . .
0.51	0.240	2.700	1.357	1.185	2.102	2.53	1.19	. . .	. . .
0.52	0.243	2.733	1.364	1.189	2.123	2.56	1.19	. . .	. . .
0.53	0.246	2.767	1.371	1.192	2.145	2.59	1.19	. . .	. . .
0.54	0.249	2.800	1.378	1.196	2.166	2.62	1.20	. . .	. . .
0.55	0.252	2.833	1.385	1.200	2.188	2.65	1.20	. . .	. . .
0.56	0.253	2.867	1.392	1.203	2.210	. . .	. . .	. . .	. . .
0.57	0.255	2.900	1.399	1.207	2.231	. . .	. . .	. . .	. . .
0.58	0.258	2.933	1.406	1.211	2.253	. . .	. . .	. . .	. . .
0.59	0.260	2.967	1.413	1.214	2.274	. . .	. . .	. . .	. . .
0.60	0.262	3.000	1.420	1.218	2.296	. . .	. . .	. . .	. . .
0.61	0.264	3.033	1.427	1.221	2.318	. . .	. . .	. . .	. . .

TABLE 6 *Continued*

% Alloy	Carbon-Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V	Zr
0.62	0.267	3.067	1.434	1.225	2.339	. . .	. . .	. . .	. . .
0.63	0.269	3.100	1.441	1.229	2.361	. . .	. . .	. . .	. . .
0.64	0.271	3.133	1.448	1.232	2.382	. . .	. . .	. . .	. . .
0.65	0.273	3.167	1.455	1.236	2.404	. . .	. . .	. . .	. . .
0.66	0.275	3.200	1.462	1.240	2.426	. . .	. . .	. . .	. . .
0.67	0.277	3.233	1.469	1.243	2.447	. . .	. . .	. . .	. . .
0.68	0.279	3.267	1.476	1.247	2.469	. . .	. . .	. . .	. . .
0.69	0.281	3.300	1.483	1.250	2.490	. . .	. . .	. . .	. . .
0.70	0.283	3.333	1.490	1.254	2.512	. . .	. . .	. . .	. . .
0.71	0.285	3.367	1.497	1.258	2.534	. . .	. . .	. . .	. . .
0.72	0.287	3.400	1.504	1.261	2.555	. . .	. . .	. . .	. . .
0.73	0.289	3.433	1.511	1.265	2.577	. . .	. . .	. . .	. . .
0.74	0.291	3.467	1.518	1.269	2.598	. . .	. . .	. . .	. . .
0.75	0.293	3.500	1.525	1.272	2.620	. . .	. . .	. . .	. . .
0.76	0.295	3.533	1.532	1.276	2.642	. . .	. . .	. . .	. . .
0.77	0.297	3.567	1.539	1.280	2.663	. . .	. . .	. . .	. . .
0.78	0.299	3.600	1.546	1.283	2.685	. . .	. . .	. . .	. . .
0.79	0.301	3.633	1.553	1.287	2.706	. . .	. . .	. . .	. . .
0.80	0.303	3.667	1.560	1.290	2.728	. . .	. . .	. . .	. . .
0.81	0.305	3.700	1.567	1.294	2.750	. . .	. . .	. . .	. . .
0.82	0.307	3.733	1.574	1.298	2.771	. . .	. . .	. . .	. . .
0.83	0.308	3.767	1.581	1.301	2.793	. . .	. . .	. . .	. . .
0.84	0.310	3.800	1.588	1.305	2.814	. . .	. . .	. . .	. . .
0.85	0.312	3.833	1.595	1.309	2.836	. . .	. . .	. . .	. . .
0.86	0.314	3.867	1.602	1.312	2.858	. . .	. . .	. . .	. . .
0.87	0.316	3.900	1.609	1.316	2.879	. . .	. . .	. . .	. . .
0.88	0.318	3.933	1.616	1.319	2.901	. . .	. . .	. . .	. . .
0.89	0.317	3.967	1.623	1.323	2.922	. . .	. . .	. . .	. . .
0.90	0.321	4.000	1.630	1.327	2.944	. . .	. . .	. . .	. . .
0.91	. . .	4.033	1.637	1.330	2.966	. . .	. . .	. . .	. . .
0.92	. . .	4.067	1.644	1.334	2.987	. . .	. . .	. . .	. . .
0.93	. . .	4.100	1.651	1.338	3.009	. . .	. . .	. . .	. . .
0.94	. . .	4.133	1.658	1.341	3.030	. . .	. . .	. . .	. . .
0.95	. . .	4.167	1.665	1.345	3.052	. . .	. . .	. . .	. . .
0.96	. . .	4.200	1.672	1.348	3.074	. . .	. . .	. . .	. . .
0.97	. . .	4.233	1.679	1.352	3.095	. . .	. . .	. . .	. . .
0.98	. . .	4.267	1.686	1.356	3.117	. . .	. . .	. . .	. . .
0.99	. . .	4.300	1.693	1.359	3.138	. . .	. . .	. . .	. . .
1.00	. . .	4.333	1.700	1.363	3.160	. . .	. . .	. . .	. . .
1.01	. . .	4.367	1.707	1.367	3.182	. . .	. . .	. . .	. . .
1.02	. . .	4.400	1.714	1.370	3.203	. . .	. . .	. . .	. . .
1.03	. . .	4.433	1.721	1.374	3.225	. . .	. . .	. . .	. . .
1.04	. . .	4.467	1.728	1.378	3.246	. . .	. . .	. . .	. . .
1.05	. . .	4.500	1.735	1.381	3.268	. . .	. . .	. . .	. . .
1.06	. . .	4.533	1.742	1.385	3.290	. . .	. . .	. . .	. . .
1.07	. . .	4.567	1.749	1.388	3.311	. . .	. . .	. . .	. . .
1.08	. . .	4.600	1.756	1.392	3.333	. . .	. . .	. . .	. . .
1.09	. . .	4.633	1.763	1.396	3.354	. . .	. . .	. . .	. . .
1.10	. . .	4.667	1.770	1.399	3.376	. . .	. . .	. . .	. . .
1.11	. . .	4.700	1.777	1.403	3.398	. . .	. . .	. . .	. . .
1.12	. . .	4.733	1.784	1.407	3.419	. . .	. . .	. . .	. . .
1.13	. . .	4.767	1.791	1.410	3.441	. . .	. . .	. . .	. . .
1.14	. . .	4.800	1.798	1.414	3.462	. . .	. . .	. . .	. . .
1.15	. . .	4.833	1.805	1.417	3.484	. . .	. . .	. . .	. . .
1.16	. . .	4.867	1.812	1.421	3.506	. . .	. . .	. . .	. . .
1.17	. . .	4.900	1.819	1.425	3.527	. . .	. . .	. . .	. . .
1.18	. . .	4.933	1.826	1.428	3.549	. . .	. . .	. . .	. . .
1.19	. . .	4.967	1.833	1.432	3.570	. . .	. . .	. . .	. . .
1.20	. . .	5.000	1.840	1.436	3.592	. . .	. . .	. . .	. . .
1.21	. . .	5.051	1.847	1.439	3.614	. . .	. . .	. . .	. . .
1.22	. . .	5.102	1.854	1.443	3.635	. . .	. . .	. . .	. . .

TABLE 6 *Continued*

% Alloy	Carbon-Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V	Zr
1.23	...	5.153	1.861	1.446	3.657	...	...	...	...
1.24	...	5.204	1.868	1.450	3.678	...	...	...	...
1.25	...	5.255	1.875	1.454	3.700	...	...	...	...
1.26	...	5.306	1.882	1.457	3.722	...	...	...	...
1.27	...	5.357	1.889	1.461	3.743	...	...	...	...
1.28	...	5.408	1.896	1.465	3.765	...	...	...	...
1.29	...	5.459	1.903	1.468	3.786	...	...	...	...
1.30	...	5.510	1.910	1.472	3.808	...	...	...	...
1.31	...	5.561	1.917	1.476	3.830	...	...	...	...
1.32	...	5.612	1.924	1.479	3.851	...	...	...	...
1.33	...	5.663	1.931	1.483	3.873	...	...	...	...
1.34	...	5.714	1.938	1.486	3.894	...	...	...	...
1.35	...	5.765	1.945	1.490	3.916	...	...	...	...
1.36	...	5.816	1.952	1.494	3.938	...	...	...	...
1.37	...	5.867	1.959	1.497	3.959	...	...	...	...
1.38	...	5.918	1.966	1.501	3.981	...	...	...	...
1.39	...	5.969	1.973	1.505	4.002	...	...	...	...
1.40	...	6.020	1.980	1.508	4.024	...	...	...	...
1.41	...	6.071	1.987	1.512	4.046	...	...	...	...
1.42	...	6.122	1.994	1.515	4.067	...	...	...	...
1.43	...	6.173	2.001	1.519	4.089	...	...	...	...
1.44	...	6.224	2.008	1.523	4.110	...	...	...	...
1.45	...	6.275	2.015	1.526	4.132	...	...	...	...
1.46	...	6.326	2.022	1.530	4.154	...	...	...	...
1.47	...	6.377	2.029	1.534	4.175	...	...	...	...
1.48	...	6.428	2.036	1.537	4.197	...	...	...	...
1.49	...	6.479	2.043	1.541	4.218	...	...	...	...
1.50	...	6.530	2.050	1.545	4.240	...	...	...	...
1.51	...	6.581	2.057	1.547	4.262	...	...	...	...
1.52	...	6.632	2.064	1.552	4.283	...	...	...	...
1.53	...	6.683	2.071	1.556	4.305	...	...	...	...
1.54	...	6.734	2.078	1.561	4.326	...	...	...	...
1.55	...	6.785	2.085	1.565	4.348	...	...	...	...
1.56	...	6.836	2.092	1.570	4.370	...	...	...	...
1.57	...	6.887	2.099	1.574	4.391	...	...	...	...
1.58	...	6.938	2.106	1.579	4.413	...	...	...	...
1.59	...	6.989	2.113	1.583	4.434	...	...	...	...
1.60	...	7.040	2.120	1.588	4.456	...	...	...	...
1.61	...	7.091	2.127	1.593	4.478	...	...	...	...
1.62	...	7.142	2.134	1.597	4.499	...	...	...	...
1.63	...	7.193	2.141	1.602	4.521	...	...	...	...
1.64	...	7.244	2.148	1.606	4.542	...	...	...	...
1.65	...	7.295	2.155	1.611	4.564	...	...	...	...
1.66	...	7.346	2.162	1.615	4.586	...	...	...	...
1.67	...	7.397	2.169	1.620	4.607	...	...	...	...
1.68	...	7.448	2.176	1.624	4.629	...	...	...	...
1.69	...	7.499	2.183	1.629	4.650	...	...	...	...
1.70	...	7.550	2.190	1.633	4.672	...	...	...	...
1.71	...	7.601	2.197	1.638	4.694	...	...	...	...
1.72	...	7.652	2.204	1.643	4.715	...	...	...	...
1.73	...	7.703	2.211	1.647	4.737	...	...	...	...
1.74	...	7.754	2.218	1.652	4.759	...	...	...	...
1.75	...	7.805	2.225	1.656	4.780	...	...	...	...
1.76	...	7.856	2.232	1.661	4.802	...	...	...	...
1.77	...	7.907	2.239	1.666	4.823	...	...	...	...
1.78	...	7.958	2.246	1.670	4.845	...	...	...	...
1.79	...	8.009	2.253	1.675	4.866	...	...	...	...
1.80	...	8.060	2.260	1.679	4.888	...	...	...	...
1.81	...	8.111	2.267	1.684	4.910	...	...	...	...
1.82	...	8.162	2.274	1.689	4.931	...	...	...	...
1.83	...	8.213	2.281	1.693	4.953	...	...	...	...
1.84	...	8.264	2.288	1.698	4.974	...	...	...	...

TABLE 6 *Continued*

% Alloy	Carbon-Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V	Zr
1.85	. . .	8.315	2.295	1.703	4.996	. . .	. . .	. . .	. . .
1.86	. . .	8.366	2.302	1.708	5.018	. . .	. . .	. . .	. . .
1.87	. . .	8.417	2.309	1.712	5.039	. . .	. . .	. . .	. . .
1.88	. . .	8.468	2.316	1.717	5.061	. . .	. . .	. . .	. . .
1.89	. . .	8.519	2.323	1.722	5.082	. . .	. . .	. . .	. . .
1.90	. . .	8.570	2.330	1.727	5.104	. . .	. . .	. . .	. . .
1.91	. . .	8.621	2.337	1.732	5.126	. . .	. . .	. . .	. . .
1.92	. . .	8.672	2.344	1.736	5.147	. . .	. . .	. . .	. . .
1.93	. . .	8.723	2.351	1.741	5.169	. . .	. . .	. . .	. . .
1.94	. . .	8.774	2.358	1.746	5.190	. . .	. . .	. . .	. . .
1.95	. . .	8.825	2.365	1.751	5.212	. . .	. . .	. . .	. . .
1.96	. . .	. . .	2.372	1.756	5.234	. . .	. . .	. . .	. . .
1.97	. . .	. . .	2.379	1.761	5.255	. . .	. . .	. . .	. . .
1.98	. . .	. . .	2.386	1.766	5.277	. . .	. . .	. . .	. . .
1.99	. . .	. . .	2.393	1.771	5.298	. . .	. . .	. . .	. . .
2.00	. . .	. . .	2.400	1.776	5.320	. . .	. . .	. . .	. . .
2.01	. . .	. . .	. . .	1.781	5.342	. . .	. . .	. . .	. . .
2.02	. . .	. . .	. . .	1.786	5.363	. . .	. . .	. . .	. . .
2.03	. . .	. . .	. . .	1.791	5.385	. . .	. . .	. . .	. . .
2.04	. . .	. . .	. . .	1.797	5.406	. . .	. . .	. . .	. . .
2.05	. . .	. . .	. . .	1.802	5.428	. . .	. . .	. . .	. . .
2.06	. . .	. . .	. . .	1.807	5.450	. . .	. . .	. . .	. . .
2.07	. . .	. . .	. . .	1.812	5.471	. . .	. . .	. . .	. . .
2.08	. . .	. . .	. . .	1.818	5.493	. . .	. . .	. . .	. . .
2.09	. . .	. . .	. . .	1.823	5.514	. . .	. . .	. . .	. . .
2.10	. . .	. . .	. . .	1.828	5.536	. . .	. . .	. . .	. . .
2.11	. . .	. . .	. . .	1.834	5.558	. . .	. . .	. . .	. . .
2.12	. . .	. . .	. . .	1.839	5.579	. . .	. . .	. . .	. . .
2.13	. . .	. . .	. . .	1.845	5.601	. . .	. . .	. . .	. . .
2.14	. . .	. . .	. . .	1.850	5.622	. . .	. . .	. . .	. . .
2.15	. . .	. . .	. . .	1.856	5.644	. . .	. . .	. . .	. . .
2.16	. . .	. . .	. . .	1.861	5.666	. . .	. . .	. . .	. . .
2.17	. . .	. . .	. . .	1.867	5.687	. . .	. . .	. . .	. . .
2.18	. . .	. . .	. . .	1.872	5.709	. . .	. . .	. . .	. . .
2.19	. . .	. . .	. . .	1.878	5.730	. . .	. . .	. . .	. . .
2.20	. . .	. . .	. . .	1.884	5.752	. . .	. . .	. . .	. . .
2.21	. . .	. . .	. . .	1.890	5.774	. . .	. . .	. . .	. . .
2.22	. . .	. . .	. . .	1.896	5.795	. . .	. . .	. . .	. . .
2.23	. . .	. . .	. . .	1.901	5.817	. . .	. . .	. . .	. . .
2.24	. . .	. . .	. . .	1.907	5.838	. . .	. . .	. . .	. . .
2.25	. . .	. . .	. . .	1.913	5.860	. . .	. . .	. . .	. . .
2.26	. . .	. . .	. . .	1.919	5.882	. . .	. . .	. . .	. . .
2.27	. . .	. . .	. . .	1.925	5.903	. . .	. . .	. . .	. . .
2.28	. . .	. . .	. . .	1.932	5.925	. . .	. . .	. . .	. . .
2.29	. . .	. . .	. . .	1.938	5.946	. . .	. . .	. . .	. . .
2.30	. . .	. . .	. . .	1.944	5.968	. . .	. . .	. . .	. . .
2.31	. . .	. . .	. . .	1.950	5.990	. . .	. . .	. . .	. . .
2.32	. . .	. . .	. . .	1.956	6.011	. . .	. . .	. . .	. . .
2.33	. . .	. . .	. . .	1.963	6.033	. . .	. . .	. . .	. . .
2.34	. . .	. . .	. . .	1.969	6.054	. . .	. . .	. . .	. . .
2.35	. . .	. . .	. . .	1.976	6.076	. . .	. . .	. . .	. . .
2.36	. . .	. . .	. . .	1.982	6.098	. . .	. . .	. . .	. . .
2.37	. . .	. . .	. . .	1.989	6.119	. . .	. . .	. . .	. . .
2.38	. . .	. . .	. . .	1.995	6.141	. . .	. . .	. . .	. . .
2.39	. . .	. . .	. . .	2.002	6.162	. . .	. . .	. . .	. . .
2.40	. . .	. . .	. . .	2.009	6.184	. . .	. . .	. . .	. . .
2.41	. . .	. . .	. . .	2.016	6.206	. . .	. . .	. . .	. . .
2.42	. . .	. . .	. . .	2.023	6.227	. . .	. . .	. . .	. . .
2.43	. . .	. . .	. . .	2.030	6.249	. . .	. . .	. . .	. . .
2.44	. . .	. . .	. . .	2.037	6.270	. . .	. . .	. . .	. . .

TABLE 6 *Continued*

% Alloy	Carbon-Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V	Zr
2.45	. . .	. . .	. . .	2.044	6.292	. . .	. . .	. . .	. . .
2.46	. . .	. . .	. . .	2.051	6.314	. . .	. . .	. . .	. . .
2.47	. . .	. . .	. . .	2.058	6.335	. . .	. . .	. . .	. . .
2.48	. . .	. . .	. . .	2.065	6.357	. . .	. . .	. . .	. . .
2.49	. . .	. . .	. . .	2.072	6.378	. . .	. . .	. . .	. . .
2.50	. . .	. . .	. . .	2.080	6.400	. . .	. . .	. . .	. . .
2.51	. . .	. . .	. . .	2.087	. . .	. . .	. . .	. . .	. . .
2.52	. . .	. . .	. . .	2.095	. . .	. . .	. . .	. . .	. . .
2.53	. . .	. . .	. . .	2.102	. . .	. . .	. . .	. . .	. . .
2.54	. . .	. . .	. . .	2.110	. . .	. . .	. . .	. . .	. . .
2.55	. . .	. . .	. . .	2.118	. . .	. . .	. . .	. . .	. . .
2.56	. . .	. . .	. . .	2.125	. . .	. . .	. . .	. . .	. . .
2.57	. . .	. . .	. . .	2.133	. . .	. . .	. . .	. . .	. . .
2.58	. . .	. . .	. . .	2.141	. . .	. . .	. . .	. . .	. . .
2.59	. . .	. . .	. . .	2.149	. . .	. . .	. . .	. . .	. . .
2.60	. . .	. . .	. . .	2.157	. . .	. . .	. . .	. . .	. . .
2.61	. . .	. . .	. . .	2.165	. . .	. . .	. . .	. . .	. . .
2.62	. . .	. . .	. . .	2.174	. . .	. . .	. . .	. . .	. . .
2.63	. . .	. . .	. . .	2.182	. . .	. . .	. . .	. . .	. . .
2.64	. . .	. . .	. . .	2.190	. . .	. . .	. . .	. . .	. . .
2.65	. . .	. . .	. . .	2.199	. . .	. . .	. . .	. . .	. . .
2.66	. . .	. . .	. . .	2.207	. . .	. . .	. . .	. . .	. . .
2.67	. . .	. . .	. . .	2.216	. . .	. . .	. . .	. . .	. . .
2.68	. . .	. . .	. . .	2.224	. . .	. . .	. . .	. . .	. . .
2.69	. . .	. . .	. . .	2.233	. . .	. . .	. . .	. . .	. . .
2.70	. . .	. . .	. . .	2.242	. . .	. . .	. . .	. . .	. . .
2.71	. . .	. . .	. . .	2.251	. . .	. . .	. . .	. . .	. . .
2.72	. . .	. . .	. . .	2.260	. . .	. . .	. . .	. . .	. . .
2.73	. . .	. . .	. . .	2.269	. . .	. . .	. . .	. . .	. . .
2.74	. . .	. . .	. . .	2.278	. . .	. . .	. . .	. . .	. . .
2.75	. . .	. . .	. . .	2.287	. . .	. . .	. . .	. . .	. . .
2.76	. . .	. . .	. . .	2.297	. . .	. . .	. . .	. . .	. . .
2.77	. . .	. . .	. . .	2.306	. . .	. . .	. . .	. . .	. . .
2.78	. . .	. . .	. . .	2.315	. . .	. . .	. . .	. . .	. . .
2.79	. . .	. . .	. . .	2.325	. . .	. . .	. . .	. . .	. . .
2.80	. . .	. . .	. . .	2.335	. . .	. . .	. . .	. . .	. . .
2.81	. . .	. . .	. . .	2.344	. . .	. . .	. . .	. . .	. . .
2.82	. . .	. . .	. . .	2.354	. . .	. . .	. . .	. . .	. . .
2.83	. . .	. . .	. . .	2.364	. . .	. . .	. . .	. . .	. . .
2.84	. . .	. . .	. . .	2.374	. . .	. . .	. . .	. . .	. . .
2.85	. . .	. . .	. . .	2.384	. . .	. . .	. . .	. . .	. . .
2.86	. . .	. . .	. . .	2.395	. . .	. . .	. . .	. . .	. . .
2.87	. . .	. . .	. . .	2.405	. . .	. . .	. . .	. . .	. . .
2.88	. . .	. . .	. . .	2.415	. . .	. . .	. . .	. . .	. . .
2.89	. . .	. . .	. . .	2.426	. . .	. . .	. . .	. . .	. . .
2.90	. . .	. . .	. . .	2.436	. . .	. . .	. . .	. . .	. . .
2.91	. . .	. . .	. . .	2.447	. . .	. . .	. . .	. . .	. . .
2.92	. . .	. . .	. . .	2.458	. . .	. . .	. . .	. . .	. . .
2.93	. . .	. . .	. . .	2.469	. . .	. . .	. . .	. . .	. . .
2.94	. . .	. . .	. . .	2.480	. . .	. . .	. . .	. . .	. . .
2.95	. . .	. . .	. . .	2.491	. . .	. . .	. . .	. . .	. . .
2.96	. . .	. . .	. . .	2.502	. . .	. . .	. . .	. . .	. . .
2.97	. . .	. . .	. . .	2.513	. . .	. . .	. . .	. . .	. . .
2.98	. . .	. . .	. . .	2.524	. . .	. . .	. . .	. . .	. . .
2.99	. . .	. . .	. . .	2.536	. . .	. . .	. . .	. . .	. . .
3.00	. . .	. . .	. . .	2.547	. . .	. . .	. . .	. . .	. . .
3.01	. . .	. . .	. . .	2.559	. . .	. . .	. . .	. . .	. . .
3.02	. . .	. . .	. . .	2.571	. . .	. . .	. . .	. . .	. . .
3.03	. . .	. . .	. . .	2.583	. . .	. . .	. . .	. . .	. . .
3.04	. . .	. . .	. . .	2.595	. . .	. . .	. . .	. . .	. . .

TABLE 6 *Continued*

% Alloy	Carbon-Grain Size 7	Mn	Si	Ni	Cr	Mo	Cu	V	Zr
3.05	...	...	...	2.607	...	...	...	...	...
3.06	...	...	...	2.619	...	...	...	...	...
3.07	...	...	...	2.631	...	...	...	...	...
3.08	...	...	...	2.644	...	...	...	...	...
3.09	...	...	...	2.656	...	...	...	...	...
3.10	...	...	...	2.669	...	...	...	...	...
3.11	...	...	...	2.682	...	...	...	...	...
3.12	...	...	...	2.694	...	...	...	...	...
3.13	...	...	...	2.707	...	...	...	...	...
3.14	...	...	...	2.721	...	...	...	...	...
3.15	...	...	...	2.734	...	...	...	...	...
3.16	...	...	...	2.747	...	...	...	...	...
3.17	...	...	...	2.760	...	...	...	...	...
3.18	...	...	...	2.774	...	...	...	...	...
3.19	...	...	...	2.788	...	...	...	...	...
3.20	...	...	...	2.801	...	...	...	...	...
3.21	...	...	...	2.815	...	...	...	...	...
3.22	...	...	...	2.829	...	...	...	...	...
3.23	...	...	...	2.843	...	...	...	...	...
3.24	...	...	...	2.858	...	...	...	...	...
3.25	...	...	...	2.872	...	...	...	...	...
3.26	...	...	...	2.887	...	...	...	...	...
3.27	...	...	...	2.901	...	...	...	...	...
3.28	...	...	...	2.916	...	...	...	...	...
3.29	...	...	...	2.931	...	...	...	...	...
3.30	...	...	...	2.946	...	...	...	...	...
3.31	...	...	...	2.961	...	...	...	...	...
3.32	...	...	...	2.976	...	...	...	...	...
3.33	...	...	...	2.991	...	...	...	...	...
3.34	...	...	...	3.007	...	...	...	...	...
3.35	...	...	...	3.023	...	...	...	...	...
3.36	...	...	...	3.038	...	...	...	...	...
3.37	...	...	...	3.054	...	...	...	...	...
3.38	...	...	...	3.070	...	...	...	...	...
3.39	...	...	...	3.086	...	...	...	...	...
3.40	...	...	...	3.103	...	...	...	...	...
3.41	...	...	...	3.119	...	...	...	...	...
3.42	...	...	...	3.136	...	...	...	...	...
3.43	...	...	...	3.152	...	...	...	...	...
3.44	...	...	...	3.169	...	...	...	...	...
3.45	...	...	...	3.186	...	...	...	...	...
3.46	...	...	...	3.203	...	...	...	...	...
3.47	...	...	...	3.220	...	...	...	...	...
3.48	...	...	...	3.238	...	...	...	...	...
3.49	...	...	...	3.255	...	...	...	...	...
3.50	...	...	...	3.273	...	...	...	...	...

TABLE 7 Carbon Content, Initial Hardness, 50 % Martensite Hardness

% Carbon Content	Hardness – HRC: Initial 100 % Martensite	Hardness – HRC: 50 % Martensite	% Carbon Content	Hardness – HRC: Initial 100 % Martensite	Hardness – HRC: 50 % Martensite	% Carbon Content	Hardness – HRC: Initial 100 % Martensite	Hardness – HRC: 50 % Martensite
0.10	38	26	0.30	50	37	0.50	61	47
0.11	39	27	0.31	51	38	0.51	61	47
0.12	40	27	0.32	51	38	0.52	62	48
0.13	40	28	0.33	52	39	0.53	62	48
0.14	41	28	0.34	53	40	0.54	63	48
0.15	41	29	0.35	53	40	0.55	63	49
0.16	42	30	0.36	54	41	0.56	63	49
0.17	42	30	0.37	55	41	0.57	64	50
0.18	43	31	0.38	55	42	0.58	64	50
0.19	44	31	0.39	56	42	0.59	64	51
0.20	44	32	0.40	56	43	0.60	64	51
0.21	45	32	0.41	57	43	0.61	64	51
0.22	45	33	0.42	57	43	0.62	65	51
0.23	46	34	0.43	58	44	0.63	65	52
0.24	46	34	0.44	58	44	0.64	65	52
0.25	47	35	0.45	59	45	0.65	65	52
0.26	48	35	0.46	59	45	0.66	65	52
0.27	49	36	0.47	59	45	0.67	65	53
0.28	49	36	0.48	59	46	0.68	65	53
0.29	50	37	0.49	60	46	0.69	65	53

TABLE 8 Jominy Distance for 50 % Martensite versus DI (in.)

"J" 1⁄16 in.	DI, in.	"J" 1⁄16 in.	DI, in.	"J" 1⁄16 in.	DI, in.
0.5	0.25	11.5	3.75	22.5	5.46
1.0	0.50	12.0	3.85	23.0	5.52
1.5	0.74	12.5	3.95	23.5	5.58
2.0	0.96	13.0	4.04	24.0	5.64
2.5	1.18	13.5	4.13	24.5	5.69
3.0	1.38	14.0	4.22	25.0	5.75
3.5	1.58	14.5	4.31	25.5	5.80
4.0	1.76	15.0	4.39	26.0	5.85
4.5	1.94	15.5	4.47	26.5	5.90
5.0	2.10	16.0	4.56	27.0	5.95
5.5	2.26	16.5	4.63	27.5	6.00
6.0	2.42	17.0	4.71	28.0	6.05
6.5	2.56	17.5	4.79	28.5	6.10
7.0	2.70	18.0	4.86	29.0	6.14
7.5	2.84	18.5	4.93	29.5	6.19
8.0	2.97	19.0	5.00	30.0	6.23
8.5	3.09	19.5	5.07	30.5	6.28
9.0	3.21	20.0	5.14	31.0	6.32
9.5	3.33	20.5	5.21	31.5	6.37
10.0	3.44	21.0	5.27	32.0	6.41
10.5	3.55	21.5	5.34		
11.0	3.65	22.0	5.40		

TABLE 9 Jominy Distance for 50 % Martensite versus DI (mm)

"J" mm	DI, mm	"J" mm	DI, mm	"J" mm	DI, mm
1.0	7.9	18.0	94.5	35.0	137.3
2.0	15.8	19.0	97.1	36.0	139.3
3.0	23.2	20.0	100.8	37.0	141.2
4.0	30.2	21.0	103.7	38.0	143.0
5.0	36.6	22.0	106.6	39.0	144.8
6.0	42.7	23.0	109.3	40.0	146.6
7.0	48.4	24.0	112.0	41.0	148.3
8.0	53.8	25.0	114.7	42.0	149.9
9.0	58.9	26.0	117.2	43.0	151.5
10.0	63.7	27.0	119.7	44.0	153.1
11.0	68.2	28.0	122.1	45.0	154.6
12.0	72.5	29.0	124.5	46.0	156.1
13.0	76.6	30.0	126.7	47.0	157.6
14.0	80.5	31.0	129.0	48.0	159.0
15.0	84.3	32.0	131.2	49.0	160.5
16.0	87.8	33.0	133.3	50.0	161.9
17.0	91.2	34.0	135.3		

TABLE 10 Boron Factors versus % Carbon and Alloy Factor[A]

% Carbon	5	7	9	11	13	15	18	22	26
0.10	6.18	5.38	5.09	4.61	4.28	4.14	3.72	3.68	3.55
0.11	5.76	5.07	4.77	4.34	4.05	3.88	3.54	3.48	3.35
0.12	5.38	4.78	4.48	4.10	3.84	3.65	3.37	3.30	3.18
0.13	5.04	4.52	4.22	3.88	3.65	3.44	3.21	3.14	3.03
0.14	4.72	4.28	3.98	3.68	3.47	3.25	3.07	2.99	2.89
0.15	4.44	4.06	3.76	3.50	3.31	3.09	2.94	2.86	2.76
0.16	4.19	3.86	3.57	3.34	3.16	2.94	2.82	2.74	2.64
0.17	3.96	3.68	3.40	3.19	3.03	2.81	2.71	2.63	2.54
0.18	3.75	3.51	3.24	3.05	2.91	2.70	2.61	2.53	2.44
0.19	3.57	3.36	3.10	2.93	2.80	2.59	2.52	2.44	2.36
0.20	3.40	3.22	2.97	2.82	2.70	2.50	2.43	2.35	2.28
0.21	3.26	3.10	2.86	2.72	2.60	2.42	2.35	2.28	2.20
0.22	3.12	2.98	2.76	2.63	2.52	2.34	2.28	2.20	2.13
0.23	3.01	2.88	2.67	2.55	2.44	2.27	2.21	2.14	2.07
0.24	2.90	2.78	2.59	2.47	2.37	2.21	2.15	2.07	2.01
0.25	2.81	2.70	2.51	2.40	2.30	2.15	2.09	2.02	1.95
0.26	2.73	2.62	2.45	2.34	2.24	2.10	2.03	1.96	1.89
0.27	2.66	2.55	2.39	2.28	2.18	2.05	1.98	1.91	1.84
0.28	2.59	2.49	2.33	2.23	2.13	2.00	1.93	1.86	1.79
0.29	2.54	2.43	2.28	2.18	2.08	1.96	1.88	1.81	1.74
0.30	2.48	2.38	2.24	2.14	2.04	1.92	1.83	1.76	1.70
0.31	2.44	2.33	2.20	2.10	1.99	1.88	1.79	1.72	1.65
0.32	2.40	2.28	2.16	2.06	1.95	1.84	1.74	1.68	1.61
0.33	2.36	2.24	2.12	2.02	1.91	1.80	1.70	1.64	1.57
0.34	2.32	2.20	2.09	1.98	1.87	1.76	1.66	1.60	1.53
0.35	2.29	2.16	2.05	1.95	1.84	1.72	1.63	1.56	1.49
0.36	2.26	2.13	2.02	1.92	1.80	1.69	1.59	1.52	1.45
0.37	2.23	2.10	1.99	1.88	1.77	1.65	1.55	1.49	1.42
0.38	2.20	2.07	1.96	1.85	1.74	1.62	1.52	1.45	1.38
0.39	2.17	2.04	1.93	1.82	1.70	1.58	1.49	1.42	1.35
0.40	2.15	2.01	1.90	1.79	1.67	1.55	1.46	1.39	1.32
0.41	2.12	1.98	1.87	1.76	1.64	1.52	1.43	1.36	1.29
0.42	2.09	1.95	1.84	1.73	1.62	1.49	1.40	1.33	1.26
0.43	2.06	1.93	1.81	1.71	1.59	1.46	1.37	1.31	1.24
0.44	2.04	1.90	1.78	1.68	1.56	1.43	1.35	1.28	1.21
0.45	2.01	1.88	1.75	1.65	1.53	1.41	1.32	1.26	1.19
0.46	1.98	1.85	1.73	1.62	1.51	1.38	1.30	1.23	1.17
0.47	1.95	1.82	1.70	1.59	1.48	1.36	1.28	1.21	1.15
0.48	1.92	1.80	1.67	1.57	1.46	1.33	1.26	1.19	1.13
0.49	1.89	1.77	1.64	1.54	1.43	1.31	1.24	1.17	1.11
0.50	1.86	1.75	1.61	1.51	1.41	1.29	1.22	1.14	1.09
0.51	1.83	1.72	1.59	1.49	1.39	1.28	1.20	1.12	1.07
0.52	1.80	1.70	1.56	1.46	1.37	1.26	1.18	1.10	1.04
0.53	1.77	1.67	1.53	1.44	1.34	1.24	1.16	1.07	1.02
0.54	1.74	1.65	1.51	1.42	1.32	1.23	1.14	1.05	1.00
0.55	1.71	1.62	1.48	1.39	1.30	1.21	1.12	1.02	1.00
0.56	1.68	1.60	1.46	1.37	1.28	1.20	1.10	1.00	1.00
0.57	1.65	1.57	1.44	1.35	1.26	1.18	1.08	1.00	1.00
0.58	1.62	1.55	1.42	1.33	1.24	1.16	1.05	1.00	1.00
0.59	1.59	1.52	1.39	1.31	1.22	1.14	1.02	1.00	1.00
0.60	1.56	1.50	1.37	1.29	1.20	1.12	1.00	1.00	1.00
0.61	1.54	1.48	1.36	1.27	1.18	1.09	1.00	1.00	1.00
0.62	1.51	1.45	1.34	1.25	1.16	1.06	1.00	1.00	1.00
0.63	1.49	1.43	1.32	1.23	1.13	1.02	1.00	1.00	1.00
0.64	1.46	1.41	1.30	1.21	1.11	1.00	1.00	1.00	1.00
0.65	1.44	1.39	1.29	1.20	1.08	1.00	1.00	1.00	1.00
0.66	1.42	1.37	1.27	1.18	1.05	1.00	1.00	1.00	1.00
0.67	1.40	1.35	1.26	1.16	1.02	1.00	1.00	1.00	1.00
0.68	1.38	1.32	1.24	1.14	1.00	1.00	1.00	1.00	1.00
0.69	1.36	1.30	1.22	1.12	1.00	1.00	1.00	1.00	1.00
0.70	1.35	1.28	1.20	1.10	1.00	1.00	1.00	1.00	1.00
0.71	1.33	1.26	1.19	1.07	1.00	1.00	1.00	1.00	1.00

TABLE 10 *Continued*

% Carbon	5	7	9	11	13	15	18	22	26
0.72	1.32	1.24	1.17	1.05	1.00	1.00	1.00	1.00	1.00
0.73	1.30	1.22	1.14	1.02	1.00	1.00	1.00	1.00	1.00
0.74	1.29	1.20	1.12	1.00	1.00	1.00	1.00	1.00	1.00
0.75	1.27	1.18	1.08	1.00	1.00	1.00	1.00	1.00	1.00
0.76	1.26	1.15	1.05	1.00	1.00	1.00	1.00	1.00	1.00
0.77	1.24	1.13	1.01	1.00	1.00	1.00	1.00	1.00	1.00
0.78	1.22	1.10	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.79	1.20	1.08	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.80	1.18	1.05	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.81	1.16	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.82	1.13	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.83	1.09	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.84	1.05	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.85	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.86	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

[A] Alloy factor is the product of all the multiplying factors (Table 5) excluding that for carbon.

TABLE 11 Equations for Table 6 Multiplying Factors

Carbon/Grain Size 7	
Up to 0.39 %, incl	MF $= 0.54\ (\%C)$
Over 0.39 to 0.55 %, incl	$= 0.171 + 0.001\ (\%C) + 0.265\ (\%C)^2$
Over 0.55 to 0.65 %, incl	$= 0.115 + 0.268\ (\%C) - 0.038\ (\%C)^2$
Over 0.65 to 0.75 %, incl	$= 0.143 + 0.2\ (\%C)$
Over 0.75 to 0.90 %, incl	$= 0.062 + 0.409\ (\%C) - 0.135\ (\%C)^2$
Manganese	
Up to 1.20 %, incl	$= 3.3333\ (\%Mn) + 1.00$
Over 1.20 to 1.95 %, incl	$= 5.10\ (\%Mn) - 1.12$
Silicon to 2.00 %, incl	$= 1.00 + 0.7\ (\%Si)$
Nickel	
Up to 1.50 %, incl	$= 1.00 + 0.363\ (\%Ni)$
Over 1.50 % to 3.5 %, incl	$= 0.3211 + 1.4501\ (\%Ni) - 0.6119\ (\%Ni)^2 + 0.1253\ (\%Ni)^3$
Chromium to 2.50 %, incl	$= 1.00 + 2.16\ (\%Cr)$
Molybdenum to 0.55 %, incl	$= 1.00 + 3.00\ (\%Mo)$
Copper to 0.55 %, incl	$= 1.00 + 0.365\ (\%Cu)$
Vanadium to 0.20 %, incl	$= 1.00 + 1.73\ (\%V)$
Zirconium to 0.25 %, incl	$= 1.00 + 2.5\ (\%Zr)$

TABLE 12 Equations for Table 7 Carbon Content, Initial Hardness, 50 % Martensite Hardness

Initial Hardness,	$H = 33.087 + 50.723x + 33.662x^2 - 2.7048x^3 - 107.02x^4 + 43.523x^5$
50 % Martensite Hardness,	$H = 21.93 + 27.153x + 226.89x^2 - 717.17x^3 + 958.62x^4 - 491.25x^5$

where:
H = Hardness in HRC
x = % Carbon

TABLE 13 Equations for Tables 8 and 9 Jominy Distance for 50 % Martensite versus DI

DI (in.) = $-0.0156 + 0.54358x - 0.0292133x^2 + 0.001186x^3 - 2.696E\text{-}05x^4 + 2.49E\text{-}07x^5$

DI (mm) = $-0.5203 + 8.7522x - 0.3003x^2 + 0.00778x^3 - 0.0001125x^4 + 6.5978E\text{-}07x^5$

where:
x = J Position in 1⁄16 in. or mm

TABLE 14 Equations for Table 10 Boron Factor versus % Carbon and Alloy Factor

Alloy Factor	Boron Factor
5 to 0.85 % C, incl	B.F. = $13.121 - 101.16\ X + 383.76\ X^2 - 729.90\ X^3 + 675.13\ X^4 - 242.44\ X^5$
Over 0.85 % C	B.F. = 1.00
7 to 0.81 % C, incl	B.F. = $10.318 - 70.135\ X + 248.92\ X^2 - 454.75\ X^3 + 411.02\ X^4 - 146.47\ X^5$
Over 0.81 % C	B.F. = 1.00
9 to 0.77 % C, incl	B.F. = $10.542 - 80.631\ X + 320.36\ X^2 - 653.01\ X^3 + 655.52\ X^4 - 257.51\ X^5$
Over 0.77 % C	B.F. = 1.00
11 to 0.73 % C, incl	B.F. = $9.034 - 64.879\ X + 252.92\ X^2 - 515.53\ X^3 + 522.33\ X^4 - 208.46\ X^5$
Over 0.73 % C	B.F. = 1.00
13 to 0.67 % C, incl	B.F. = $8.0941 - 55.906\ X + 219.38\ X^2 - 466.23\ X^3 + 504.97\ X^4 - 219.45\ X^5$
Over 0.67 % C	B.F. = 1.00
15 to 0.63 % C, incl	B.F. = $9.0484 - 77.438\ X + 362.81\ X^2 - 895.73\ X^3 + 1101.9\ X^4 - 532.49\ X^5$
Over 0.63 % C	B.F. = 1.00
18 to 0.59 % C, incl	B.F. = $6.9212 - 48.238\ X + 207.29\ X^2 - 507.17\ X^3 + 644.04\ X^4 - 328.39\ X^5$
Over 0.59 % C	B.F. = 1.00
22 to 0.55 % C, incl	B.F. = $7.240 - 55.334\ X + 254.54\ X^2 - 655.33\ X^3 + 867.43\ X^4 - 459.59\ X^5$
Over 0.55 % C	B.F. = 1.00
26 to 0.53 % C, incl	B.F. = $7.116 - 56.58\ X + 273.62\ X^2 - 740.01\ X^3 + 1021.50\ X^4 - 559.45\ X^5$
Over 0.53 % C	B.F. = 1.00

where:
X = % carbon

TABLE 15 Equations for Table 2 Distance Hardness Dividing Factors for Non-Boron Steels, in.

"J" Distance ($^1/_{16}$ in.)	DI[A]	Dividing Factor
2	To 2.1, incl	DF = 4.68961 – 11.00832 X + 13.83314 X^2 – 8.80283 X^3 + 2.78698 X^4 – 0.34880 X^5
	Over 2.1	DF = 1.00
3	To 3.1, incl	DF = 2.34904 – 0.28254 X – 1.42995 X^2 + 1.16697 X^3 – 0.33813 X^4 + 0.03403 X^5
	Over 3.1	DF = 1.00
4	To 4.1, incl	DF = 5.66795 – 6.14648 X + 3.52874 X^2 – 1.06026 X^3 + 0.16301 X^4 – 0.01015 X^5
	Over 4.1	DF = 1.00
5	To 4.4, incl	DF = 4.52902 – 2.90739 X + 0.986508 X^2 – 0.163586 X^3 + 0.012095 X^4 – 0.000257202 X^5
	Over 4.4	DF = 1.00
6	To 5.0, incl	DF = 4.39436 – 2.16072 X + 0.56027 X^2 – 0.08145 X^3 + 0.00840 X^4 – 0.000530827 X^5
	Over 5.0	DF = 1.00
7	To 5.3, incl	DF = 4.15002 – 1.43154 X + 0.00235893 X^2 + 0.112947 X^3 – 0.0237546 X^4 + 0.00150903 X^5
	Over 5.3	DF = 1.00
8	To 5.6, incl	DF = 4.44473 – 1.79085 X + 0.24617 X^2 + 0.03378 X^3 – 0.01189 X^4 + 0.000841843 X^5
	Over 5.6	DF = 1.00
9	To 5.8, incl	DF = 4.95421 – 2.43521 X + 0.62983 X^2 – 0.07914 X^3 + 0.00399154 X^4 – 0.0000120363 X^5
	Over 5.8	DF = 1.00
10	To 6.1, incl	DF = 5.31610 – 2.80977 X + 0.84183 X^2 – 0.141781 X^3 + 0.0130138 X^4 – 0.000512388 X^5
	Over 6.1	DF = 1.00
12	To 6.6, incl	DF = 5.63649 – 2.89264 X + 0.90309 X^2 – 0.17297 X^3 + 0.01881 X^4 – 0.00086593 X^5
	Over 6.6	DF = 1.00
14		DF = 5.83176 – 2.99646 X + 0.94088 X^2 – 0.17734 X^3 + 0.0183885 X^4 – 0.000790018 X^5
16		DF = 6.06952 – 3.15198 X + 0.99297 X^2 – 0.18010 X^3 + 0.0172029 X^4 – 0.000664079 X^5
18		DF = 7.32018 – 4.60605 X + 1.68442 X^2 – 0.338443 X^3 + 0.0345114 X^4 – 0.00138927 X^5
20		DF = 7.81382 – 5.10022 X + 1.921410 X^2 – 0.394591 X^3 + 0.040784 X^4 – 0.00165327 X^5
24		DF = 9.18138 – 6.69048 X + 2.75891 X^2 – 0.611613 X^3 + 0.0677165 X^4 – 0.002930700 X^5
28		DF = 9.27904 – 6.21461 X + 2.33158 X^2 – 0.46972 X^3 + 0.0472654 X^4 – 0.00186035 X^5
32		DF = 8.62857 – 5.16125 X + 1.81214 X^2 – 0.35489 X^3 + 0.035687 X^4 – 0.001434 X^5

where:
X = DI in inches.

[A] Max DI = 7.0 in.

TABLE 16 Equations for Table 3 Distance Hardness Dividing Factors for Non-Boron Steels, mm

"J" Distance (mm)	DI[A]	Dividing Factor
3.0	To 52.5, incl	DF = 0.170547 + 0.173925 X – 0.0109281 X^2 + 3.13863E-04 X^3 – 4.32086E-06 X^4 + 2.31674E-08 X^5
	Over 52.5	DF = 1.00
5.0	To 105.0, incl	DF = 3.03987 – 0.0855161 X + 0.00138048 X^2 – 9.98717E-06 X^3 + 2.64963E-08 X^4 + 5.46044E-12 X^5
	Over 105.0	DF = 1.00
7.0	To 122.5, incl	DF = 4.32366 – 0.134451 X + 0.00228151 X^2 – 1.96250E-05 X^3 + 8.35338E-08 X^4 – 1.38456E-10 X^5
	Over 122.5	DF = 1.00
9.0	To 135.0, incl	DF = 4.46324 – 0.0992003 X + 0.00119387 X^2 – 7.40686E-06 X^3 + 2.26087E-08 X^4 – 2.46815E-11 X^5
	Over 135.0	DF = 1.00
11.0	To 140.0, incl	DF = 4.40915 – 0.0792024 X + 6.74319E-04 X^2 – 1.97223E-06 X^3 – 3.21758E-09 X^4 + 2.08025E-11 X^5
	Over 140.0	DF = 1.00
13.0	To 147.5, incl	DF = 4.60261 – 0.0820023 X + 7.18416E-04 X^2 – 2.52800E-06 X^3 + 2.30089E-10 X^4 + 1.25368E-11 X^5
	Over 147.5	DF = 1.00
15.0	To 155.0, incl	DF = 5.01595 – 0.0957696 X + 9.56240E-04 X^2 – 4.62213E-06 X^3 + 8.92787E-09 X^4 – 8.74859E-13 X^5
	Over 155.0	DF = 1.00
20.0	To 172.5, incl	DF = 5.51133 – 0.104310 X + 1.15299E-03 X^2 – 7.51801E-06 X^3 + 2.75126E-08 X^4 – 4.3110E-11 X^5
	Over 172.5	DF = 1.00
25.0		DF = 6.15369 – 0.127486 X + 1.57885E-03 X^2 – 1.12233E-05 X^3 + 4.21359E-08 X^4 – 6.42460E-11 X^5
30.0		DF = 7.16001 – 0.171328 X + 2.42820E-03 X^2 – 1.91259E-05 X^3 + 7.67320E-08 X^4 – 1.21571E-10 X^5
35.0		DF = 8.46964 – 0.229424 X + 3.54915E-03 X^2 – 2.97166E-05 X^3 + 1.24831E-07 X^4 – 2.0543E-10 X^5
40.0		DF = 9.13657 – 0.252296 X + 3.94419E-03 X^2 – 3.33383E-05 X^3 + 1.41462E-07 X^4 – 2.35541E-10 X^5
45.0		DF = 8.84696 – 0.223317 X + 3.25787E-03 X^2 – 2.62930E-05 X^3 + 1.08190E-07 X^4 – 1.76244E-10 X^5
50.0		DF = 8.10202 – 0.171039 X + 2.12643E-03 X^2 – 1.52754E-05 X^3 + 5.78179E-08 X^4 – 8.79890E-11 X^5

where:
X = DI in millimetres.

[A] Max DI = 177.5 mm.

TABLE 17 Equations for Table 4 Distance Hardness Dividing Factors for Boron Steels, in.

"J" Distance ($^1/_{16}$ in.)	DI_B[A]	Dividing Factor
2	To 2.5, incl	DF = 26.36590 – 63.93760 X + 64.5141 X^2 – 32.4046 X^3 + 8.08566 X^4 – 0.801282 X^5
	Over 2.5	DF = 1.00
3	To 2.9, incl	DF = 11.11180 – 23.185 X + 21.5865 X^2 – 10.0461 X^3 + 2.32282 X^4 – 0.212967 X^5
	Over 2.9	DF = 1.00
4	To 3.5, incl	DF = 28.50611 – 46.70430 X + 31.90431 X^2 – 10.91263 X^3 + 1.86570 X^4 – 0.12747 X^5
	Over 3.5	DF = 1.00
5	To 4.4, incl	DF = 24.56368 – 33.70604 X + 19.34623 X^2 – 5.52132 X^3 + 0.78088 X^4 – 0.0437473 X^5
	Over 4.4	DF = 1.00
6	To 4.9, incl	DF = 5.32872 + 1.00334 X – 3.67571 X^2 + 1.70752 X^3 – 0.31024 X^4 + 0.0201755 X^5
	Over 4.9	DF = 1.00
7	To 5.2, incl	DF = 5.34598 + 0.98810 X – 3.15067 X^2 + 1.33727 X^3 – 0.22285 X^4 + 0.0133182 X^5
	Over 5.2	DF = 1.00
8	To 5.6, incl	DF = 2.61397 + 4.69073 X – 4.71553 X^2 + 1.58031 X^3 – 0.22844 X^4 + 0.01219 X^5
	Over 5.6	DF = 1.00
9	To 5.8, incl	DF = 3.80939 + 2.96448 X – 3.58847 X^2 + 1.22906 X^3 – 0.17730 X^4 + 0.00938121 X^5
	Over 5.8	DF = 1.00
10	To 6.1, incl	DF = 11.75138 – 8.15904 X + 2.57305 X^2 – 0.42384 X^3 + 0.03679 X^4 – 0.00135613 X^5
	Over 6.1	DF = 1.00
12	To 6.6, incl	DF = 10.94580 – 6.42904 X + 1.72900 X^2 – 0.24187 X^3 + 0.01769 X^4 – 0.000547832 X^5
	Over 6.6	DF = 1.00
14	To 6.9, incl	DF = 14.86832 – 10.1637 X + 3.32700 X^2 – 0.59480 X^3 + 0.0563926 X^4 – 0.00221015 X^5
	Over 6.9	DF = 1.00
16		DF = 14.10267 – 7.94906 X + 1.93841 X^2 – 0.22357 X^3 + 0.0108383 X^4 – 0.00010342 X^5
18		DF = 11.29531 – 4.46248 X + 0.41286 X^2 + 0.09097 X^3 – 0.020345 X^4 + 0.00109529 X^5
20		DF = 7.14752 + 0.35500 X – 1.61359 X^2 + 0.49403 X^3 – 0.0587857 X^4 + 0.00250946 X^5
24		DF = 12.3738 – 4.50690 X + 0.29009 X^2 + 0.12299 X^3 – 0.02325 X^4 + 0.00117 X^5
28		DF = 27.50991 – 20.45946 X + 6.97580 X^2 – 1.25184 X^3 + 0.11543 X^4 – 0.00432751 X^5
32		DF = 43.35623 – 35.34260 X + 12.58238 X^2 – 2.29821 X^3 + 0.21196 X^4 – 0.00785122 X^5

where:
X = DI_B in inches.

[A] Max DI_B = 7.0 in.

TABLE 18 Equations for Table 5 Distance Hardness Dividing Factors for Boron Steels, mm

"J" Distance (mm)	DI_B[A]	Dividing Factor
3.0	To 65.0, incl	$DF = -7.4491 + 0.865852 X - 0.0344068 X^2 + 6.71203E\text{-}04 X^3 - 6.46154E\text{-}06 X^4 + 2.46154E\text{-}08 X^5$
	Over 65.0	DF = 1.00
5.0	To 77.5, incl	$DF = -0.0786266 + 0.192924 X - 0.00833546 X^2 + 1.55518E\text{-}04 X^3 - 1.35556E\text{-}06 X^4 + 4.54711E\text{-}09 X^5$
	Over 77.5	DF = 1.00
7.0	To 97.5, incl	$DF = 17.3759 - 0.917265 X + 0.0207515 X^2 - 2.35993E\text{-}04 X^3 + 1.34895E\text{-}06 X^4 - 3.10646E\text{-}09 X^5$
	Over 97.5	DF = 1.00
9.0	To 130.0, incl	$DF = 12.4010 - 0.46868 X + 0.0076767 X^2 - 6.19712E\text{-}05 X^3 + 2.45123E\text{-}07 X^4 - 3.78588E\text{-}10 X^5$
	Over 130.0	DF = 1.00
11.0	To 145.0, incl	$DF = 11.6875 - 0.367030 X + 0.00494941 X^2 - 3.23202E\text{-}05 X^3 + 1.00462E\text{-}07 X^4 - 1.15393E\text{-}10 X^5$
	Over 145.0	DF = 1.00
13.0	To 150.0, incl	$DF = 10.4880 - 0.274123 X + 0.00292721 X^2 - 1.31351E\text{-}05 X^3 + 1.64929E\text{-}08 X^4 + 2.31368E\text{-}11 X^5$
	Over 150.0	DF = 1.00
15.0	To 157.5, incl	$DF = 10.2270 - 0.238757 X + 0.00217091 X^2 - 6.49911E\text{-}06 X^3 - 1.02394E\text{-}08 X^4 + 6.42594E\text{-}11 X^5$
	Over 157.5	DF = 1.00
20.0	To 167.5, incl	$DF = 12.0019 - 0.289503 X + 0.00321898 X^2 - 1.87998E\text{-}05 X^3 + 5.73608E\text{-}08 X^4 - 7.29343E\text{-}11 X^5$
	Over 167.5	DF = 1.00
25.0		$DF = 12.7759 - 0.267261 X + 0.00240278 X^2 - 1.00713E\text{-}05 X^3 + 1.72914E\text{-}08 X^4 - 4.94824E\text{-}12 X^5$
30.0		$DF = 11.4394 - 0.17577 X + 6.41712E\text{-}04 X^2 + 5.14585E\text{-}06 X^3 - 4.47370E\text{-}08 X^4 + 9.20061E\text{-}11 X^5$
35.0		$DF = 10.0009 - 0.0998560 X - 6.21697E\text{-}04 X^2 + 1.48920E\text{-}05 X^3 - 8.07801E\text{-}08 X^4 + 1.43570E\text{-}10 X^5$
40.0		$DF = 21.5687 - 0.570960 X + 0.00707779 X^2 - 4.71456E\text{-}05 X^3 + 1.64959E\text{-}07 X^4 - 2.39499E\text{-}10 X^5$
45.0		$DF = 43.7678 - 1.47943 X + 0.0218008 X^2 - 1.64441E\text{-}04 X^3 + 6.24269E\text{-}07 X^4 - 9.47543E\text{-}10 X^5$
50.0		$DF = 47.0305 - 1.56500 X + 0.0226057 X^2 - 1.66970E\text{-}04 X^3 + 6.21257E\text{-}07 X^4 - 9.26214E\text{-}10 X^5$

where:
$X = DI_B$ in millimetres.

[A] Max DI_B = 177.5 mm.

APPENDIX

(Nonmandatory Information)

X1. SPECIMENS FOR SPECIAL APPLICATIONS

X1.1 Scope

X1.1.1 The end-quench or Jominy hardenability test may be applied with some modification when the test specimens available are smaller in size than those shown in Figs. 2 and 3 or when shallow hardening steel is to be tested.

X1.2 Subsize Specimens

X1.2.1 *Dimensions of Specimens and Quenching Fixtures*—For determining the hardenability of steel received in bars less than 1.0 in. (25.4 mm) in diameter, the test specimen may be 0.75, 0.50, or 0.25 in. (19.0, 12.7, or 6.4 mm) in diameter by 3.0 or 4.0 in. (76.2 or 10.1.6 mm) in length. Fig. X1.1, in which a 0.25-in. (6.4-mm) specimen is shown in position, shows a suitable support for the smaller size specimens. These smaller specimens shall be tested in accordance with 5 of the method except that modifications are required in the water streams for quenching. The orifice size and distance of the specimen from the orifice for testing these smaller specimens shall conform to the following requirements specified in Table X1.1.

X1.2.2 *Correlation with Standard End-Quench Specimens*—Due to the greater air-cooling effect on test specimens less than 1.0 in. (25.4 mm) in diameter, and especially in specimens smaller than 0.75 in. (19.0 mm) in diameter, the cooling rates at various distances from the quenched end will not be the same as in the standard 1.0-in. round specimen. Hardenability curves obtained from tests on these smaller specimens therefore are not comparable with curves obtained from tests on the standard 1.0-in. round specimens. If the standard hardenability curve is needed, then the insert test specimen shown in Fig. X1.2 shall be used and tested as described in X1.4.

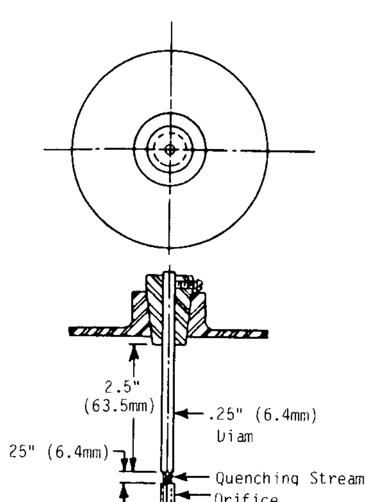

FIG. X1.1 Support for Smaller-Size Specimens, Showing 0.25-in. (6.4-mm) Specimen in Position

TABLE X1.1 Orifice Sizes for Testing Small-Size Specimens

Diameter of Test Specimen, in. (mm)	Orifice Size, in. (mm)	Distance from Orifice to Quenched End of Specimen, in. (mm)	Free Height of Water Column, in. (mm)
0.75 (19.0)	0.50 (12.7)	0.50 (12.7)	2.5 (63.5)
0.50 (12.7)	0.25 (6.4)	0.375 (9.5)	4.0 (102)
0.25 (6.4)	0.125 (3.2)	0.25 (6.4)	8.0 (203)

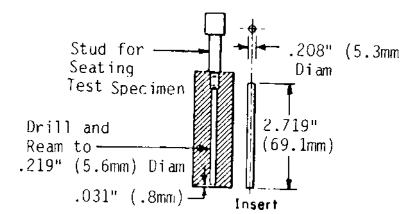

FIG. X1.2 Drilled Bar Specimen for Steel Available Only in Small Sizes

X1.3 Shallow-Hardening Steels

X1.3.1 The 1.0-in. (25.4-mm) diameter standard hardenability specimen may be used to determine the hardenability of shallow-hardening steels, other than the carbon tool steels, by a modification in the hardness survey. The procedure in preparing the specimen prior to hardness measurements is described in Sections 4, 5, and 6. An anvil providing a means of very accurately measuring the distance from the quenched end is essential.

X1.3.2 Hardness values are obtained from $\frac{1}{16}$ to $\frac{8}{16}$ in. (1.6 to 12.7 mm) from the quenched end in intervals of $\frac{1}{32}$ in. (0.8 mm). Beyond $\frac{8}{16}$ in., hardness values are obtained at $\frac{10}{16}$, $\frac{12}{16}$, $\frac{14}{16}$, and $\frac{16}{16}$ in. (15.9, 19.1, 22.2 and 25.4 mm) from the quenched end. For readings to $\frac{8}{16}$ in. from the quenched end, two hardness traverses are made, both with readings $\frac{1}{16}$ in. apart; one starting at $\frac{1}{16}$ in. and being completed at $\frac{8}{16}$ in. from the quenched end, and the other starting at $\frac{3}{32}$ in. (2.4 mm) and being completed at $\frac{15}{32}$ in. (11.9 mm) from the quenched end.

X1.3.3 Only two flats 180° apart need be ground if the mechanical fixture has a grooved bed that will accommodate the indentations of the flat surveyed first. The second hardness traverse is made after turning the bar over. If the fixture does not have such a grooved bed, two pairs of flats should be ground, the flats of each pair being 180° apart. The two hardness surveys are made on adjacent flats.

X1.3.4 For plotting test results, the standard form for plotting hardenability curves (Fig. 4) should be used. Distances for the odd number $\frac{1}{32}$ in. (0.8 mm) should be measured with care.

X1.4 Subsize Specimen as Insert in Standard End-Quench Test

X1.4.1 A specimen available only in a small size may be prepared as an insert in an axially drilled standard size test which serves as a sheath (Fig. X1.2). About 0.2 g of Woods metal[4] shall be placed in the bottom of the test sheath (Fig. X1.2). The small test specimen inserted in the sheath, and the sheath warmed to a temperature above the melting point of the Woods metal. After the Woods metal is molten, screw the stud in place so that the specimen is forced firmly against the bottom of the hole. Then heat the assembly and quench in accordance with 6.2 and 6.3. The sheath shall preferably be made from a plain low-carbon steel. After the quench, warm the assembly in boiling water to melt the Woods metal and remove the specimen. Then make Rockwell hardness measurements on the C scale on the specimen as prescribed in 6.3.

[4] The composition of Woods metal is 50 % bismuth, 25 % lead, and 25 % tin, and the melting point is 200°F (93°C).

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INTERNATIONAL

Designation: A 266/A 266M – 03

An American National Standard

Standard Specification for Carbon Steel Forgings for Pressure Vessel Components[1]

This standard is issued under the fixed designation A 266/A 266M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification[2] covers four grades of carbon steel forgings for boilers, pressure vessels, and associated equipment.

NOTE 1—Designations have been changed as follows:

Current	Formerly
Grade 1	Class 1
Grade 2	Class 2
Grade 3	Class 3
Grade 4	Class 4

1.2 Supplementary requirements are provided for use when additional testing or inspection is desired. These shall apply only when specified individually by the purchaser in the order.

1.3 The values stated in either inch-pound units or SI (metric) units are to be regarded separately as the standard. Within the text and tables, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.4 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings[4]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[5]

A 788 Specification for Steel Forgings, General Requirements[4]

E 112 Test Methods for Determining the Average Grain Size[6]

E 165 Test Method for Liquid Penetrant Examination[7]

E 381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings[6]

2.2 *Other Standard:*

ASME Boiler and Pressure Vessel Code, Section IX, Welding Qualifications[8]

3. Ordering Information and General Requirements

3.1 In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order a detailed drawing, sketch, or written description of the forging.

3.2 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

3.3 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

3.4 For hubbed flanges and tube sheets ordered for ASME Boiler and Pressure Vessel Code application, Supplementary Requirement S12 of Specification A 788 should be specified in addition to Supplementary Requirement S8 of this specification.

4. Materials and Manufacture

4.1 The steel shall be made in accordance with the Melting Process Section of Specification A 788. A sufficient discard shall be made to secure freedom from injurious pipe and undue segregation.

4.2 The material shall be forged as close as practical to the specified shape and size.

4.3 The finished product shall be a hot-worked forging as defined by Specification A 788.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved April 10, 2003. Published June 2003. Originally approved in 1943. Last previous edition approved in 1999 as A 266/A 266M–99.

[2] For ASME Boiler and Pressure Vessel Code applications, see related Specification SA–266/ SA–266M in Section II of that code.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] *Annual Book of ASTM Standards*, Vol 01.05.

[5] *Annual Book of ASTM Standards*, Vol 01.03.

[6] *Annual Book of ASTM Standards*, Vol 03.01.

[7] *Annual Book of ASTM Standards*, Vol 03.03.

[8] Available from the American Society of Mechanical Engineers, 345 East 47th St., New York, NY 10017.

***A Summary of Changes section appears at the end of this standard.**

5. Machining

5.1 Surfaces shall be machined as designated by the purchaser. Unmachined surfaces shall be sufficiently free of scale to permit inspection.

5.2 Machining may be performed either prior to or after heat treatment at the option of the manufacturer unless specified in accordance with Supplementary Requirement S1.

6. Heat Treatment

6.1 After forging and before reheating for heat treatment, the forgings shall be cooled in such a manner as to prevent injury and to accomplish transformation.

6.2 All forgings shall be annealed, normalized, or normalized and tempered, but alternatively may be liquid quenched and tempered when mutually agreed upon between the manufacturer and the purchaser. When tempering is performed, it shall be at a subcritical temperature, but no less than 1100°F [595°C].

6.3 A multiple stage austenitizing procedure may be used whereby the forging is first fully austenitized and liquid quenched, followed by reheating within the intercritical temperature range to partially reaustenitize, and again liquid quenched. On completion of the austenitizing/quenching cycles, tempering at a temperature between 1100°F [595°C] and the lower critical temperature shall follow.

NOTE 2—Although liquid quenching from the austenitizing temperatures is more effective in enhancing impact properties, air cooling from the austenitizing temperatures is also beneficial and may be used instead of the normalizing procedure in 6.2.

7. Chemical Composition

7.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 shall comply with Table 1 except that the additional features of Supplementary Requirements S11 and S12 shall also apply as individually specified in the ordering information.

7.2 *Product Analysis*—The purchaser may use the product analysis provision of Specification A 788 to obtain a product analysis from a forging representing each heat or multiple heat.

8. Mechanical Properties

8.1 *General Requirements*—Except when otherwise specified in accordance with Supplementary Requirement S2, the material shall conform to the requirements for mechanical properties prescribed in Table 2 when tested in accordance with the latest issue of Test Methods and Definitions A 370. The largest obtainable tension test specimen as specified in Test Methods and Definitions A 370 shall be used.

TABLE 1 Chemical Requirements

	Composition, %		
	Grades 1 and 2	Grade 3	Grade 4
Carbon, max	0.30	0.35	0.30
Manganese	0.40–1.05	0.80–1.35	0.80–1.35
Phosphorus, max	0.025	0.025	0.025
Sulfur, max	0.025	0.025	0.025
Silicon	0.15–0.35	0.15–0.35	0.15–0.35

TABLE 2 Tensile Requirements

	Grade 1	Grades 2 and 4	Grade 3
Tensile strength, min, ksi [MPa]	60–85 [415–585]	70–95 [485–655]	75–100 [515–690]
Yield strength (0.2 % offset), min, ksi [MPa]	30 [205]	36 [250]	37.5 [260]
Elongation in 2 in. or 50 mm, min, %	23	20	19
Reduction of area, min, %	38	33	30

8.1.1 Except when otherwise specified in accordance with Supplementary Requirement S2, the longitudinal axis of the specimens shall be parallel to the direction of major working of the forging. For upset-disc forgings, the longitudinal axis of the test specimen shall be in the tangential direction.

8.1.1.1 The longitudinal axis of the specimen shall be located midway between the parallel surfaces of the test extension if added to the periphery of disks or midway between the center and surface of solid forgings. For hollow forgings, the longitudinal axis of the specimens shall be located midway between the center and outer surfaces of the wall. When separately forged test blocks are employed as defined in 8.1.3, the tension test specimens shall be taken from a location that represents the midwall of the heaviest section of the production forgings. When specimens are required from opposite ends, they shall be taken from the diagonal corners of an axial plane.

8.1.2 Except as specified herein, tests for acceptance shall be made after heat treatment has been completed. When the ends of the cylindrical forgings are closed in by reforging, the cylindrical forgings may be annealed, normalized, or normalized and tempered and tested prior to reforging. After reforging, the entire forging shall be reheat-treated in the same manner and at the same temperature range as employed when the forging was heat-treated prior to certification testing.

8.1.3 When mutually agreed upon between manufacturer and purchaser, test specimens may be machined from a specially forged block suitably worked and heat treated with the production forgings. Such a special block shall be obtained from an ingot, slab, or billet from the same heat used to make the forgings it represents. This block shall receive essentially the same type of hot working and forging reduction as the production forgings; however, a longitudinally forged bar with dimensions not less than T by T by $3T$ may be used to represent a ring forging. The dimension T shall be representative of the heaviest effective cross section of the forging. For quenched and tempered forgings for which tests are required at both ends by 8.2.2.3 and 8.2.2.4, separately forged test blocks are not allowed.

NOTE 3—In using separately forged test blocks, attention is drawn to the effect of mass differences between the production forgings and the test blocks.

8.2 *Specific Requirements*—The number and location of tests are based on forging length, weight, and heat treatment, and shall be as prescribed below. The length and weight to be used for this purpose shall be the shipped length and weight of forgings produced individually or the aggregate shipped length and weight of all pieces cut from a multiple forging.

8.2.1 *Annealed, Normalized, or Normalized and Tempered Steel Forgings*:

8.2.1.1 For forgings weighing 5000 lb [2250 kg] or less at the time of heat treatment, one tension test shall be taken from one forging per heat in each heat–treatment charge. When heat treatment is performed in continuous-type furnaces with suitable temperature controls and equipped with recording pyrometers so that complete heat-treatment records are available, a tempering charge may be considered as any continuous run not exceeding an 8-h period.

8.2.1.2 For forgings and forged bars weighing over 5000 lb [2250 kg] at the time of heat treatment, one tension test shall be taken from each forging.

8.2.2 *Quenched and Tempered Forgings*:

8.2.2.1 For quenched and tempered forgings weighing 5000 lb [2250 kg] or less at the time of heat treatment, but not exceeding 12 ft [3.7 m] in length, one tension test shall be taken from one forging per heat in each heat–treatment charge. When heat treatment is performed in continuous-type furnaces with suitable temperature controls and equipped with recording pyrometers so that complete heat-treatment records are available, a tempering charge may be considered as any continuous run not exceeding an 8-h period.

8.2.2.2 For quenched and tempered forgings and forged bars weighing over 5000 lb [2250 kg] to 10 000 lb [4500 kg] at the time of heat treatment, but not exceeding 12 ft [3.7 m] in length, one tension test shall be taken from each forging.

8.2.2.3 For quenched and tempered forgings and forged bars that exceed 12 ft [3.7 m] in length, one tension test shall be taken from each end of each forging.

8.2.2.4 For quenched and tempered forgings and forged bars weighing more than 10 000 lb [4500 kg] at the time of heat treatment, two tension test specimens shall be taken from each forging. These shall be offset 180° from each other except that if the length of the forging, excluding test prolongations, exceeds 12 ft [3.7 m], then one specimen shall be taken from each end of the forging.

9. Repair Welding

9.1 Repair welding of forgings is permissible only at the option of the purchaser. If repair welding is performed, welders and weld procedures shall be qualified in accordance with Section IX of the ASME Boiler and Pressure Vessel Code.

10. Certification

10.1 In addition to the mandatory certification requirements of Specification A 788, the heat treatment cycle data shall be included.

11. Product Marking

11.1 Each forging shall be identified in accordance with the Marking Section of Specification A 788. In addition, the forging shall be marked following the grade designation by the letter “A” for annealed, “N” for normalized, “NT” for normalized and tempered, and “S” for liquid quenched and tempered, as applicable.

12. Keywords

12.1 pressure vessel service; steel forgings—carbon

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order. Details of these supplementary requirements shall be agreed upon between the manufacturer and the purchaser.

S1. Rough Turning and Boring

S1.1 The position of the rough turning and boring in the sequence of manufacturing operations shall be as specified by the purchaser.

S2. Alternative Tension Test Orientation

S2.1 In lieu of the requirements of Section 8, the longitudinal axis of the test specimens shall be transverse to the direction of major working of the forging. The results shall conform with requirements of Table 2, with the exception of the ductility limits that shall be as follows:

Grade	1	2 and 4	3
Elongation in 2 in. [50 mm], min, %	20	19	18
Reduction of area, min, %	30	25	25

S3. Hydrostatic Test

S3.1 A hydrostatic pressure test shall be applied. The details of the test, including its position in the sequence of manufacturing operations, shall be specified.

S4. Magnetic Particle Examination

S4.1 All accessible surfaces of the finished forging shall be examined by a magnetic particle method. The method shall be in accordance with Test Method A 275/A 275 M. Acceptance limits shall be as agreed upon between the manufacturer and the purchaser.

S5. Liquid Penetrant Examination

S5.1 After forgings have been heat treated by liquid quenching and tempering, all accessible surfaces shall be inspected for quench cracks by the liquid penetrant method in accordance with Test Method E 165 as an alternative to magnetic particle examination.

S6. Macroetch Test

S6.1 A sample forging shall be sectioned and etched to show flow lines and internal imperfections. The test shall be conducted in accordance with Method E 381. Details of the test shall be agreed upon between the manufacturer and the purchaser.

S7. Product Analysis

S7.1 A product analysis in accordance with Section 7 shall be made from one randomly selected forging representing each size and shape of forging on the order. If the analysis fails to comply, each forging shall be checked or the lot rejected. All results shall be reported to the purchaser.

S8. Specimen Location on Forged Hubs

S8.1 Forged hubs to be butt-welded to shells shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material, in a direction parallel to the axis of the vessel. A tension specimen (subsize if necessary) shall be taken in this direction and as close to the finished hub outside diameter as practical.

S9. Hardness

S9.1 The purchaser may check the Brinell hardness of the forging at any location on the surface of the forging, and the hardness shall be within the following limits:

Grade	Brinell Hardness Limits
1	121 to 170
2 and 4	137 to 197
3	156 to 207

S10. Grain Size

S10.1 The austenitic grain size of the steel shall be 1 to 5 as determined using Test Methods E 112.

S11. Restriction on Residual Elements (Applicable to Heat Analysis)

S11.1 Nickel, chromium, and molybdenum shall be determined and shall not exceed the following limits:

Nickel	0.25 % max
Chromium	0.20 % max
Molybdenum	0.08 % max

S12. Restriction on Carbon (Applicable to Grade I)

S12.1 The carbon content shall be 0.30 % max.

S13. Impact Tests

S13.1 Charpy impact tests shall be made. The number and location of the tests, minimum properties, and test temperatures shall be specified.

S13.2 The specimens shall be machined and tested in accordance with Test Methods and Definitions A 370.

S13.3 Retests may be conducted in accordance with Section 10 of Specification A 788.

S14. Individual Forging

S14.1 Forgings, whether identical or not, shall be pro-duced individually. They shall not be forged in multiples and separated prior to or after heat treatment.

S14.2 The shape and size of individual forgings shall be agreed upon between the manufacturer and the purchaser by means of a forging drawing or the purchase order.

S15. Carbon Equivalancy

S15.1 The heat analysis including the residual element restrictions of S1 in Specification A 788 shall be limited such that the carbon equivalent shall not exceed 0.45 for Grade 1 or 0.50 for Grade 2 or 4 when calculated in accordance with the following formula:

$$CE = \%\,C + \frac{\%\,Mn}{6} + \frac{\%\,Cr + \%\,Mo + \%\,V}{5} + \frac{\%\,Ni + \%\,Cu}{15}$$

SUMMARY OF CHANGES

(1) Added supplementary requirement reference to ordering information.

Standard Test Method for Magnetic Particle Examination of Steel Forgings[1]

This standard is issued under the fixed designation A 275/A 275M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method[2] covers a procedure for magnetic particle examination of steel forgings. The procedure will produce consistent results upon which acceptance standards can be based. This standard does not contain acceptance standards or recommended quality levels.

1.2 Only direct current or rectified alternating (full or half wave) current shall be used as the electric power source for any of the magnetizing methods. Alternating current is not permitted because its capability to detect subsurface discontinuities is very limited and therefore unsuitable.

NOTE 1—Guide E 709 may be utilized for magnetic particle examination in the field for machinery components originally manufactured from steel forgings.

1.3 The minimum requirements for magnetic particle examination shall conform to practice standards of Practice E 1444. If the requirements of this test method are in conflict with the requirements of Practice E 1444, the requirements of this test method shall prevail.

1.4 This specification and the applicable material specifications are expressed in both inch-pound units and SI units. However, unless the order specifies the applicable "M" specification designation [SI units], the material shall be furnished to inch-pound units.

1.5 The values stated in either inch-pound or SI units are to be regarded as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 709 Guide for Magnetic Particle Examination[3]

E 1444 Practice for Magnetic Particle Examination[3]

2.2 *Other Document:*

Recommended Practice No. SNT-TC-1A, Supplement B-Magnetic Particle Method[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *indication*—the visual magnetic particle buildup resulting from leakage fields in the magnetic field.

3.1.2 *linear indication*—an indication in which the length is at least three times the width. The minimum length of indications to be considered linear shall be 1⁄16 in. [1.6 mm].

3.1.3 *magnetic flux*—the product of the magnetic induction and the area of a surface (or cross section) when the magnetic induction is uniformly distributed and normal to the plane of the surface. The concept that the magnetic field is flowing along the lines of force suggests that these lines are therefore "flux" lines, and they are called magnetic flux.

3.1.4 *magnetic particle method of examination*—a method for detecting discontinuities on or near the surface in suitably magnetized materials, which employs finely divided magnetic particles that tend to congregate in regions of leakage fields.

3.1.5 *nonrelevant indications*—indications produced by leakage fields. However, the conditions causing them are present by design or accident, or other features of the part having no relation to the damaging flaws being sought. The term signifies that such an indication has no relation to the discontinuities that might constitute defects.

4. Basis of Application

4.1 When in accordance with the requirements of the inquiry, contract, order, or specifications, forgings are furnished subject to magnetic particle examination, the manufacturer and the purchaser shall be in agreement concerning the following:

[1] This test method is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Method SA-275/SA-275M in Section II of that Code.

[3] *Annual Book of ASTM Standards*, Vol 03.03.

[4] Available from American Society for Nondestructive Testing, 4153 Arlingate Plaza, Caller #28515, Columbus, OH 43228-0518.

4.1.1 The locations on the forgings that are to be subjected to magnetic particle examination.

4.1.2 The type, size, number, location, and orientation of indications that are to be considered injurious.

4.1.3 The method of application of magnetic particles, demagnetization requirements and magnetic field strengths.

4.2 In cases where large undercuts in the forgings are to be taken by the purchaser, the manufacturer shall be given the privilege (when the design permits) of machining slots or grooves in the rough-machined forging to explore the internal conditions prior to shipping.

4.3 Acceptance standards.

5. Personnel Requirements

5.1 Personnel performing the magnetic particle examination to this test method shall be qualified and certified in accordance with a written procedure conforming to Recommended Practice No. SNT-TC-1A or another national standard that is acceptable to both the purchaser and the supplier.

6. Stage of Inspection

6.1 Unless otherwise specified by the purchaser, acceptance inspection shall be performed on a forging in the final machined surface condition and final thermally treated condition (including stress relief) or within 0.030 in. [0.8 mm] of the final machined surface.

7. Magnetizing Apparatus

7.1 Rectified alternating (full or half wave) or direct-current electric power sources may be used. When current is passed through the part itself, the equipment shall consist of contacting or clamping elements with sufficient surface area and clamping pressure to allow the required current to flow without damaging (burning) the part being examined.

7.2 Portable electromagnetic (ac-dc) yokes may be used in the dc mode as a magnetizing apparatus, provided the sensitivity to detect crack-like defects is demonstrated to be at least equivalent to that of the direct-magnetization method.

8. Magnetic Particles

8.1 The inspection medium shall consist of finely divided ferromagnetic particles, which may be suspended in a suitable liquid medium, or used in dry powder form.

8.2 The size and shape of the particles, and their magnetic properties, both individually and collectively, are important (see Section 11).

9. Surface Preparation

9.1 The sensitivity of the magnetic particle examination will depend to a considerable extent upon the condition of the surface being tested. Defects may be satisfactorily revealed on shot-blasted or otherwise cleaned forged surfaces, or on surfaces having small amounts of heat-treating scale without any special surface preparation; however, loose scale must be removed. To reveal fine defects, the surfaces to be inspected should be smooth machined to at least a 250-µin. [6.35-µm] finish.

9.2 The surfaces shall be free of grease, oils, or other substances to which the particles may adhere.

9.3 Rough surfaces hamper the mobility of magnetic powders due to mechanical trapping which in turn produces false indications. Such areas should be surface ground. If grinding is impractical, a paper tape overlay (as described in 14.1.1.2) may eliminate the problem.

10. Methods of Magnetization

10.1 The forging may be magnetized either by passing current through the piece or by inducing a magnetic field by means of a central conductor or by coils.

10.1.1 *Continuous Method*—In the continuous method, the inspection medium is applied to the surface under inspection while the current is still flowing. The current source generates high amperage current in pulses of up to 1-s duration. The duration of this flow shall allow at least three pulses of current or in the case where machines supply continuous current flow a minimum shot of ⅕ to ½-s duration should be applied.

10.1.2 *Surge Method*—In the surge method a high-magnetizing force is applied and then reduced to a lower continuous value, which is maintained during application of the inspection medium.

10.1.3 *Residual Method*—In the residual method the inspection medium is applied to the surface under inspection after the magnetizing current has ceased to flow. The effectiveness of this method depends upon the strength of the magnetizing force and the retentivity of the piece, which in turn depends upon such factors as chemical composition, heat treatment, etc. The residual method is not acceptable for forgings being inspected to comply with some regulatory bodies; it shall be used, therefore, only when approved by the purchaser.

10.2 At least two separate examinations shall be carried out on each area. The second examination shall be with the lines of magnetic flux approximately perpendicular to those used for the first examination in that area. A different means of magnetizing may be used for the second examination. Magnetizing in more than one direction cannot be accomplished simultaneously.

NOTE 2—An exception to the above rule is overall sequential multi-vector magnetization whereby several magnetizing circuits are provided for sequentially magnetizing a part in multiple directions depending upon the locations of the current connectors. By this technique, flaws of any orientation can be detected with a single application of magnetic particles.

10.3 The two general types of magnetization with regard to direction are longitudinal and circular, as follows:

10.3.1 *Longitudinal*—When a forging is magnetized longitudinally, the magnetic flux lines are usually parallel to the axis of the piece. A longitudinally magnetized piece always has definite poles readily detectable by compass or magnetometer. Longitudinal magnetization is usually accomplished by placing the forging within a solenoid, often formed by wrapping cable around the piece (Fig. 1). For special applications, magnetic yokes can be used (Fig. 2) when requirements of 7.2 are met.

10.3.2 *Circular*—Circular magnetization is obtained by passing a current directly through the piece (Fig. 3), or induced through a conductor (Fig. 4), or conductors threaded (Fig. 5) through an opening in the piece. Localized circular magentization may be obtained by passing current through the local areas by use of prod-type contacts (Fig. 6).

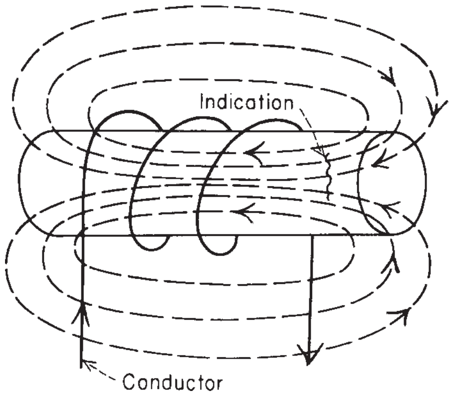

FIG. 1 Longitudinal Magnetization

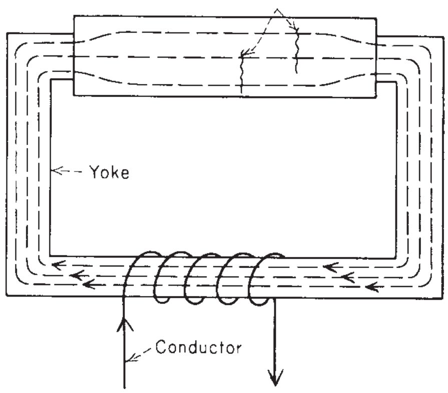

FIG. 2 Longitudinal Magnetization, with Yoke

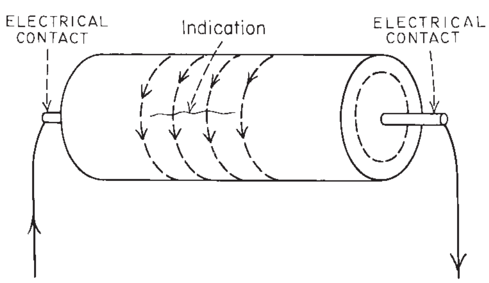

FIG. 3 Circular Magnetization, Current Directly Through Forging

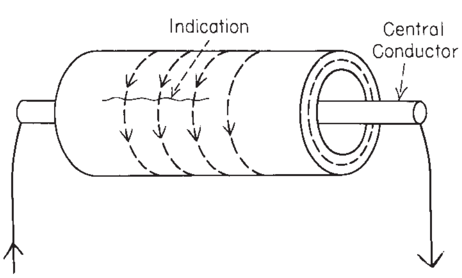

FIG. 4 Circular Magnetization, Current Through a Conductor

10.4 The magnetic field is confined almost entirely to the piece and there may be no external manifestation of the magnetized condition. Indications will appear strongest in the direction perpendicular to the direction of the magnetic field.

10.5 *Field Strength*—The minimum field strength that will reveal and permit classification of all objectionable defects shall be used. The maximum field strengths practical are the

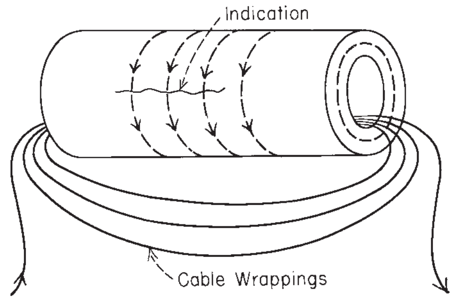

FIG. 5 Circular Magnetization, Current Through Conductors Threaded Through Forging

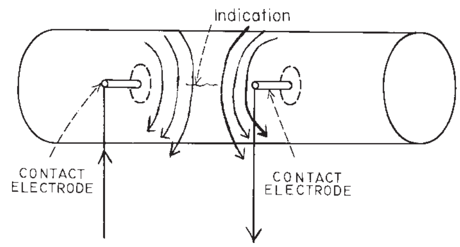

FIG. 6 Circular Magnetization with "Prod" Type Contact Electrodes

ones just below the point at which excessive adherence of the particles begins to occur over the surface being inspected.

10.5.1 *Coil Magnetization*—When coil magnetization is used, the magnetic field strength is directly proportional to the current (ampere-turns if a coil or solenoid is used) and inversely proportional to the thickness of the section being inspected.

10.5.1.1 *Longitudinal Magnetization*—For encircling coils (Fig. 1), the turns of the coil shall be kept closely together. The field strength decreases as distance from the coil increases and long parts must be magnetized in sections. If the area to be inspected extends beyond 6 in. [150 mm] on either side of the coils, the adequacy of the field shall be demonstrated by the use of field indicators (see 10.5.6).

(1) Small Forgings—Magnetizing force shall be 35 000 ampere-turns divided by the sum of 2 plus the "length over diameter" ratio of the test part. For example, a part 10 in. [250 mm] long by 2 in. [50 mm] in outside diameter has an *L/D* ratio of 5. Therefore, 35 000/(2 + 5) = 5000 ampere-turns; if a 5-turn coil is used, the current required is 5000/5 or 1000 A. This formula provides an adequate field strength on small parts having an *L/D* ratio of 4 or greater. For parts having a smaller *L/D* ratio, adequate field strengths shall be demonstrated by the use of a field indicator (see 10.5.6). The graph in Fig. 7 may be used to determine the ampere-turns required for each *L/D* relationship.

(2) Large Forgings—For large forgings the magnetizing force shall be in the range from 1200 to 4500 ampere-turns. A field indicator (see 10.5.6) shall be used to demonstrate the presence of an adequate field strength over the area to be inspected.

10.5.1.2 *Circular Magnetization* (Fig. 5)—For circular magnetization with through coils, use the current with amperage as specified in 10.5.2 divided by the number of turns in the coil.

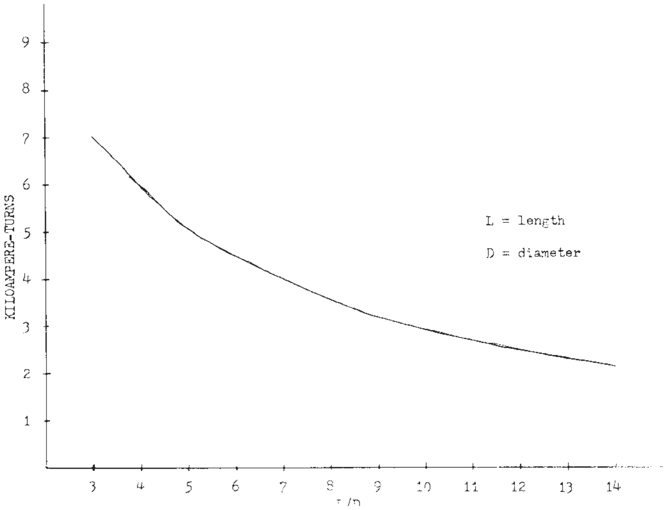

FIG. 7 Longitudinal Magnetization

10.5.2 *Direct Magnetization*—When current is passed directly through the part to be examined, the current shall be between 100 and 900 A [4 and 35 A per mm] per in. of diameter or cross section (per in. or mm of greatest width in a plane at right angles to current flow). For hollow parts this would be wall thickness when cables are clamped to the wall. Suggested current for diameters or sections up to 5 in. [125 mm] are 600 to 900 A/in. [25 to 35 A per mm]; for diameters or sections between 5 and 10 in. [125 to 250 mm], 400 to 600 A/in. [15 to 25 A per mm]; and 100 to 400 A/in. [4 to 15 A per mm] for outside diameters or sections over 10 in. [250 mm]. If it is not practical to obtain these current levels for diameters over 10 in. [250 mm], the presence of an adequate field strength shall be demonstrated using a field indicator. In all other instances the adequacy of the magnetizing force shall be demonstrated by means of a field indicator (see 10.5.6). When large parts have been examined by clamping contacts to the wall thickness the adequacy of the field in the circumferential direction shall also be determined by the field indicator.

10.5.3 *Prod Magnetization*—When prods are used to circularly magnetize a local area, the field strength is directly proportional to the amperage used but also varies with the prod spacing and thickness of section being inspected.

10.5.3.1 A magnetizing force of 75 to 100 A per linear in. [3 to 4 A per mm] of prod spacing shall be used for material under ¾ in. [20 mm] thick, and 100 to 125 A per linear in. [4 to 5 A per mm] of prod spacing shall be used for material ¾ in. [20 mm] and over in thickness.

10.5.3.2 Prod spacing shall be a maximum of 8 in. [200 mm]. Prod spacing less than 3 in. [75 mm] usually is not feasible due to banding of the particles around the prods. Care shall be taken to prevent local overheating or burning of the surface being examined. Steel- or aluminum-tipped prods or copper-brush-type prods rather than solid copper-tipped prods are recommended where the magnetizing voltage is over 25 V open circuit (bad contact) in order to avoid copper penetration. Permanent magnetic leeches may be used as a pair or in conjunction with a prod. Leeches should not be used in excess of 1500 A because loss of magnetization occurs.

10.5.3.3 A remote control switch, which may be built into the prod handles, shall be provided to permit the current to be turned on after the prods have been properly positioned and to turn if off before the prods are removed in order to prevent arcing.

10.5.3.4 *Examination Coverage*—Examinations shall be conducted with sufficient overlap to assure 100 % coverage at the established sensitivity.

10.5.3.5 *Direction of Magnetization*—At least two separate examinations shall be carried out on each area. The prods shall be placed so that the lines of flux during one examination are approximately perpendicular to the lines of flux during the other.

10.5.4 Indirect circular magnetization of the bores of shaft forgings (Fig. 4) shall be performed using a current of 100 to 125 A/in. [4 to 5 A per mm] of bore diameter.

10.5.5 A suitable instrument such as an ammeter shall be used to measure the specified or agreed upon current.

10.5.6 A magnetic particle field indicator (Fig. 8) where necessary shall be used to establish adequacy of the magnetic field. The magnetizing current shall be sufficient to develop the pattern in the indicator clearly.

10.5.6.1 The magnetic particle field indicator shall be used by positioning the indicator on the forging being examined while applying the required current and ferromagnetic particles. The production of a pattern (usually a cross) of discernible ferromagnetic particles indicates that adequate field strength has been generated in the forging being examined.

10.5.7 *Yoke Magnetization*—When electromagnetic yokes are used to magnetize a local area, a longitudinal field is formed between the poles.

10.5.7.1 *Equipment*—Yokes may be of the fixed or articulated leg types.

10.5.7.2 *Yoke Qualification*—Direct-current electromagnetic yokes shall have a lifting power of at least 40 lbf [175 N] at a pole spacing of 3 to 6 in. [75 to 150 mm].

10.5.7.3 *Direction of Magnetization*—At least two separate examinations shall be carried out on each area. In the second examination, the lines of magnetic flux shall be approximately perpendicular to those used for the first examination in that area.

10.5.7.4 *Pole Spacing*—Pole spacing shall be limited to 2 to 8 in. [50 to 200 mm].

10.5.7.5 *Inspection Area*—Inspection area is limited to a maximum distance of ¼ of the pole spacing on either side of a line joining the two poles. Overlapping of pole spacing shall be at least 1 in. [25 mm].

11. Application of Particles

11.1 While the forging is properly magnetized, the particles may be applied by one of the following methods:

11.1.1 *Dry Method*—In the dry method the particles shall be applied from a hand shaker (such as a shaker can), mechanical shaker, bulb blower, or mechanical blower. The use of the shaker shall be limited to flat and nearly horizontal surfaces, whereas the blowers may be used on vertical or overhead surfaces. The powder shall be applied evenly on the surface of the forging. The color of the dry powder should be chosen to

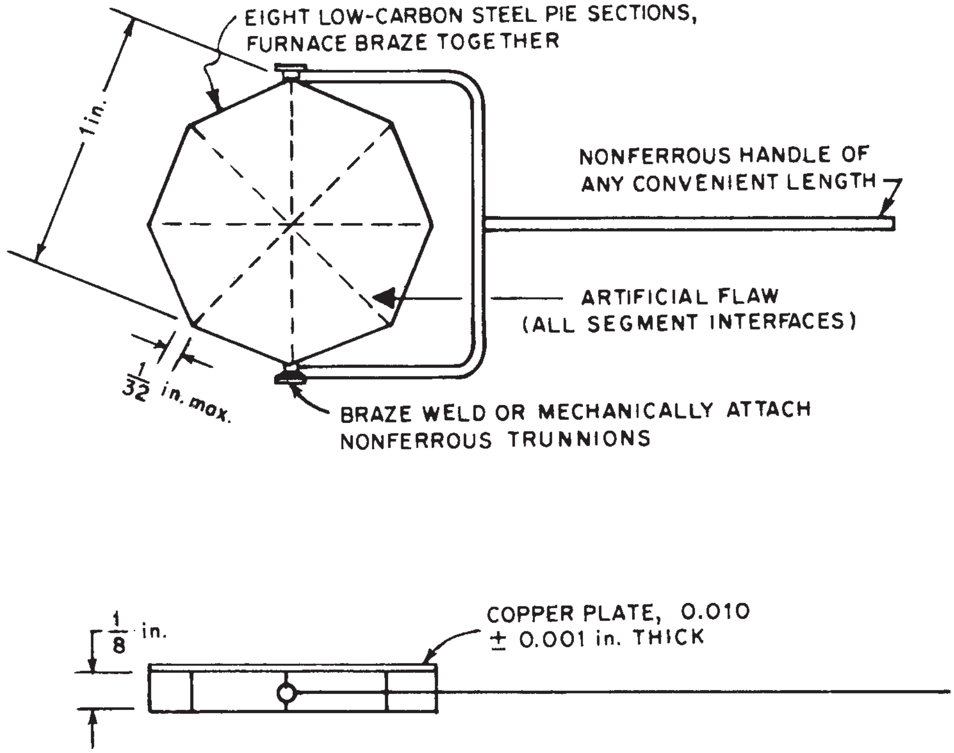

FIG. 8 Magnetic Particle Field Indicator

provide suitable contrast. Too much powder is disadvantageous as it masks the patterns.

11.1.2 Care shall be exercised in blowing off excess powder so as not to disturb the indications.

11.2 *Wet Methods*:

11.2.1 *Oil*—The material for the wet method is usually supplied in concentrate form, and the inspection medium shall be prepared by mixing the concentrate with a suitable light oil. The liquid recommended for the inspection vehicle is a well refined, light, petroleum distillate having a relatively high flash point. The approximate characteristics of a suitable liquid are as follows:

API gravity, °	46
Viscosity, SUS	31
Flash point (Tag Open Cup), °F [°C]	155 to 175 [65 to 80]
Initial boiling point, °F [°C]	390 [200]
End point, °F [°C]	490 [255]
Color, Saybolt	25

A suspension of from 1 to 2 % solid material by volume shall generally be used. The inspection medium shall be flowed or sprayed over the area being inspected. The color of the particles should be chosen to provide suitable contrast.

11.2.2 *Water*—Magnetic particles suspended in clean water, or clean water with suitable wetting agents may be used. Suspension of from 2 to 2½ % solid material by volume shall generally be used.

11.3 *Fluorescent Method*—Fluorescent magnetic particle inspection is a variation of the wet method. A concentrate, similar to that used in the wet method, shall be used, except that the magnetic particle shall be coated with material that fluoresces when activated by "black" light.

11.3.1 The same procedure specified when mixing the wet medium shall be followed, except that the suspension shall contain 0.1 to 0.7 % of solid material by volume when petroleum distillate or water is used.

11.3.2 The vehicle shall not be fluorescent.

11.3.3 If fluorescent particles are used, the examination shall be conducted in a darkened area using "black light," and the light intensity shall be at least 1000 μW/cm^2 at a distance of 15 in. from the lamp. The "black light" shall emit ultraviolet radiation of a wavelength within the range from 3300 to 3900 Å. The particles shall emit a brilliant fluorescence when subjected to this light. The bulb shall be allowed to warm up for a minimum of 5 min prior to its use in examination.

12. Demagnetization

12.1 When specified, parts shall be sufficiently demagnetized after inspection so that the residual field will not interfere with future welding or machining operations, magnetic instruments used in the proximity of the part, or so that leakage fields will not occur in areas of dynamic contact surfaces.

12.2 When direct current is used, demagnetizing may usually be accomplished by repeatedly reversing and progressively decreasing the magnetizing current. The initial field strength used during demagnetization shall be equal to or greater than the original magnetizing force. When the current has been reduced to the vanishing point, the part should be practically demagnetized. Direct current is recommended for demagnetizing large parts.

12.3 When alternating current is used, it is necessary merely to decrease the magnetizing current in small steps or continuously to a very low current.

12.4 Demagnetization will not be necessary if the piece is to be subject to an austenitizing treatment prior to future use or machining.

13. Interpretation and Evaluation of Indications

13.1 The following shall not be used as a standard for rejection or acceptance of a part, but may be used as an aid in interpreting and evaluating indications obtained. Examples of discontinuities and reference photographs of magnetic particle indications may be found in Practice E 709.

13.2 Factors that must be considered in interpreting an indication as to its cause are as follows:

13.2.1 Appearance of the indication.

13.2.2 Direction and shape of the indication.

13.2.3 Type of material from which the part is made.

13.2.4 Processing history of the part; type of machining; heat treatment; etc.

13.2.5 Past experience with similar parts based on destructive tests such as sectioning, etching, fracturing, chipping, grinding, etc.

13.3 The indications may be grouped into three broad classes:

13.3.1 Surface defects that produce sharp, distinct, clear-cut, tightly adhering patterns. These may generally be interpreted from characteristic indications as follows:

13.3.1.1 *Laminar Defects* give strong indications which are parallel to the surface.

13.3.1.2 *Forging Laps and Folds* are indications that may not be very heavy, and are not straight. They follow metal flow lines.

13.3.1.3 *Flakes* (thermal ruptures caused by entrapped hydrogen) can occur in areas that have been machined away. They are characterized by irregular, scattered indications.

13.3.1.4 *Heat-Treating Crack* indications are strong and occur at corners, notches, and changes of section.

13.3.1.5 *Shrinkage Crack* indications are very strong and sharp, usually continuous with few branches, and occur at changes of section.

13.3.1.6 *Grinding Crack* indications usually occur in groups at right angles to the direction of grinding.

13.3.1.7 *Etching or Plating Cracks* produce strong indications in a direction perpendicular to residual stresses.

13.3.2 Subsurface defects produce less distinct or fuzzy patterns which are broad rather than sharp, and are less tightly held. They generally produce the following characteristic indications:

13.3.2.1 *Stringers of Nonmetallic Inclusions* often have strong indications like surface seams but are usually discontinuous or short and occur in groups. These indications follow the grain flow in forgings. The indications show only when the defects are near the surface.

13.3.2.2 *Large Nonmetallics* produce indications ranging from sharp to diffuse, which may occur anywhere in a section.

13.3.2.3 *Cracks in Underbeads of Welds* produce indications that occur in broad diffuse patterns.

13.3.2.4 *Forging Bursts* produce irregular and diffuse indications.

13.3.3 Nonrelevant or "false" indications are generally confusing but can usually be identified, as follows:

13.3.3.1 *Magnetic Writing* indications are fuzzy and will be destroyed by demagnetization. These indications are caused by contact with other steel or magnets while magnetized.

13.3.3.2 *Changes in Section* are indications that are broad and fuzzy and caused by concentration of magnetic field in gear teeth, fillets, keyways, etc.

13.3.3.3 *Edge of Weld* indications are caused by change of magnetic properties due to diffusion. These indications are not tightly adherent.

13.3.3.4 *Flow Lines* are large groups of parallel indications that occur particularly in forgings examined by means of excessive currents.

13.3.4 Any indication that is believed to be nonrelevant shall be regarded as unacceptable until the indication is either eliminated by surface conditioning or it is reexamined by the same or other nondestructive means and demonstrated to be nonrelevant.

14. Report of Indications

14.1 Record the size, number, and location of all linear indications. Use sketches to show location, direction, and frequency of indications. The report shall indicate the type of magnetization and location of contacts.

14.1.1 *Permanent Recording of Data*:

14.1.1.1 A permanent record of the indications may be made by carefully covering the surface with transparent, adhesive-backed, cellophane tape. The tape is then removed with the particle indication adhering to it. The tape may then be placed on white paper or cardboard and photographed or otherwise reproduced.

14.1.1.2 If a more accurate reproduction of the indication is desired the following technique may be used. Once an indication has been detected using the normal examining technique, remove the accumulated powder and place a piece of white paper tape with a gloss surface and a gum adhesive backing over the area containing the indication; reapply the current and dust the tape surface with the powder. Immediately the particles will collect over the discontinuity, and with the current still passing through the test piece, spray the tape surface with a thin coating of acrylic lacquer. Terminate the current flow and remove the tape; this will leave an exact replica of the powder buildup adhering to it.

15. Acceptance Standards

15.1 The standards for acceptance of defects detected by magnetic particle examination shall be as specified in the applicable ASTM product specification, contract, or order.

Designation: A 288 – 91 (Reapproved 2003)

Standard Specification for Carbon and Alloy Steel Forgings for Magnetic Retaining Rings for Turbine Generators[1]

This standard is issued under the fixed designation A 288; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers quenched and tempered carbon and alloy steel forgings for magnetic retaining rings for turbine generators.

1.2 Supplementary requirements of an optional nature are provided. These shall apply only when specified by the purchaser.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings[2]

A 531/A 531M Practice for Ultrasonic Examination of Turbine-Generator Steel Retaining Rings[2]

A 788 Specification for Steel Forgings, General Requirements[2]

3. Ordering Information

3.1 In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order a detailed drawing, sketch, or written description of the forging, including the number and location of mechanical test specimens.

4. Manufacture

4.1 The melting processes of Specification A 788 shall be applicable except that the basic electric furnace process shall be used if separate refining or remelting is not employed.

4.2 *Vacuum Degassing*—For Class 3 machined forgings over 2½ in. (63.5 mm) wall thickness, and Classes 4 to 8, the molten steel shall be vacuum treated immediately prior to or during the operation of pouring the ingot in order to remove objectionable gases, especially hydrogen.

4.3 *Discard*—Sufficient discard shall be made from each ingot to secure freedom from piping and undue segregation.

4.4 *Heat Treatment*:

4.4.1 *Heat Treatment for Mechanical Properties*—Heat treatment for properties shall be by quenching and tempering.

4.4.2 *Tempering Temperature*—The final tempering temperature shall be not less than 1100°F (595°C).

4.5 *Machining*:

4.5.1 *Preliminary Machining*—Forgings shall be machined all over prior to quenching and tempering for mechanical properties.

4.5.2 *Machine to Purchaser's Requirements for Shipment*—If required, forgings shall be machined to the dimensions shown on the purchaser's drawing prior to shipment.

5. Chemical Composition

5.1 The steel shall conform to the chemical composition prescribed in Table 1.

5.2 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 shall comply with Table 1.

5.3 *Product Analysis*—The purchaser may use the product analysis provision of Table 1 of Specification A 788 to obtain a product analysis from a forging representing each heat or multiple heat.

6. Mechanical Properties

6.1 *Tensile Requirements*—The material shall conform to the requirements for tensile properties prescribed in Table 2.

6.2 *Notch Toughness Requirements*—The material shall conform to the requirements for notch toughness as prescribed in Table 2.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved April 10, 2003. Published July 2003. Originally approved in 1946. Last previous edition approved in 1998 as A 288 – 91(1998).

[2] *Annual Book of ASTM Standards*, Vol 01.05.

TABLE 1 Chemical Requirements

	Class 1, %	Classes 2 and 3, %	Classes 4, 5, 6, 7, and 8, %
Carbon, max	0.50 max	0.45 max	0.45
Manganese	0.60–1.00	0.60–1.00	1.00 max
Phosphorus, max	0.025	0.025	0.025
Sulfur, max	0.025	0.020	0.020
Silicon	0.15–0.30	0.15–0.35	0.15–0.35
Nickel	. . .	[A]	1.65–3.50
Chromium	. . .	0.70–1.25	0.70–1.25
Molybdenum	. . .	0.15 min	0.20 min
Vanadium	. . .	optional	0.07–0.12

[A] For Class 3 rings with wall thickness over 2½ in. (63.5 mm) drawing size, the nickel content shall be 0.85–2.0 %.

TABLE 2 Tensile and Notch Toughness Requirements

Class	Tensile Strength min, psi (MPa)	Yield Strength (0.02 %, offset), min, psi (MPa)	Elongation in 2 in. or 50 mm, min, %	Reduction of Area, min, %	Charpy V-notch Impact Strength, Room Temperature min, ft-lbf (J)
1	70 000 (485)	45 000 (310)	18	40	15 (20)
2	90 000 (620)	65 000 (450)	20	50	25 (34)
3	110 000 (760)	80 000 (550)	18	50	20 (27)
4	120 000 (825)	95 000 (655)	18	45	35 (47)
5	130 000 (895)	110 000 (760)	16	40	30 (41)
6	140 000 (965)	125 000 (860)	14	40	30 (41)
7	150 000 (1035)	135 000 (930)	13	35	25 (34)
8	165 000 (1140)	150 000 (1035)	12	35	25 (34)

7. General Requirements

7.1 Material supplied to this specification shall conform to the requirements of Specification A 788 which outlines additional ordering information, manufacturing, requirements, testing and retesting methods, and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

7.2 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

8. Sampling

8.1 *Test Location*—Tension and notch toughness test specimens shall be taken tangentially from prolongations on one or both ends of the forging. The direction of the notch of the Charpy bars shall be radial. All test specimens shall be located at midwall and at a distance at least equal to one-half the wall thickness from the end face of the prolongation.

8.2 *Removal*—All tension and notch toughness test specimens shall be removed after final heat treatment.

9. Number of Tests and Retests

9.1 *Number of Tests*—The number of tension and notch toughness test specimens shall be as prescribed by the purchaser, but in no case shall there be less than one tension and one notch toughness test specimen for each ring.

9.2 If any test specimen fails to meet the requirements specified, two adjacent test specimens may be selected for retest without reheat-treatment if the failure was not caused by ruptures, cracks, or flakes in the steel. Both of these must meet the requirements of this specification.

9.3 If the results of the mechanical tests of any forging do not conform to the requirements specified, the manufacturer may reaustenitize the forging, but not more than once without approval of the purchaser. Forgings may be retempered without obtaining approval of the purchaser.

10. Test Methods

10.1 *Nondestructive Tests*:

10.1.1 *General Requirements*—The ring shall be free from cracks, seams, laps, shrinkage, and other injurious imperfections.

10.1.2 *Magnetic Particle Test*—Magnetic particle tests of all surfaces shall be made at the manufacturer's plant. The procedure for tests shall be in accordance with Test Method A 275/A 275M. The standards of acceptance shall be by agreement between purchasers and manufacturers.

10.1.3 *Ultrasonic Inspection*—An ultrasonic inspection shall be made at the manufacturer's plant on the machined ring in accordance with Practice A 531/A 531M. The standards of acceptance shall be by agreement between purchaser and manufacturer.

Designation: A 289/A 289M – 97 (Reapproved 2003)

Standard Specification for Alloy Steel Forgings for Nonmagnetic Retaining Rings for Generators[1]

This standard is issued under the fixed designation A 289/A 289M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers nonmagnetic alloy steel retaining ring forgings for generators.

1.2 The values stated in either inch-pound units or SI (metric) units are to be regarded separately as standards. Within the text and tables, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore each system must be used independent of the other. Combining values from the two systems may result in nonconformance with the specification.

1.3 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:*

A 342/A 342M Test Methods for Permeability of Feebly Magnetic Materials[2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

A 531/A 531M Practice for Ultrasonic Examination of Turbine-Generator Steel Retaining Rings[4]

A 788 Standard Specification for Steel Forgings, General Requirements[4]

E 45 Practice for Determining the Inclusion Content of Steel[5]

E 112 Test Method for Determining Average Grain Size[6]

E 165 Practice for Liquid Penetrant Examination[7]

3. Ordering Information and General Requirements

3.1 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines ordering information, manufacturing requirements, testing methods and retesting procedures, marking, certification, product analysis variation, and additional supplementary requirements.

3.2 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

3.3 Supplementary requirements of an optional nature are provided. They shall apply only when specified by the purchaser.

4. Manufacture

4.1 The steel shall be made by the electro-slag-remelt (ESR) process. The electrodes shall be made by either the basic electric furnace or ladle refining processes.

4.2 Sufficient discard shall be taken from each ingot to secure freedom from piping and undue segregation.

4.3 Forged rings shall be solution treated following hot working and prior to the cold expansion procedure.

4.4 Rings shall be rough machined prior to cold expansion or final heat treatment.

4.5 Rings shall be expanded by an appropriate method such as segmented dies, tapered plug, etc. in the temperature range of 60 to 390°F [15 to 200°C] in order to develop the required tensile properties.

4.6 After cold expansion, the rings shall be heated to between 575 and 750°F [300 to 400°C] at a rate not to exceed 75°F [40°C]/h, held at this temperature for 6 to 12 h, and then slow cooled to ambient temperature.

5. Chemical Requirements

5.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 shall comply with Table 1 of this specification.

5.2 *Product Analysis*—When a product analysis is performed at the request of the purchaser, the provisions of Table 1 of Specification A 788 shall apply. The analysis shall be made from a forging representing each heat.

NOTE 1—The material shown in Table 1 of A 289/A 289M was formerly known as Class C.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved April 10, 2003. Published July 2003. Originally approved in 1946. Last previous edition approved in 1997 as A 289 – 97/A 289M.

[2] *Annual Book of ASTM Standards*, Vol 03.04.

[3] *Annual Book of ASTM Standards*, Vol 01.13.

[4] *Annual Book of ASTM Standards*, Vol 01.05.

[5] *Annual Book of ASTM Standards*, Vol 04.09.

[6] *Annual Book of ASTM Standards*, Vol 04.08.

[7] *Annual Book of ASTM Standards*, Vol 03.03.

TABLE 1 Chemical Requirements

	Composition, weight %
Carbon	0.10 max
Manganese	17.5–20.0
Phosphorus	0.060 max
Sulfur	0.015 max
Silicon	0.80 max
Nickel	2.00 max
Chromium	17.5–20.0
Nitrogen	0.45-0.80
Titanium	0.10 max
Aluminum	0.04 max
Vanadium	0.25 max

6. Mechanical Properties

6.1 The rings shall conform to the tensile properties for the ordered grade listed in Table 2. The largest obtainable tension test specimen as specified in Test Methods and Definitions, A 370, shall be used.

6.2 Unless Supplementary Requirement S2 is invoked, tension tests shall be performed in the temperature range of 68 to 80°F [20 to 27°C]. The yield strength at 0.2 % offset shall not exceed the tensile strength.

6.3 Rings shall conform to the Charpy V-notch requirements of Table 2 corresponding to the ordered strength grade when tested in the temperature range specified in 6.2.

7. Electrical Properties

7.1 The permeability of the forgings at a magnetizing force of 100 oersteds shall not exceed 1.5. Test bars and testing shall be in accordance with Test Method A 342.

8. Number and Location of Tests

8.1 The number of tension tests shall be as ordered by the purchaser, but in no case shall there be less than one tension test for each ring.

TABLE 2 Room Temperature Mechanical Property Requirements

Grade	Tensile Strength, min, ksi [MPa]	0.2 % Offset Yield Strength, min, psi [MPa]	Elongation in 2 in. or 50 mm, min, %	Reduction of Area, min, %	Charpy V-Notch Energy, min. ft/lb [J]
1	145 [1000]	135 [930]	28	60	70 [95]
2	155 [1070]	145 [1000]	25	55	65 [88]
3	165 [1140]	160 [1105]	20	50	60 [81]
4	170 [1170]	165 [1140]	19	48	58 [79]
5	175 [1205]	170 [1170]	17	45	55 [75]
6	185 [1275]	180 [1240]	14	40	50 [68]
7	195 [1345]	190 [1310]	12	35	40 [54]
8	200 [1380]	195 [1345]	10	30	35 [47]

8.2 Tangentially oriented tension test samples shall be located at the midwall location of an integral prolongation forged at one or both ends of the ring, as shown in Fig. 1. The specimens shall be removed after cold working and subsequent stress relief.

8.3 A minimum of one set of three tangentially oriented Charpy V-notch specimens shall be removed from the inside diameter location of the test prolongation as shown in Fig. 1. The notch shall be aligned parallel to the longitudinal axis of the ring. The purchaser may specify the side of the specimen to be notched and that the distance of the root of the notch from the inside diameter of the ring be different from that shown in Fig. 1.

9. Metallographic Tests

9.1 The inclusion content of the material shall be determined in accordance with Method A of Practice E 45 utilizing a sample taken from the tension test location. The maximum allowable rating for any inclusion type shall be 3.0.

9.2 Grain size shall be determined according to Test Method E 112 from a sample taken from the midwall tension test location in the test prolongation. The results shall be reported for information.

9.3 A photomicrograph at a magnification of 100x shall be taken of the etched microstructure from the grain size sample and submitted with the certification data required by the specification and Specification A 788.

10. Nondestructive Tests

10.1 The ring shall be free from cracks, seams, laps, shrinkage, and other injurious defects.

10.2 An ultrasonic examination of the machined ring shall be made by the manufacturer in accordance with Practice A 531/A 531M. The acceptance criteria shall be by agreement between manufacturer and purchaser.

10.3 A liquid penetrant examination of the finished ring shall be made by the manufacturer in accordance with Practice E 165. The acceptance criteria shall be agreed to between the manufacturer and the purchaser.

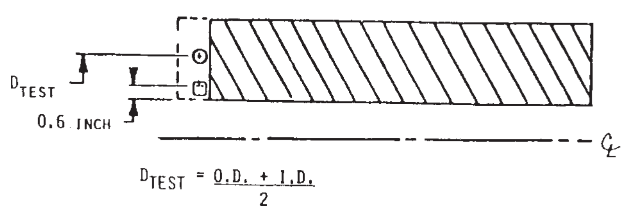

FIG. 1 Outside Diameter and Inside Diameter as Required by Drawing

11. Keywords

11.1 alloy steel; cold worked; generator retaining rings; nonmagnetic; steel forgings

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry and order. Details of these supplementary requirements shall be agreed upon between the manufacturer and the purchaser.

S1. Charpy V-Notch Impact Tests

S1.1 Requirements for energy absorption at room temperature as determined on Charpy impact specimens shall be specified by the purchaser.

S2. Alternative Elevated Temperature Tensile Requirements

S2.1 Tensile tests shall be performed at 200 to 220°F [95 to 105°C] and shall meet the requirements of Table S1.

NOTE S1—The Charpy V-Notch test temperature requirements are not altered by this requirement.

TABLE S1 Alternative Elevated Temperature Tensile Requirements (200-220°F)

Grade	Tensile Strength, min, ksi [MPa]	0.2 % Offset Yield Strength, min, psi [MPa]	Elongation, 2 in. [50 mm] min,%	Reduction of area, min,%
1	120 [830]	110 [760]	25	60
2	125 [860]	120 [830]	23	58
3	135 [930]	135 [930]	19	56
4	140 [965]	140 [965]	17	55
5	145 [1000]	145 [1000]	15	54
6	155 [1070]	155 [1070]	13	52
7	165 [1140]	165 [1140]	10	51
8	170 [1170]	170 [1170]	10	50

Designation: A 290 – 02

Standard Specification for Carbon and Alloy Steel Forgings for Rings for Reduction Gears[1]

This standard is issued under the fixed designation A 290; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers normalized and tempered, and quenched and tempered carbon and alloy steel forged or rolled rings for reduction gears.

1.2 Several grades and classes of steel are covered as follows:

1.2.1 Grade 1 Classes A and B, Grade 2 Classes C and D are carbon steel.

1.2.2 Grade 3 Classes E and F, Grade 4 Classes G, H, I, J, K and L, Grade 5 Classes M and P, and Grade 6 Class T are alloy steel.

1.2.3 All grades and classes are considered weldable under proper conditions. Welding techniques are of fundamental importance and it is presupposed that welding procedure and inspection will be in accordance with proper methods for the class of material used.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A275M Test Method for Magnetic Particle Examination of Steel Forgings[2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

A 388/A388M Practice for Ultrasonic Examination of Heavy Steel Forgings[2]

A 788 Specification for Steel Forgings, General Requirements[2]

3. Terminology

3.1 *Definitions*—Definitions of the terms used may be found in Specification A 788.

4. Ordering Information and General Requirements

4.1 In addition to the ordering information required by Specification A 788, the purchaser shall specify in the inquiry, contract, and order the grade and class desired and the supplementary requirements, if any, which should apply.

4.2 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

5. Materials and Manufacture

5.1 *Melting Process*:

5.1.1 The steel shall be produced by any of the melting requirements in Specification A 788, which may be supplemented by Supplementary Requirement S6, Vacuum Degassing.

5.2 *Discard*—Sufficient discard shall be taken from each ingot to secure freedom from piping and undue segregation.

5.3 *Forging Process*—The forgings shall receive their hot mechanical work in accordance with the requirements of Specification A 788.

5.4 *Heat Treatment*:

5.4.1 *Cooling Prior to Heat Treatment*— After forging and before reheating for heat treatment, the forgings shall be allowed to cool in a manner to prevent injury, to accomplish transformation, and prevent flakes.

5.4.2 Heat treatment shall consist of normalizing and tempering for Grade 1 classes A and B and quenching and tempering for all other grades and classes.

5.4.2.1 *Normalizing*—A furnace charge thus treated is termed a normalizing charge.

5.4.2.2 *Quenching*—The forgings shall be completely austenitized and then quenched in a suitable medium. A group thus treated is termed a quenching charge.

5.4.2.3 *Tempering*—A furnace charge thus treated is termed a tempering charge. Minimum tempering temperatures shall be as follows:

Grade and Class	Minimum Tempering Temperature °F	(°C)
Grade 1 Classes A and B	1200	(650)

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved September 2002. Published June 2003. Originally published as A 290 – 46 T. Last previous edition A 290 – 95 (1999).

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

***A Summary of Changes section appears at the end of this standard.**

Grade and Class	Minimum Tempering Temperature °F	(°C)
Grade 2 Classes C & D, E, F, G, H, M, P	1100	(595)
Grade 3 Classes E & F	1100	(595)
Grade 4 Classes G & H	1100	(595)
Grade 5 Classes M & P	1100	(595)
Grade 4 Classes I, J, K & L	1050	(565)
Grade 6 Class T	1000	(540)

5.5 *Machining*:

5.5.1 Rough machining before heat treatment for mechanical properties may be performed at the option of the producer.

5.5.2 The forgings shall conform to the sizes and shapes specified by the purchaser.

6. Chemical Composition

6.1 *Composition*—The steel shall conform to the requirements for chemical composition prescribed in Table 1. Alternative compositions may be agreed upon in accordance with Supplementary Requirement S1.1.

6.1.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 shall comply with Table 1.

6.1.2 *Product Analysis*—An analysis may be made by the purchaser from a forging representing each heat. Samples for analysis may be taken from the forging or from a full-size prolongation at any point midway between the inner and outer surfaces of the ring or samples may be taken from the test specimen. The chemical composition thus determined shall not vary from the requirements prescribed in Table 1 by more than the amounts prescribed in Specification A 788.

7. Mechanical Properties

7.1 *Tension and Impact Test Requirements*—The requirements for tensile and impact properties shall be as prescribed in Table 2.

7.1.1 *Number, Location, and Orientation of Test Specimens*—On classes requiring tension tests, two tension test specimens and two sets of impact tests shall be taken 180° apart from a full-size prolongation left on one end of each individual forging or both ends of each multiple forging. The test specimens shall be in a tangential direction at midwall of the ring as close as practical to the end of the rough-machined forging face.

7.1.2 *Test Method*—Full-size tension and Charpy V-notch impact tests shall be conducted in accordance with Test Methods and Definitions A 370.

7.2 *Brinell Hardness*—Forgings shall be within the hardness ranges specified in Table 2. The permissible variation of hardness in any forging shall not exceed 30 numbers for all classes except Classes K and L which shall be 40 numbers.

7.2.1 *Number and Location of Tests*—Brinell hardness tests shall be taken on each forging, regardless of weight or class, after final heat treatment and final machining to dimensions shown on the drawing submitted with the purchase order. Each test shall be approximately ¼ of the radial thickness from the outside diameter. The number and location of the hardness tests follows:

Outside Diameter, in. (cm)	Number of Tests
To 40 (102)	1 on each end 180° apart
40 to 80 (102 to 203)	2 on each end 180° apart
80 to 120 (203 to 305)	3 on each end 120° apart
Over 120 (305)	4 on each end 90° apart

7.2.2 *Test Method*—Tests shall be made in accordance with Test Methods and Definitions A 370.

8. Workmanship, Finish, and Appearance

8.1 The forgings shall conform to the sizes and shapes specified by the purchaser, shall be free from injurious defects, and shall have a workmanlike finish.

9. Retests

9.1 If the results of the tension tests do not conform to the requirements specified because a flaw develops in the test specimen during testing, a retest shall be allowed if the defect is not caused by flakes in the steel.

10. Inspection

10.1 The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector, without charge, all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests and inspection shall be made at the place of manufacture prior to

TABLE 1 Chemical Requirements

Element	Composition, %					
	Grade 1 Classes A and B	Grade 2 Classes C and D	Grade 3 Classes E and F	Grade 4 Classes G, H, I, J, K, and L	Grade 5 Classes M and P	Grade 6 Class T
Carbon	0.35–0.50	0.40–0.50	0.35–0.45	0.35–0.45	0.38–0.45	0.25–0.39
Manganese	0.60–0.90	0.60–0.90	0.70–1.00	0.60–0.90	0.40–0.70	0.20–0.60
Phosphorus, max	0.040	0.040	0.040	0.040	0.040	0.015
Sulfur, max	0.040	0.040	0.040	0.040	0.040	0.015
Silicon[A], max	0.35	0.35	0.35	0.35	0.40	0.35
Nickel	0.30 max	0.30 max	0.50 max	1.65–2.00	0.30 max	3.25–4.00
Chromium	0.25 max	0.25 max	0.80–1.15	0.60–0.90	1.40–1.80	1.25–1.75
Molybdenum	0.10 max	0.10 max	0.15–0.25	0.20–0.50	0.30–0.45	0.30–0.70
Vanadium, max	0.06	0.06	0.06	0.10	0.03	0.05–0.15
Copper, max	0.35	0.35	0.35	0.35	0.35	0.35
Aluminum	. . .	. . .	. . .	. . .	0.85–1.30	. . .

[A] When vacuum carbon deoxidation is used, silicon maximum shall be 0.10 %.

TABLE 2 Mechanical Requirements

Grade	Class	Tensile Strength, min, psi (MPa)	Yield Strength, 0.2 % Offset, min, psi (MPa)	Elongation in 2 in. or 50 mm, min, %	Reduction in Area, min, %	Brinell Hardness Range	Charpy V-Notch at 70 to 80°F (21 to 27°C), ft·lbf (J)
1	A	80 000 (550)	45 000 (310)	22	45	163 to 202	10 (14)
1	B	...	...	...	...	163 to 202	...
2	C	95 000 (655)	65 000 (450)	20	40	197 to 241	10 (14)
2	D	...	...	...	...	197 to 241	...
3	E	105 000 (725)	75 000 (515)	20	45	223 to 269	30 (41)
3	F	...	...	...	...	223 to 269	...
4	G	125 000 (860)	100 000 (690)	15	42	262 to 311	30 (41)
4	H	...	...	...	...	262 to 311	...
4	I	145 000 (1000)	120 000 (825)	14	40	302 to 352	25 (34)
4	J	...	...	...	...	302 to 352	...
4	K	170 000 (1175)	145 000 (1000)	10	35	341 to 401	20 (27)
4	L	...	...	...	...	341 to 401	...
5	M	120 000 (825)	85 000 (585)	15	40	255 to 302	8 (11)
5	P	...	...	...	...	255 to 302	...
6	T	170 000 (1175)	140 000 (960)	10	30	352 to 401	25 (34)

shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

11. Rejection

11.1 Unless otherwise specified, any rejection based on tests made in accordance with Section 7 shall be reported to the manufacturer within 60 working days from the receipt of samples by the purchaser.

11.2 Material that shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected and the manufacturer shall be notified.

12. Certification

12.1 The certification requirements of Specification A 788 shall apply together with a manufacturer's certification that the material was manufactured and tested in accordance with this specification.

13. Product Marking

13.1 In addition to the marking requirements of Specification A 788, identification marks shall be legibly stamped on each forging. The purchaser may indicate the desired location of such identification marks.

14. Keywords

14.1 alloy steel forgings; carbon steel forgings; gear rings; heat-treated; reduction gears

SUPPLEMENTARY REQUIREMENTS

These requirements shall not be considered unless specified in the order in which event the supplementary tests specified in S1 to S3 shall be made at the mill, unless otherwise agreed upon, and witnessed by the purchaser's inspector before shipment of the material.

S1. Chemical Requirements

S1.1 Alternate compositions may be agreed upon between the manufacturer and the purchaser.

S2. Machining

S2.1 Rough machining prior to heat treatment for mechanical properties may be specified by the purchaser.

S3. Nondestructive Testing

S3.1 Magnetic particle tests may be specified by agreement between manufacturer and purchaser and if required should be in accordance with Test Method A 275/A 275M.

S3.2 Ultrasonic tests may be specified by agreement between manufacturer and purchaser and if required should be in accordance with Practice A 388/A 388M.

S4. Restricted Chemistry—Vanadium

S4.1 The vanadium content shall be 0.03 % maximum for Classes A, B, C, and D when determined in accordance with S1 and .

S5. Restricted Chemistry—Phosphorus

S5.1 Phosphorus shall not exceed 0.015 %, and sulfur shall not exceed 0.018 % for all Classes when determined in accordance with 6.1.1 or at the locations specified in 6.1.2.

S6. Vacuum Degassing

S6.1 The molten steel shall be vacuum treated, prior to or during pouring of the ingot to remove objectionable gases, particularly hydrogen.

SUMMARY OF CHANGES

(1) Added grades for all classes
(2) Incorporated A 788
(3) Deleted reference to E 44
(4) Deleted Table 2

Standard Specification for Steel Forgings, Carbon and Alloy, for Pinions, Gears and Shafts for Reduction Gears[1]

This standard is issued under the fixed designation A 291; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers normalized and tempered carbon steel and quenched and tempered alloy steel forgings for pinions, gears, and shafts.

1.2 Several grades of steel are covered as follows:

1.2.1 *Grade 1 Class A* is normalized and tempered carbon steel.

1.2.2 *Grade 2 Class B, Grade 3 Class C, Grade 3A Class D, Grades 4 to 7 Classes E, F, G, and H, Grade 8 Class I, and Grade 9 Class J* are liquid quenched and tempered alloy steel.

1.3 All grades and classes are considered weldable under proper conditions. Welding technique is of fundamental importance and it is presupposed that welding procedure and inspection shall be in accordance with approved methods for the class of material used.

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings[2]

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings[2]

A 788 Specification for Steel Forgings, General Requirements[2]

3. Ordering Information

3.1 Instructions for purchasing forgings to this specification should be in accordance with Specification A 788. In addition, a detailed drawing, sketch, or written description of the forging should be included with the inquiry or order.

3.2 Supplementary requirements are provided and shall apply only when specified in the purchase order.

4. Heat Treatment

4.1 *Preliminary Heat Treatment*:

4.1.1 The forgings shall be given such preliminary heat treatment as is proper for the design and composition. The forgings shall be heated to a suitable temperature for a sufficient length of time for austenitization and shall be suitably cooled to bring about complete transformation.

4.1.2 Forgings may be immediately treated for mechanical properties after preliminary heat treatment or may be rough turned prior to treatment for mechanical properties.

4.2 *Heat Treatment for Mechanical Properties*—The forging shall be reheated to a temperature above the upper critical temperature and held a sufficient length of time for complete austenitization. Grade 1 shall be air cooled while Grades 2 through 9 shall be liquid quenched.

4.3 *Tempering*—The forgings shall be tempered to develop the specified properties. Minimum tempering temperatures shall be as follows:

Grade	Class	Minimum Tempering Temperature °F	(°C)
1 and 2	A and B	1150	(620)
3, 3A, and 4	C, D, and E	1075	(580)
5, 6, 7	F, G, and H	1050	(565)
8	I	1100	(595)
9	J	1000	(540)

The charge shall be cooled under uniform conditions in the furnace at a maximum rate of 100°F (55°C) per h to 600°F (316°C).

4.4 *Stress Relief*—If the manufacturer elects to heat treat for mechanical properties prior to machining, the forgings shall be stress relieved after machining (4.5) at a temperature that is 50 to 100°F (28 to 55°C) below the last previous tempering temperature but in no case below 1000°F (540°C). The forgings shall be cooled under uniform conditions in the furnace at a maximum rate of 100°F (55°C)/h to 600°F (316°C).

4.5 *Machining*:

4.5.1 Rough machining before heat treatment for mechanical properties may be performed at the option of the manufacturer.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

***A Summary of Changes section appears at the end of this standard.**

4.5.2 If the producer elects to heat treat for mechanical properties prior to machining, the forgings shall be stress relieved after machining.

4.5.3 *Boring*—Forgings, after being heat treated for mechanical properties and subsequently bored, shall be stress relieved.

5. General Requirements

5.1 Unless otherwise specified herein, the requirements of Specification A 788 shall apply to forgings supplied to this specification.

6. Chemical Requirements

6.1 The steel shall conform to the requirements for chemical composition prescribed in Table 1.

6.2 The limits for elements other than carbon, manganese, phosphorus, sulfur, and silicon in Grade 2 alloy shall be agreed upon between the manufacturer and purchaser.

7. Mechanical Requirements

7.1 *Tensile and Impact Requirements*:

7.1.1 The material shall conform to the requirements for tensile and impact properties prescribed in Table 2 and impact properties (see S2) when agreed upon between the purchaser and the supplier.

7.1.2 *Classification*—The nominal or specified rough-machined diameter or thickness of solid forgings, disregarding large ends, collars and flanges, or the nominal rough-machined wall thickness of bored forgings shall determine the size classification.

7.1.3 *Number, Location, and Orientation of Test Specimens*:

7.1.3.1 At least one tension test specimen either longitudinal or tangential at the option of the manufacturer shall be taken from each forging unless a number of forgings are forged and treated in multiple, in which case one tension test specimen shall be taken from each end of the multiple forging. When impact tests are specified in accordance with Supplementary Requirement S2, one set of impact tests shall also be taken from each end of the multiple forging. When agreed upon between the manufacturer and the purchaser, forgings weighing less than 500 lb (227 kg) each (rough-machined weight) may be tested in lots; the number of forgings to make up a lot shall be by mutual agreement.

7.1.3.2 Tension and impact test specimens shall be taken from an extension of the main body of the forging, or from a full-size prolongation left on one end of each individual forging or on both ends of the multiple forging if the forgings are made in multiple. The nominal or specified outside rough-machined diameter or thickness of the forgings, disregarding large ends, collars and flanges, shall determine the size of prolongations for test specimens.

7.1.3.3 The axis of the longitudinal tension test specimen shall be located at any point 1¼ in. (31.75 mm) below the surface of the forging. The axis of the tangential test specimen shall be located as near to the surface of the forging as practicable.

7.2 *Brinell Hardness*:

7.2.1 The material shall conform to the requirements for hardness as prescribed in Table 2. Brinell hardness tests shall be made on prepared areas on the forgings after machining to the sizes ordered by the purchaser and after stress relieving if stress relieving is required.

7.2.2 *Number and Location of Tests*—On each forging 8 in. (203 mm) and over in diameter, four Brinell hardness tests shall be made on the outside surface of that portion of the forging on which teeth will be cut, two tests being made on each helix 180° apart and the tests on the two helices shall be 90° apart. On each forging under 8 in. in diameter, two Brinell hardness tests shall be made, one on each helix 180° apart. Hardness tests shall be performed at the quarter-face width of the tooth portion diameter. On shaft forgings, two hardness tests shall be made on each end 180° apart.

8. Retreatment

8.1 If the results of the mechanical tests of any forging do not conform to the specified requirements, the manufacturer may retreat the forging one or more times, but not more than three additional times without approval of the purchaser.

9. Dimensions and Tolerance

9.1 The forgings shall conform to the dimensions and tolerances specified on the purchaser's drawing or order.

TABLE 1 Chemical Requirements

Element	Composition, %						
	Grade 1 Class A	Grade 2 Class B	Grade 3 Class C	Grade 3A Class D	Grades 4 to 7 Classes E, F, G, and H	Grade 8 Class I	Grade 9 Class J
Carbon	0.55 max	0.50 max	0.45 max	0.45 max	0.35–0.50	0.38–0.45	0.25–0.39
Manganese	0.60–0.90	0.40–0.90	0.40–0.90	0.40–0.90	0.40–0.90	0.40–0.70	0.20–0.60
Phosphorus, max	0.040	0.040	0.040	0.040	0.040	0.040	0.015
Sulfur, max	0.040	0.040	0.040	0.040	0.040	0.040	0.015
Silicon[A], max	0.35	0.35	0.35	0.35	0.35	0.40	0.35
Nickel	0.30 max	[B]	0.50 max	1.00–3.00	1.65 min	0.30 max	3.25–4.00
Chromium	0.25 max	[B]	1.25 max	1.50 max	0.60 min	1.40–1.80	1.25–1.75
Molybdenum	0.10 max	[B]	0.15 min	0.15 min	0.20–0.60	0.30–0.45	0.30–0.70
Vanadium, max	0.06	0.10	0.05	0.10	0.10	0.03	0.05–0.15
Copper, max	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Aluminum	. . .	. . .	. . .	. . .	. . .	0.85–1.30	. . .

[A] When vacuum carbon deoxidation is used, silicon maximum shall be 0.10 %.
[B] Optional with manufacturer and purchaser.

TABLE 2 Mechanical Properties

Grade	Class	Size, Solid Diameter or Thickness, in.[A] Over	Not Over	Tensile Strength, min psi	MPa	Yield Strength, 0.2% Offset, min psi	MPa	Elongation in 2 in. or 50 mm, min, % Longitudinal	Transverse (Tangential)	Reduction of Area, min, % Longitudinal	Transverse (Tangential)	Charpy V-notch	Brinell Hardness Number Range
1	A	...	10	85 000	585	50 000	345	22	...	45	...	. . .	170 to 223
		10	...	80 000	550	45 000	310	20	16	37	30		
2	B	...	10	95 000	655	70 000	485	20	...	45	...	. . .	201 to 241
		10	20	95 000	655	70 000	485	20	18	45	34		
		20	...	95 000	655	70 000	485	18	16	38	30		
3, 3A	C, D	...	10	105 000	725	80 000	550	19	...	45	...	. . .	223 to 262
		10	20	105 000	725	80 000	550	19	16	45	32		
		20	...	105 000	725	80 000	550	18	14	38	30		
4	E	...	10	120 000	825	95 000	655	16	...	40	...	. . .	248 to 293
		10	20	120 000	825	95 000	655	14	12	35	30		
		20	...	115 000	795	90 000	620	13	10	33	25		
5	F	...	10	140 000	965	115 000	795	16	...	40	...	. . .	285 to 331
		10	20	135 000	930	110 000	760	14	12	35	30		
		20	...	130 000	905	105 000	725	12	10	30	25		
6	G	...	10	145 000	1000	120 000	825	15	...	40	...	. . .	302 to 352
		10	20	140 000	965	115 000	795	14	12	35	30		
		20	...	135 000	930	110 000	760	12	10	30	25		
7	H	...	10	170 000	1375	140 000	960	14	...	35	...	. . .	341 to 415
		10	20	165 000	1140	135 000	930	12	10	30	25		
		20	...	160 000	1105	130 000	905	10	10	25	25		
8	I	...	10	120 000	825	85 000	585	15	...	40	...		255 to 302
9	J	20	. . .	170 000	1175	140 000	960	10	10	30	30	25	352 to 401

[A] 10 in. = 250 mm. 20 in. = 500 mm.

10. Certification and Reports

10.1 Material test reports as specified in Specification A 788 are required and shall include the final austenitizing and tempering temperatures, holding times, and methods of cooling.

11. Marking, Packaging, and Loading

11.1 Each forging shall be legibly stamped by the manufacturer with the manufacturer's name or trademark, the manufacturer's serial number, ASTM designation A 291, followed by the appropriate class number. The purchaser may indicate the desired location of such identification information.

11.2 Packaging and loading shall be done so the forging is not damaged during shipment to the purchaser.

12. Keywords

12.1 alloy steel forgings; carbon steel forgings; gear forgings; gear shaft forgings; heat-treated; pinion forgings

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser on the order and agreed to by the manufacturer.

S1. Rough Turning and Boring

S1.1 The position of rough turning and boring in the sequence of manufacturing operations is specified.

S2. Impact Tests

S2.1 Impact tests shall be made. The specimens shall be machined and tested with minimum properties and test temperatures specified as follows. The Charpy V-notch test temperature should be 70 to 80°F (21 to 27°C).

Grade	Class	Charpy V-Notch, ft·lbf (J), 70°F (21°C) min Longitudinal	Transverse (Tangential)
1	A	10 (13)	8 (11)
2	B	10 (13)	8 (11)
3	C	30 (40)	20 (27)
3A	D	30 (40)	20 (27)
4	E	30 (40)	20 (27)
5	F	25 (34)	15 (20)
6	G	25 (34)	15 (20)
7	H	20 (27)	10 (13)
8	I	8 (11)	. . .

S3. Nondestructive Examination

S3.1 Magnetic particle examination may be specified in accordance with Test Method A 275/A 275M.

S3.2 Ultrasonic examination may be specified in accordance with Practice A 388/A 388M.

S4. Phosphorus

S4.1 Phosphorus shall not exceed 0.015 %, and sulfur shall not exceed 0.018 % for all classes.

S5. Vacuum Degassing

S5.1 The molten steel shall be vacuum treated prior to, or during, pouring of the ingot, to remove objectionable gases, particularly hydrogen.

APPENDIX

(Nonmandatory Information)

X1. PREVIOUS CLASSES AND CORRESPONDING CURRENT GRADES

Previous Class	Current Grade	Current Class
Class 1	Grade 1	Class A
Class 2	Grade 2	Class B
Class 3	Grade 3	Class C
Class 3A	Grade 3A	Class D
Class 4	Grade 4	Class E
Class 5	Grade 5	Class F
Class 6	Grade 6	Class G
Class 7	Grade 7	Class H
Class 8	Grade 8	Class I
Class 9	Grade 9	Class J

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since the last issue (A 291 – 02) that may impact the use of this standard (approved Apr. 10, 2003).

(1) Test Method A 370 was removed from Section 2.
(2) The term "Classes" was changed to "Grades" throughout the standard.
(3) Table 2, "Product Analysis," was removed.
(4) Appendix was added.

Committee A01 has identified the location of selected changes to this standard since the last issue (A 291 – 99) that may impact the use of this standard (approved June 10, 2002).

(1) The vanadium content in Table 1 is revised for Class 3.

Designation: A 295 – 98

Standard Specification for High-Carbon Anti-Friction Bearing Steel[1]

This standard is issued under the fixed designation A 295; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers high-carbon bearing-quality steel to be used in the manufacture of anti-friction bearings.

1.2 Supplementary requirements of an optional nature are provided and when desired shall be so stated in the order.

1.3 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products[3]

A 892 Guide for Defining and Rating the Microstructure of High Carbon Bearing Steels[2]

E 45 Practice for Determining the Inclusion Content of Steel[4]

E 381 Method of Macroetch Testing, Inspection, and Rating Steel Products, Comprising Bars, Billets, Blooms, and Forgings[4]

E 1019 Test Methods for Determination of Carbon, Sulfur, Nitrogen, Oxygen, and Hydrogen in Steel and in Iron, Nickel, and Cobalt Alloys[5]

E 1077 Test Method for Estimating the Depth of Decarburization of Steel Specimens[4]

2.2 *Other Documents:*

SAE J418a Grain Size Determination of Steel[6]

ISO 683, Part 17 Ball and Roller Bearing Steels[7]

3. Ordering Information

3.1 Orders for material under this specification should include the following information:

3.1.1 Quantity,

3.1.2 Grade identification,

3.1.3 Specification designation and year of issue,

3.1.4 Dimensions, and

3.1.5 Supplementary requirements, if included.

4. Process

4.1 The steel shall be made by a process that is capable of providing a high quality product meeting the requirements of this specification.

5. Chemical Composition and Analysis

5.1 Typical examples of chemical compositions are shown in Table 1. Other compositions may be specified.

5.2 An analysis of each heat of steel shall be made by the steel manufacturer in accordance with Test Methods, Practices, and Terminology A 751. The chemical composition thus determined shall conform to the requirements specified in Table 1 for the ordered grade or to other requirements agreed upon between manufacturer and purchaser.

5.3 Product analysis may be made by the purchaser in accordance with Test Methods, Practices, and Terminology A 751. Permissible variations in product analysis shall be in accordance with Specification A 29/A 29M.

6. Sizes, Shapes, and Dimensional Tolerances

6.1 The physical size and shape of the material shall be agreed upon between manufacturer and purchaser.

6.2 Dimensional tolerances for hot-rolled or hot-rolled and annealed bars, in straight lengths or coils, and cold-finished bars 0.500 in. (12.7 mm) and larger in diameter furnished under this specification shall conform to the requirements specified in the latest edition of Specification A 29/29M.

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.28 on Bearing Steels.

Current edition approved Dec. 10, 1998. Published February 1999. Originally published as A 295 – 46 T. Last previous edition A 295 – 94.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] *Annual Book of ASTM Standards,* Vol 03.06.

[6] Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

[7] Available from International Organization for Standardization (ISO), 1 rue de Varembé, Case postale 56, CH-1211, Genève 20, Switzerland.

TABLE 1 Composition[A,B]

Element	52100[C]	5195	UNS K19526	1070M	5160
Carbon	0.93-1.05	0.90-1.03	0.89-1.01	0.65-0.75	0.56-0.64
Manganese	0.25-0.45	0.75-1.00	0.50-0.80	0.80-1.10	0.75-1.00
Phosphorus (max)	0.025	0.025	0.025	0.025	0.025
Sulfur (max)	0.015	0.015	0.015	0.015	0.015
Silicon	0.15-0.35	0.15-0.35	0.15-0.35	0.15-0.35	0.15-0.35
Chromium	1.35-1.60	0.70-0.90	0.40-0.60	0.20 (max)	0.70-0.90
Nickel (max)	0.25	0.25	0.25	0.25	0.25
Copper (max)	0.30	0.30	0.30	0.30	0.30
Molybdenum	0.10 (max)	0.10 (max)	0.08-0.15	0.10 (max)	0.10 (max)
Aluminum (max) (total)	0.050	0.050	0.050	0.050	0.050
Oxygen (max)[D]	0.0015	0.0015	0.0015	0.0015	0.0015

[A] Elements not quoted shall not be intentionally added to the steel without the agreement of the purchaser.
[B] Intentional additions of calcium or calcium alloys for deoxidation or inclusion shape control are not permitted unless specifically approved by the purchaser.
[C] Specified element ranges meet the requirements of ISO 683, Part 17, Table 3, NO. B1, 100CR6.
[D] Oxygen content applies to product analysis and shall be determined in accordance with Test Method E 1019.

6.3 Dimensional tolerances for cold-finished coils for ball and roller material shall be as shown in Table 2.

6.4 Coil tolerances also apply to cold-finished straight lengths under 0.500 in. in diameter.

7. Quality Tests

7.1 The supplier shall be held responsible for the quality of the material furnished and shall make the necessary tests to ensure this quality. The supplier shall be required to report results of the macroetch and micro-inclusion rating tests detailed below. Quality tests shown in 7.2 through 7.4 are based upon procedures established in Practice E 45.

7.2 *Sampling*—Samples taken in accordance with the following paragraphs shall be obtained from 4 by 4-in. (102 by 102-mm) rolled billets or forged sections. Tests may be made on smaller or larger sections by agreement between manufacturer and purchaser. A minimum 3 to 1 reduction of rolled billets or forged sections is required for strand cast products.

7.2.1 For top poured products, a minimum of six samples representing the top and bottom of the first, middle, and last usable ingots shall be examined.

7.2.2 For bottom poured products, a minimum of six samples shall be examined and they shall represent the top and bottom of three ingots. One ingot shall be taken at random from the first usable plate poured, one ingot, at random, from the usable plate poured nearest to the middle of the heat, and one ingot, at random, from the last usable plate poured. When two usable plates constitute a heat, two of the sample ingots shall be selected from the second usable plate poured. Where a single usable plate constitutes a heat, any three random ingots may be selected. Other methods of sampling shall be as agreed upon between manufacturer and purchaser.

7.2.3 For strand cast products, a minimum of six samples representing the first, middle, and last portion of the heat cast shall be examined. At least one sample shall be taken from each strand.

TABLE 2 Dimensional Tolerances for Cold-Finished Coils

Size, in. (mm)	Total Tolerance, in. (mm)
Through 0.096 (2.44)	0.002 (0.05)
Over 0.096 (2.44) to 0.270 (6.86), incl	0.003 (0.08)
Over 0.270 (6.86) to 0.750 (19.1), incl	0.004 (0.10)

7.3 *Macroetch*—Specimens representative of cross sections of billets shall be macroetched and rated in accordance with Method E 381 in hydrochloric acid and water (1:1) at 160 to 180°F (71 to 82°C). Such specimens shall not exceed S2, R2, and C2 of Method E 381.

7.4 *Inclusion Rating*—The specimens shall be ⅜ by ¾ in. (9.5 by 19.1 mm) and shall be taken from an area halfway between the center and outside of the billet. The polished face shall be longitudinal to the direction of rolling. The scale used for rating the specimens shall be the Jernkontoret chart described in Practice E 45, Plate I-r. Fields with sizes or numbers of all types of inclusions intermediate between configurations shown on the chart shall be classified as the lesser of the rating number. The worst field of each inclusion type from each specimen shall be recorded as the rating for the specimen. Two thirds of all specimens and at least one from each ingot tested, or from the first, middle, and last portion of the strands tested, as well as the average of all specimens, shall not exceed the rating specified in Table 3. If specifically ordered and certified to Supplementary Requirement S4, Type A inclusion ratings shall not exceed 3.0 thin and 2.0 heavy. See S4.1.

8. Grain Size

8.1 The steels covered by this specification shall have the capability of showing a fine fracture grain size (approximately ASTM No. 8) (SAE J418a) when quenched from normal austenitizing temperatures not exceeding 1550°F (843°C).

9. Decarburization and Surface Imperfections

9.1 Decarburization and surface imperfections shall not exceed the limits specified in Table 4 and Table 5. Decarburization shall be measured using the microscopical methods described in Test Method E 1077.

TABLE 3 Inclusion Rating

Rating Units	
Thin Series	Heavy Series
A—2½	A—1½
B—2	B—1
C—½	C—½
D—1	D—1

TABLE 4 Decarburization and Surface Imperfections for Coils and Bars for Balls and Rollers

Size, in. (mm)	Decarburization or Surface Imperfections per Side, max, in. (mm)	
	Hot-Rolled or Hot-Rolled Annealed	Cold-Finished Annealed
Through 0.250 (6.35)	0.005 (0.13)	0.003 (0.08)
Over 0.250 (6.35) to 0.500 (12.7), incl	0.006 (0.15)	0.004 (0.10)
Over 0.500 (12.7) to 0.750 (19.1), incl	0.008 (0.20)	0.006 (0.15)
Over 0.750 (19.1) to 1.000 (25.4), incl	0.010 (0.25)	0.008 (0.20)

TABLE 5 Decarburization and Surface Imperfections for Bars and Tubes

Size, in. (mm)	Decarburization or Surface Imperfections per Side, max, in. (mm)				
	Hot-Rolled Bars	Hot-Rolled Annealed		Cold-Finished Annealed	
		Bars	Tubes	Bars	Tubes
Through 1.000 (25.4)	0.012 (0.30)	0.015 (0.38)	0.012 (0.30)	0.012 (0.30)	0.010 (0.25)
Over 1.000 (25.4) to 2.000 (50.8), incl	0.017 (0.43)	0.022 (0.56)	0.020 (0.51)	0.015 (0.38)	0.014 (0.36)
Over 2.000 (50.8) to 3.000 (76.2), incl	0.025 (0.64)	0.030 (0.76)	0.030 (0.76)	0.025 (0.64)	0.019 (0.48)
Over 3.000 (76.2) to 4.000 (101.6), incl	0.035 (0.89)	0.045 (1.14)	0.035 (0.89)		0.024 (0.61)
Over 4.000 (101.6) to 5.000 (127.0), incl	0.055 (1.40)	0.065 (1.65)	0.040 (1.02)		0.028 (0.71)

10. Microstructure

10.1 When annealing is specified in the order, the structure shall be rated and reported in accordance with Guide A 892 as follows:

10.1.1 *Carbide Size (CS)*—As the appropriate carbide size is dependent on application, the limits shall be as agreed upon between manufacturer and purchaser.

10.1.2 *Carbide Network (CN)*—As the network is influenced by section size, the limits shall be as agreed upon between manufacturer and purchaser.

10.1.3 *Lamellar Content (LC)*—52100 steels shall have a lamellar content not to exceed LC1. Lamellar content of other compositions shall be as agreed upon between manufacturer and purchaser.

10.2 The material shall be free from excessive carbide segregation.

11. Hardness

11.1 When annealing is specified in the order, the steel shall have a completely spheroidized microstructure and a hardness as specified in Table 6.

11.2 Small sizes where Rockwell B scale hardness readings are impractical shall have a maximum tensile strength of 110 000 psi (760 MPa).

11.3 Hardness and tensile tests shall be in accordance with test methods described in Test Methods and Definitions A 370.

TABLE 6 Maximum Hardness for Annealed Material

Product	Condition	Maximum Hardness	
		Brinell	Rockwell B
Coils	hot-rolled, annealed	. . .	92
Bars and tubes	hot-rolled annealed	207	. . .
Coils	annealed, cold-drawn (stress-relieved)	. . .	92
Coils, bars, and tubes	annealed, cold-drawn[A]	248	. . .
Tubes	annealed, cold-rocked	331	. . .

[A] Cold-swaged material is not included.

12. Inspection

12.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Mill inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspections shall be made at the place of manufacture, unless otherwise agreed to.

13. Certification and Reports

13.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification, together with a report of the test results, shall be furnished at the time of shipment. Special requirements agreed to at the time of purchase shall be noted on the certification.

SUPPLEMENTARY REQUIREMENTS

One or more of the supplementary requirements described below apply when included in the purchaser's order or contract. When so included, a supplementary requirement shall have the same force as if it were in the body of the specification. Supplementary requirements' details not fully described shall be agreed upon between the purchaser and the supplier, but shall not negate any of the requirements in the body of the specification.

S1. Titanium Content

S1.1 The purchaser may specify that the analysis of titanium be provided by agreement with the steel manufacturer.

S2. "SAM" Inclusion Rating System

S2.1 The purchaser may specify that the "SAM" inclusion rating system described in Method E of Practice E 45, be used in addition to the micro-inclusion rating system described in 7.4.

S2.2 *Sampling*—See 7.2.

S2.3 *Limits*—The "SAM" rating for B-type inclusions shall not exceed fifteen. The "SAM" rating for D-type inclusions shall not exceed ten.

S3. Magnetic Particle Method

S3.1 The purchaser may specify that the magnetic particle method described below be used in addition to the micro-inclusion rating system described in 7.4. The magnetic particle method measures bearing steel cleanliness by evaluating the total length of macro-inclusions for a stated area or per unit area. Results are commonly expressed in millimeters per square metre.

S3.2 *Sampling*—See 7.2.

S3.3 Test specimens shall be straight cylinder quarter section samples prepared and examined in accordance with the magnetic particle method of Practice E 45.

S3.4 For purposes of calculation, an inclusion length shall be taken as the mean length of the length bracket into which it falls; that is, an inclusion in the 1⁄16 to 1⁄8 in. bracket shall be taken as being 3⁄32 in. in length. The sum of all lengths for each specimen shall be determined and expressed as total length per area inspected. The average total length per area inspected of all six specimens shall not exceed 200 mm/m^2 (or equivalent).

S4. Sulfur Requirement for Machinability

S4.1 A sulfur content in the range of 0.015–0.030 % may be specified for improved machinability.

S4.2 When this supplementary requirement is specified, the sulfide (Type A) ratings of 7.4 shall be 3.0 thin and 2.0 heavy.

S4.3 The manufacturer's certification shall state that material was produced to this supplementary requirement when applicable.

S5. Sample Reduction Ratio

S5.1 For the sampling described in 7.2, the purchaser may specify that the reduction ratio from as-cast section to test section be provided.

Designation: A 304 – 04

An American National Standard

Standard Specification for Carbon and Alloy Steel Bars Subject to End-Quench Hardenability Requirements[1]

This standard is issued under the fixed designation A 304; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers hot-worked alloy, carbon, and carbon-boron steels in a variety of compositions and sizes which may attain specified depth of hardening in the end quench test. These steel compositions are identified by the suffix letter "H" added to the conventional grade number.

1.2 This specification provides for analyses other than those listed under Table 1 and Table 2. Special hardenability limits are also permissible when approved by the purchaser and manufacturer.

1.3 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought, General Requirements for

A 255 Test Method for End-Quench Test for Hardenability of Steel

E 112 Test Methods for Determining Average Grain Size

E 527 Practice for Numbering Metals and Alloys (UNS)

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *hardenability*—The relative ability of a steel to harden under heat treatment becomes apparent in the degree to which the material hardens when quenched at different cooling rates. It is measured quantitatively, usually by noting the extent or depth of hardening of a standard size and shape test specimen in a standardized quench. In the "end-quench" test the "depth of hardening" is the distance along the specimen from the quenched end to a given hardness.

4. Ordering Information

4.1 Orders for material under this specification should include the following information, in proper sequence:

4.1.1 Quantity (weight),

4.1.2 Name of material (alloy, carbon, or carbon-boron steel),

4.1.3 Cross-sectional shape,

4.1.4 Size,

4.1.5 Length,

4.1.6 Grade,

4.1.7 End-quenched hardenability (see Section 9),

4.1.8 Report of heat analysis, if desired (see Section 7),

4.1.9 Special straightness, if required,

4.1.10 ASTM designation and date of issue,

4.1.11 End use or special requirements, and

4.1.12 Leaded steel, when required.

NOTE 1—A typical ordering description is as follows: 10 000 lb, alloy bars, round, 4.0 in. dia by 10 ft, Grade 1340H, J 40/56 = 6⁄16 in., heat analysis required, ASTM A 304, dated ________, worm gear.

4.2 The purchaser shall specify the desired grade, including the suffix letter "H," in accordance with Table 1 or Table 2.

4.3 Band limits are shown graphically and as tabulations in Figs. 2-87, inclusive. For specifications purposes, the tabulated values of Rockwell C hardness are used. Values below 20 Rockwell C hardness (20 HRC) are not specified because such values are below the normal range of the C scale. The graphs are shown for convenience in estimating the hardness values obtainable at various locations on the end quench test bar and for various locations in oil or water quenched rounds. The relationship between end-quench distance and bar diameter is approximate and should be used only as a guide.

4.4 Two points from the tabulated values are commonly designated according to one of Methods A, B, C, D, or E, which are defined in the following paragraphs. Those various methods are illustrated graphically in Fig. 1.

4.4.1 *Method A*—The minimum and maximum hardness values at any desired distance. This method is illustrated in Fig. 1 as points *A-A* and would be specified as 43 to 54 HRC at J3.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

Current edition approved March 1, 2004. Published April 2004. Originally approved in 1947. Last previous edition approved in 2002 as A 304 – 02.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard.**

Obviously the distance selected would be that distance on the end quench test bar which corresponds to the section used by the purchaser.

4.4.2 *Method B*—The minimum and maximum distances at which any desired hardness value occurs. This method is illustrated in Fig. 1 as points *B- B* and would be specified as 39 HRC at J4 minimum and J9 maximum. If the desired hardness does not fall on an exact sixteenth position, the minimum distance selected should be the nearest sixteenth position toward the quenched end and the maximum should be the nearest sixteenth position away from the quenched end.

4.4.3 *Method C*—Two maximum hardness values at two desired distances, illustrated in Fig. 1 as points *C-C*.

4.4.4 *Method D*—Two minimum hardness values at two desired distances, illustrated in Fig. 1 as points *D-D*.

4.4.5 *Method E*—Any minimum hardness plus any maximum hardness. When hardenability is specified according to one of the above Methods A to E, the balance of the hardenability band is not applicable.

4.5 In cases when it is considered desirable, the maximum and minimum limits at a distance of $\frac{1}{16}$ in. from the quenched end can be specified in addition to the other two points as previously described in 4.4.1 to 4.4.5, inclusive.

4.6 In cases when it is necessary to specify more than two points on the hardenability band (exclusive of the maximum and minimum limits at a distance of $\frac{1}{16}$ in.), a tolerance of two points Rockwell C (HRC) over any small portion of either curve (except at a distance of $\frac{1}{16}$ in.) is customary. This tolerance is necessary because curves of individual heats vary somewhat in shape from the standard band limits and thus deviate slightly at one or more positions in the full length of the curves.

5. Manufacture

5.1 *Melting Practice*—The steel shall be made by one or more of the following primary processes: open-hearth, basic-oxygen, or electric-furnace. The primary melting may incorporate separate degassing or refining and may be followed by secondary melting using electroslag remelting or vacuum arc remelting. Where secondary melting is employed, the heat shall be defined as all of the ingots remelted from a single primary heat.

5.2 *Slow Cooling*—Immediately after hot working, the bars shall be allowed to cool when necessary to a temperature below the critical range under suitable conditions, to prevent injury by too rapid cooling.

6. General Requirements

6.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 29/A 29M, unless otherwise provided for herein.

7. Chemical Composition

7.1 The heat analysis shall conform to the requirements as to chemical composition prescribed in Table 1 and Table 2 for the grade specified by the purchaser.

7.2 When a steel cannot be identified by a standard grade number in accordance with Table 1 and Table 2, other compositions may be specified, as agreed upon between the purchaser and the manufacturer. Generally, hardenability bands will not be available for such compositions.

7.3 When requested by the manufacturer, and approved by the purchaser, other steels capable of meeting the purchaser's specified hardenability may be furnished in place of the grade specified by the purchaser.

8. Grain Size Requirements

8.1 The steel shall conform to the fine austenitic grain size requirement of Specification A 29/A 29M.

8.2 Hardenability values specified herein are based on fine-grain steels and are not applicable to coarse-grain material. In case coarse-grain steel is desired, the hardenability values shall be negotiated between the purchaser and the manufacturer.

9. End-Quench Hardenability Requirements

9.1 The end-quench hardenability shall conform to the requirements specified on the purchase order.

9.2 The hardenability values shall be specified in accordance with the applicable values in Figs. 2-87 inclusive for the grade specified. See Fig. 1 for method of specifying hardenability.

9.3 When agreed upon between the purchaser and manufacturer, special hardenability limits may be ordered and shall be reflected on the purchase order.

10. Test Specimens

10.1 *Number and Location*—The number and location of test specimens shall be in accordance with the manufacturer's standard practice and shall adequately represent the hardenability of each heat.

10.2 *Thermal Treatment*—All forged or rolled hardenability test specimens must be normalized prior to testing. Cast specimens need not be normalized.

11. Test Methods

11.1 *Grain Size*—Test Methods E 112.

11.2 *End-quench Hardenability*—Test Method A 255.

12. Certification and Reports of Testing

12.1 When the full H-band is specified for alloy steels, the hardenability can be reported by listing hardness values at the following distances from the quenched end of the test specimen: 1 through 16 sixteenths, then 18, 20, 22, 24, 28, and 32 sixteenths of an inch.

12.2 Tables 2-18 in Test Methods A 255 are to be used to calculate hardenability from the chemical ideal diameter for the grades shown in 10.1 of Test Methods A 255. Hardenability results are to be reported for the first 10 sixteenths (16 mm), then 12, 14, 16, 18, 20, 24, 28, and 32 sixteenths of an inch.

NOTE 2—The reporting hardenability using the calculated method differs from the procedure shown in 6.4 of Test Methods A 255.

12.3 For carbon H-steels, distances from the quenched end may be reported by listing sixteenths or half sixteenths (rather than full sixteenths only as with alloy steels). Units of sixteenths rather than thirty-seconds are followed for all steels to avoid misunderstanding. When the full H-band is specified half sixteenths through 8 may be reported, as well as the distances listed in 12.1.

13. Keywords

13.1 alloy steel bars; carbon steel bars; end quench hardenability; steel bars

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this specification since the last issue, A 304 - 96, that may impact the use of this specification.

(1) New section 12.2 added.

(2) Previous section 12.2 renumbered as 12.3.

TABLE 1 Chemical Requirements of Alloy H Steels[A]

NOTE 1— Phosphorus and sulfur in open-hearth steel is 0.035 %, max, and 0.040 %, max respectively. Phosphorus and sulfur in electric-furnace steel (designated by the prefix letter "E") is 0.025 %, max.

NOTE 2—Small quantities of certain elements are present in alloy steels which are not specified or required. These elements are considered as incidental and may be present to the following maximum amounts: copper, 0.35 %; nickel, 0.25 %; chromium, 0.20 %; molybdenum, 0.06 %.

NOTE 3—Chemical ranges and limits shown in this table are subject to the permissible variation for product analysis shown in Specification A 29/A 29M.

NOTE 4—Standard "H" Steels can be produced with a lead range of 0.15–0.35 %. Such steels are identified by inserting the letter "L" between the second and third numerals of the grade designation, for example, 41L40H. Lead is generally reported as a range of 0.15–0.35 %.

UNS Designation[A]	Grade Designation	Chemical Composition, %					
		Carbon	Manganese	Silicon	Nickel	Chromium	Molybdenum
H 13300	1330 H	0.27–0.33	1.45–2.05	0.15–0.35	...	...	...
H 13350	1335 H	0.32–0.38	1.45–2.05	0.15–0.35	...	...	...
H 13400	1340 H	0.37–0.44	1.45–2.05	0.15–0.35	...	...	...
H 13450	1345 H	0.42–0.49	1.45–2.05	0.15–0.35	...	...	...
H 40270	4027 H	0.24–0.30	0.60–1.00	0.15–0.35	...	...	0.20–0.30
H 40280	4028 H[B]	0.24–0.30	0.60–1.00	0.15–0.35	...	...	0.20–0.30
H 40320	4032 H	0.29–0.35	0.60–1.00	0.15–0.35	...	...	0.20–0.30
H 40370	4037 H	0.34–0.41	0.60–1.00	0.15–0.35	...	...	0.20–0.30
H 40420	4042 H	0.39–0.46	0.60–1.00	0.15–0.35	...	...	0.20–0.30
H 40470	4047 H	0.44–0.51	0.60–1.00	0.15–0.35	...	...	0.20–0.30
H 41180	4118 H	0.17–0.23	0.60–1.00	0.15–0.35	...	0.30–0.70	0.08–0.15
H 41300	4130 H	0.27–0.33	0.30–0.70	0.15–0.35	...	0.75–1.20	0.15–0.25
H 41350	4135 H	0.32–0.38	0.60–1.00	0.15–0.35	...	0.75–1.20	0.15–0.25
H 41370	4137 H	0.34–0.41	0.60–1.00	0.15–0.35	...	0.75–1.20	0.15–0.25
H 41400	4140 H	0.37–0.44	0.65–1.10	0.15–0.35	...	0.75–1.20	0.15–0.25
H 41420	4142 H	0.39–0.46	0.65–1.10	0.15–0.35	...	0.75–1.20	0.15–0.25
H 41450	4145 H	0.42–0.49	0.65–1.10	0.15–0.35	...	0.75–1.20	0.15–0.25
H 41470	4147 H	0.44–0.51	0.65–1.10	0.15–0.35	...	0.75–1.20	0.15–0.25
H 41500	4150 H	0.47–0.54	0.65–1.10	0.15–0.35	...	0.75–1.20	0.15–0.25
H 41610	4161 H	0.55–0.65	0.65–1.10	0.15–0.35	...	0.65–0.95	0.25–0.35
H 43200	4320 H	0.17–0.23	0.40–0.70	0.15–0.35	1.55–2.00	0.35–0.65	0.20–0.30
H 43400	4340 H	0.37–0.44	0.55–0.90	0.15–0.35	1.55–2.00	0.65–0.95	0.20–0.30
H 43406	E4340 H	0.37–0.44	0.60–0.95	0.15–0.35	1.55–2.00	0.65–0.95	0.20–0.30
H 44190	4419 H	0.17–0.23	0.35–0.75	0.15–0.35	...	...	0.45–0.60
H 46200	4620 H	0.17–0.23	0.35–0.75	0.15–0.35	1.55–2.00	...	0.20–0.30
H 46210	4621 H	0.17–0.23	0.60–1.00	0.15–0.35	1.55–2.00	...	0.20–0.30
H 46260	4626	0.23–0.29	0.40–0.70	0.15–0.35	0.65–1.05	...	0.15–0.25
H 47180	4718 H	0.15–0.21	0.60–0.95	0.15–0.35	0.85–1.25	0.30–0.60	0.30–0.40
H 47200	4720 H	0.17–0.23	0.45–0.75	0.15–0.35	0.85–1.25	0.30–0.60	0.15–0.25
H 48150	4815 H	0.12–0.18	0.30–0.70	0.15–0.35	3.20–3.80	...	0.20–0.30
H 48170	4817 H	0.14–0.20	0.30–0.70	0.15–0.35	3.20–3.80	...	0.20–0.30
H 48200	4820 H	0.17–0.23	0.40–0.80	0.15–0.35	3.20–3.80	...	0.20–0.30
H 50401	50B40 H[C]	0.37–0.44	0.65–1.10	0.15–0.35	...	0.30–0.70	...
H 50441	50B44 H[C]	0.42–0.49	0.65–1.10	0.15–0.35	...	0.30–0.70	...

UNS Designation[A]	Grade Designation	Chemical Composition, %					
		Carbon	Manganese	Silicon	Nickel	Chromium	Molybdenum
H 50460	5046 H	0.43–0.50	0.65–1.10	0.15–0.35	...	0.13–0.43	...
H 50461	50B46 H[C]	0.43–0.50	0.65–1.10	0.15–0.35	...	0.13–0.43	...
H 50501	50B50 H[C]	0.47–0.54	0.65–1.10	0.15–0.35	...	0.30–0.70	...
H 50601	50B60 H[C]	0.55–0.65	0.65–1.10	0.15–0.35	...	0.30–0.70	...
H 51200	5120 H	0.17–0.23	0.60–1.00	0.15–0.35	...	0.60–1.00	...
H 51300	5130 H	0.27–0.33	0.60–1.10	0.15–0.35	...	0.75–1.20	...
H 51320	5132 H	0.29–0.35	0.50–0.90	0.15–0.35	...	0.65–1.10	...
H 51350	5135 H	0.32–0.38	0.50–0.90	0.15–0.35	...	0.70–1.15	...
H 51400	5140 H	0.37–0.44	0.60–1.00	0.15–0.35	...	0.60–1.00	...
H 51450	5145 H	0.42–0.49	0.60–1.00	0.15–0.35	...	0.60–1.00	...
H 51470	5147 H	0.45–0.52	0.60–1.05	0.15–0.35	...	0.80–1.25	...
H 51500	5150 H	0.47–0.54	0.60–1.00	0.15–0.35	...	0.60–1.00	...
H 51550	5155 H	0.50–0.60	0.60–1.00	0.15–0.35	...	0.60–1.00	...
H 51600	5160 H	0.55–0.65	0.65–1.10	0.15–0.35	...	0.60–1.00	...
H 51601	51B60H[C]	0.55–0.65	0.65–1.10	0.15–0.35	...	0.60–1.00	...
H 61180	6118 H[D]	0.15–0.21	0.40–0.80	0.15–0.35	...	0.40–0.80	...
H61500	6150 H[E]	0.47–0.54	0.60–1.00	0.15–0.35	...	0.75–1.20	...
H 81451	81B45 H[C]	0.42–0.49	0.70–1.05	0.15–0.35	0.15–0.45	0.30–0.60	0.08–0.15
H 86170	8617 H	0.14–0.20	0.60–0.95	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 86200	8620 H	0.17–0.23	0.60–0.95	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 86220	8622 H	0.19–0.25	0.60–0.95	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 86250	8625 H	0.22–0.28	0.60–0.95	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 86270	8627 H	0.24–0.30	0.60–0.95	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 86300	8630 H	0.27–0.33	0.60–0.95	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 86301	86B30 H	0.27–0.33	0.60–0.95	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 86370	8637 H	0.34–0.41	0.70–1.05	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 86400	8640 H	0.37–0.44	0.70–1.05	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 86420	8642 H	0.39–0.46	0.70–1.05	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 86450	8645 H	0.42–0.49	0.70–1.05	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 86451	86B45 H[C]	0.42–0.49	0.70–1.05	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 86500	8650 H	0.47–0.54	0.70–1.05	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 86550	8655 H	0.50–0.60	0.70–1.05	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 86600	8660 H	0.55–0.65	0.70–1.05	0.15–0.35	0.35–0.75	0.35–0.65	0.15–0.25
H 87200	8720 H	0.17–0.23	0.60–0.95	0.15–0.35	0.35–0.75	0.35–0.65	0.20–0.30
H 87400	8740 H	0.37–0.44	0.70–1.05	0.15–0.35	0.35–0.75	0.35–0.65	0.20–0.30
H 88220	8822 H	0.19–0.25	0.70–1.05	0.15–0.35	0.35–0.75	0.35–0.65	0.30–0.40
H 92600	9260 H	0.55–0.65	0.65–1.10	1.70–2.20	...	...	...
H 93100	9310 H	0.07–0.13	0.40–0.70	0.15–0.35	2.95–3.55	1.00–1.45	0.08–0.15
H 94151	94B15 H[C]	0.12–0.18	0.70–1.05	0.15–0.35	0.25–0.65	0.25–0.55	0.08–0.15
H 94171	94B17 H[C]	0.14–0.20	0.70–1.05	0.15–0.35	0.25–0.65	0.25–0.55	0.08–0.15
H 94301	94B30 H[C]	0.27–0.33	0.70–1.05	0.15–0.35	0.25–0.65	0.25–0.55	0.08–0.15

[A]New designations established in accordance with Practice E 527 and SAE J 1086, Recommended Practice for Numbering Metals and Alloys (UNS).
[B]Sulfur content range is 0.035 to 0.050 %.
[C]These steels can be expected to have a 0.0005 % min boron content.
[D]Vanadium content range is 0.10 to 0.15 %.
[E]Minimum vanadium content is 0.15 %.

TABLE 2 Chemical Requirements of Carbon H-Steels[A]

UNS Designation[B]	Grade Designation	Chemical Composition, %				
		Carbon	Manganese	Phosphorus, max	Sulfur, max	Silicon
H 10380	1038 H	0.34–0.43	0.50–1.00	0.040	0.050	0.15–0.30
H 10450	1045 H	0.42–0.51	0.50–1.00	0.040	0.050	0.15–0.30
H 15220	1522 H	0.17–0.25	1.00–1.50	0.040	0.050	0.15–0.30
H 15240	1524 H	0.18–0.26	1.25–1.75	0.040	0.050	0.15–0.30
H 15260	1026 H	0.21–0.30	1.00–1.50	0.040	0.050	0.15–0.30
H 15410	1541 H	0.35–0.45	1.25–1.75	0.040	0.050	0.15–0.30
H 15211[C]	15B21 H[C]	0.17–0.24	0.70–1.20	0.040	0.050	0.15–0.30
H 15351[C]	15B35 H[C]	0.31–0.39	0.70–1.20	0.040	0.050	0.15–0.30
H 15371[C]	15B37 H[C]	0.30–0.39	1.00–1.50	0.040	0.050	0.15–0.30
H 15411[C]	15B41 H[C]	0.35–0.45	1.25–1.75	0.040	0.050	0.15–0.30
H 15481[C]	15B48 H[C]	0.43–0.53	1.00–1.50	0.040	0.050	0.15–0.30
H 15621[C]	15B62 H[C]	0.54–0.67	1.00–1.50	0.040	0.050	0.40–0.60

[A] Standard H Steels can be produced with a lead range of 0.15–0.35 %. Such steels are identified by inserting the letter "L" between the second and third numerals of the grade designation, for example, 15L22 H. Lead is generally reported as a range of 0.15–0.35 %.

[B] New designations established in accordance with Practice E 527 and SAE J 1086, Recommended Practice for Numbering Metals and Alloys (UNS).

[C] These steels can be expected to have 0.0005 % min boron content.

Hardenability Band

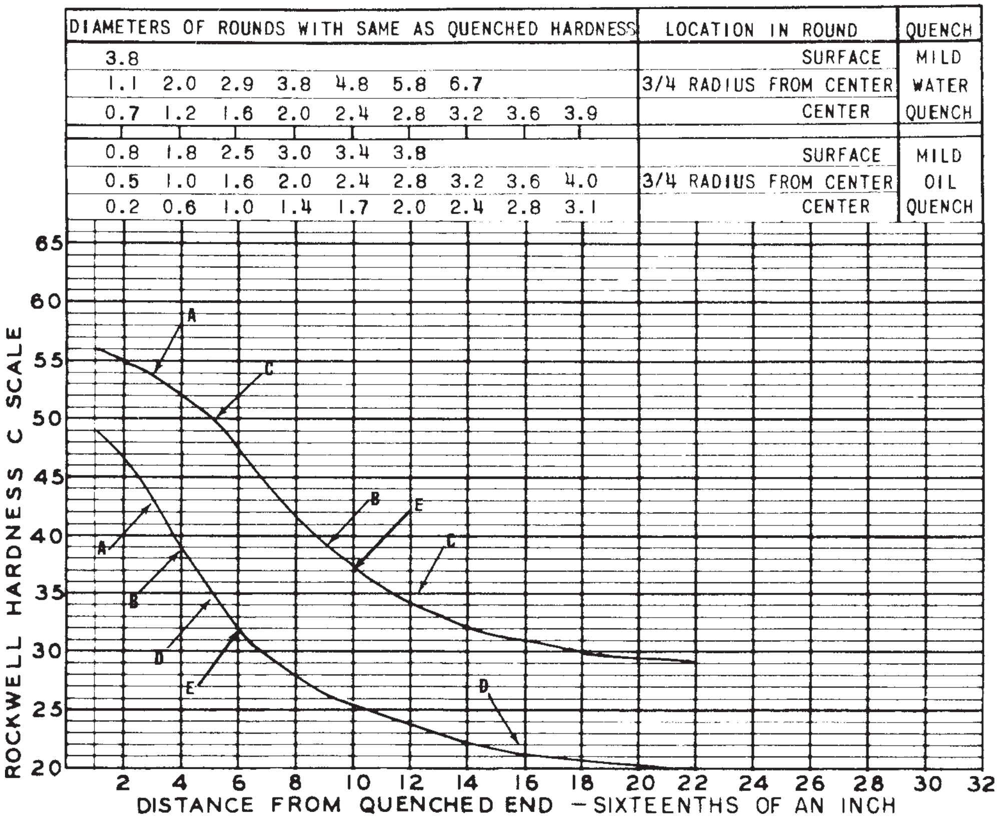


TABLE *Continued*

	Method	Points on Charts	Example—End Quench Hardenability
A	Minimum and maximum hardness values at a designated distance	A-A	HRC 43 to 54 at J3
B	A hardness value at minimum and maximum distances	B-B	HRC 39 at J4 minumum and J9 maximum
C	The maximum hardness values at two designated distances	C-C	HRC50 at J5 maximum HRC 34 at J12 maximum
D	Two minimum hardness values at two distances	D-D	HRC 35 at J5 minimum HRC 21 at J16 minimum
E	Any minimum hardness plus any maximum hardness	E-E	HRC 32 at J6 minimum HRC 37 at J10 maximum

FIG. 1 Examples Illustrating Alternative Method of Specifiying Hardenability Requirements (tabulated hardness values are used in ordering)

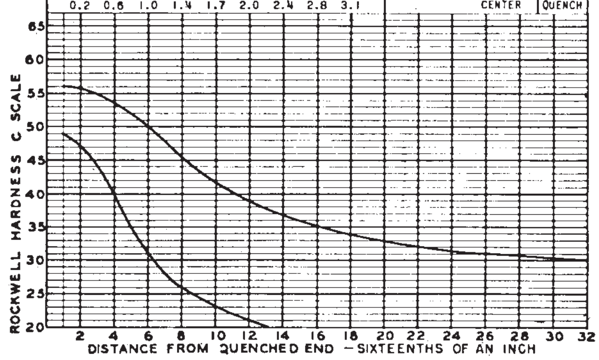
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	1330 H	
	MAX	MIN
1	56	49
2	56	47
3	55	44
4	53	40
5	52	35
6	50	31
7	48	28
8	45	26
9	43	25
10	42	23
11	40	22
12	39	21
13	38	20
14	37	-
15	36	-
16	35	-
18	34	-
20	33	-
22	32	-
24	31	-
26	31	-
28	31	-
30	30	-
32	30	

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 1330 H

C	Mn	Si			
0.27/0.33	1.45/2.05	0.15/0.35			

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD WATER QUENCH
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD OIL QUENCH
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	



NOTE—1 in. = 25.4 mm.

FIG. 2 Limits for Hardenability Band 1330 H

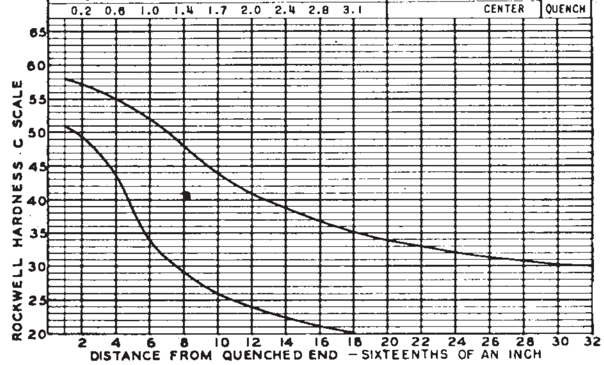
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	1335 H	
	MAX	MIN
1	58	51
2	57	49
3	56	47
4	55	44
5	54	38
6	52	34
7	50	31
8	48	29
9	46	27
10	44	26
11	42	25
12	41	24
13	40	23
14	39	22
15	38	22
16	37	21
18	35	20
20	34	-
22	33	-
24	32	-
26	31	-
28	31	-
30	30	-
32	30	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 1335 H

C	Mn	Si			
0.32/0.38	1.45/2.05	0.15/0.35			

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD WATER QUENCH
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD OIL QUENCH
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	

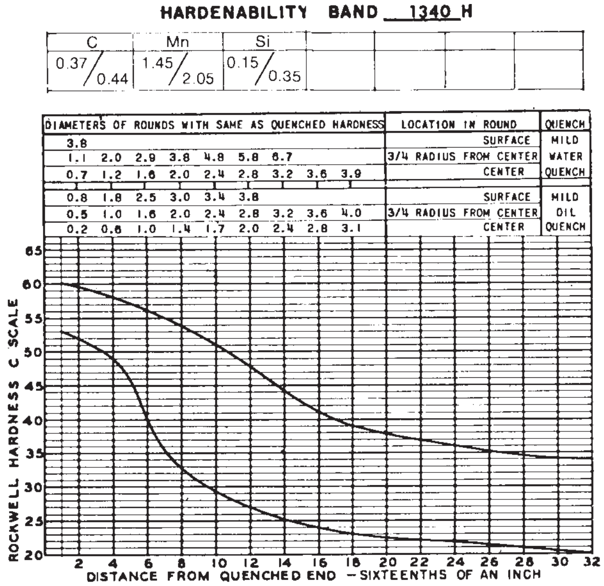


NOTE—1 in. = 25.4 mm.

FIG. 3 Limits for Hardenability Band 1335 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	1340 H	
	MAX	MIN
1	60	53
2	60	52
3	59	51
4	58	49
5	57	46
6	56	40
7	55	35
8	54	33
9	52	31
10	51	29
11	50	28
12	48	27
13	46	26
14	44	25
15	42	25
16	41	24
18	39	23
20	38	23
22	37	22
24	36	22
26	35	21
28	35	21
30	34	20
32	34	20

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

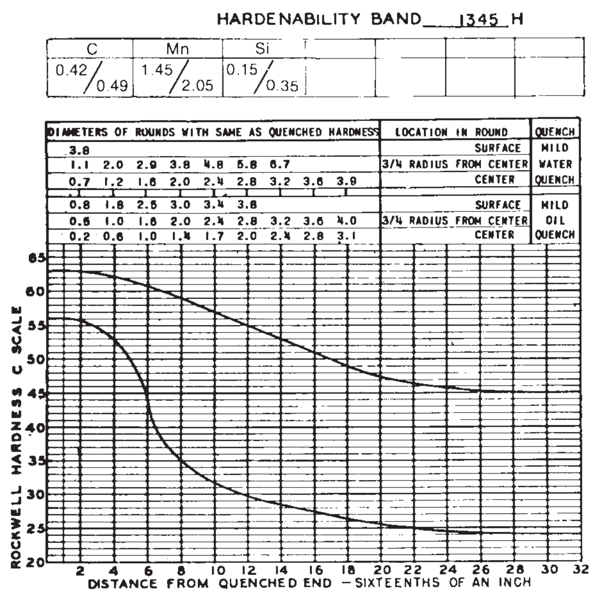


NOTE—1 in. = 25.4 mm.

FIG. 4 Limits for Hardenability Band 1340 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	1345 H	
	MAX.	MIN.
1	63	56
2	63	56
3	62	55
4	61	54
5	61	51
6	60	44
7	60	38
8	59	35
9	58	33
10	57	32
11	56	31
12	55	30
13	54	29
14	53	29
15	52	28
16	51	28
18	49	27
20	48	27
22	47	26
24	46	26
26	45	25
28	45	25
30	45	24
32	45	24

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

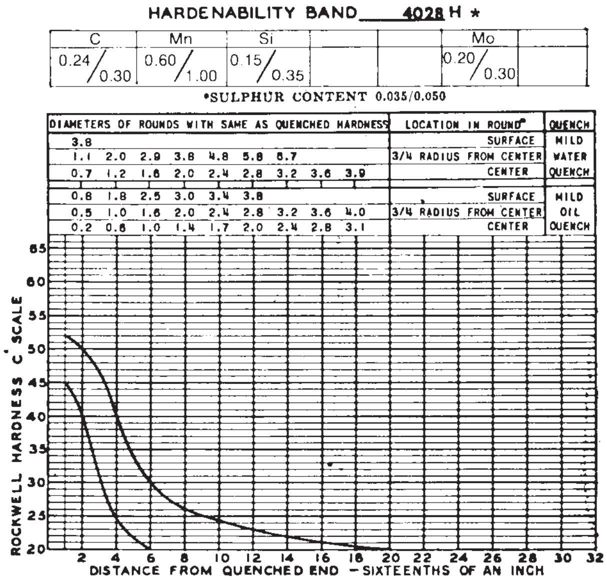


NOTE—1 in. = 25.4 mm.

FIG. 5 Limits for Hardenability Band 1345 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4027H & 4028H	
	MAX	MIN
1	52	45
2	50	40
3	46	31
4	40	25
5	34	22
6	30	20
7	28	-
8	26	-
9	25	-
10	25	-
11	24	-
12	23	-
13	23	-
14	22	-
15	22	-
16	21	-
18	21	-
20	20	-
22	-	-
24	-	-
26	-	-
28	-	-
30	-	-
32	-	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F
*For forged or rolled specimens only.

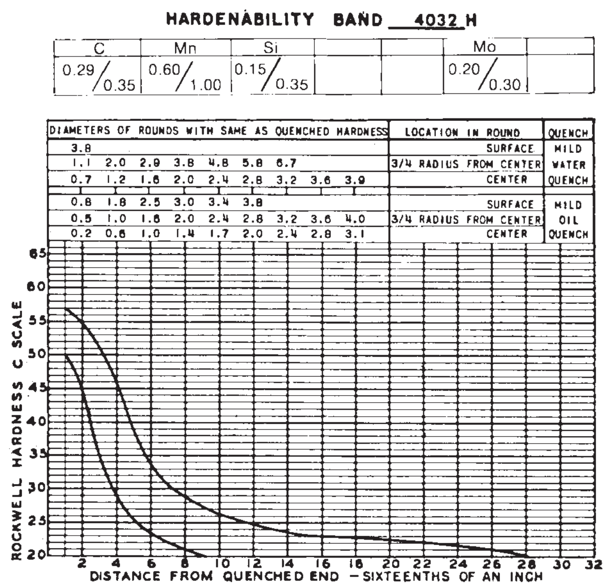


NOTE—1 in. = 25.4 mm.

FIG. 6 Limits for Hardenability Band 4027 H and 4028 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4032 H	
	MAX	MIN
1	57	50
2	54	45
3	51	36
4	48	29
5	39	25
6	34	23
7	31	22
8	29	21
9	28	20
10	26	-
11	26	-
12	25	-
13	24	-
14	24	-
15	23	-
16	23	-
18	23	-
20	22	-
22	22	-
24	21	-
26	21	-
28	20	-
30	-	-
32	-	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F
*For forged or rolled specimens only.

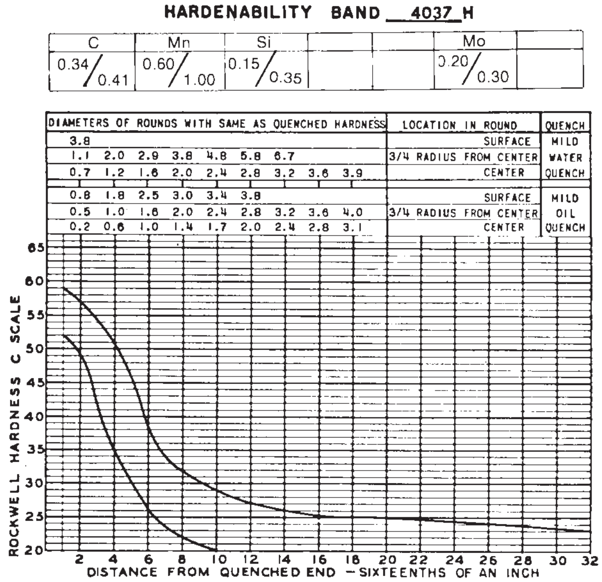


NOTE—1 in. = 25.4 mm.

FIG. 7 Limits for Hardenability Band 4032 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4037 H	
	MAX	MIN
1	59	52
2	57	49
3	54	42
4	51	35
5	45	30
6	38	26
7	34	23
8	32	22
9	30	21
10	29	20
11	28	-
12	27	-
13	26	-
14	26	-
15	26	-
16	25	-
18	25	-
20	25	-
22	25	-
24	24	-
26	24	-
28	24	-
30	23	-
32	23	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

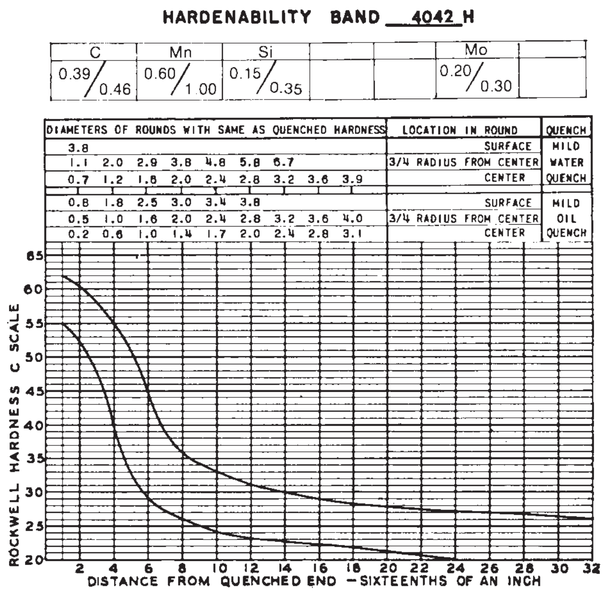


NOTE—1 in. = 25.4 mm.

FIG. 8 Limits for Hardenability Band 4037 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4042 H	
	MAX	MIN
1	62	55
2	60	52
3	58	48
4	55	40
5	50	33
6	45	29
7	39	27
8	36	26
9	34	25
10	33	24
11	32	24
12	31	23
13	30	23
14	30	23
15	29	22
16	29	22
18	28	22
20	28	21
22	28	20
24	27	20
26	27	-
28	27	-
30	26	-
32	26	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.



NOTE—1 in. = 25.4 mm.

FIG. 9 Limits for Hardenability Band 4042 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4047 H	
	MAX	MIN
1	64	57
2	62	55
3	60	50
4	58	42
5	55	35
6	52	32
7	47	30
8	43	28
9	40	28
10	38	27
11	37	26
12	35	26
13	34	25
14	33	25
15	33	25
16	32	25
18	31	24
20	30	24
22	30	23
24	30	23
26	30	22
28	29	22
30	29	21
32	29	21

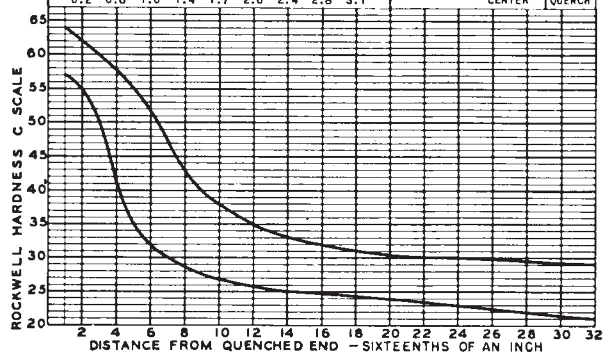
HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F

*For forged or rolled specimens only.

HARDENABILITY BAND 4047 H

C	Mn	Si			Mo	
0.44/0.51	0.60/1.00	0.15/0.35			0.20/0.30	

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD WATER QUENCH
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD OIL QUENCH
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	



NOTE—1 in. = 25.4 mm.

FIG. 10 Limits for Hardenability Band 4047 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4118 H	
	MAX	MIN
1	48	41
2	46	36
3	41	27
4	35	23
5	31	20
6	28	-
7	27	-
8	25	-
9	24	-
10	23	-
11	22	-
12	21	-
13	21	-
14	20	-
15	-	-
16	-	-
18	-	-
20	-	-
22	-	-
24	-	-
26	-	-
28	-	-
30	-	-
32	-	-

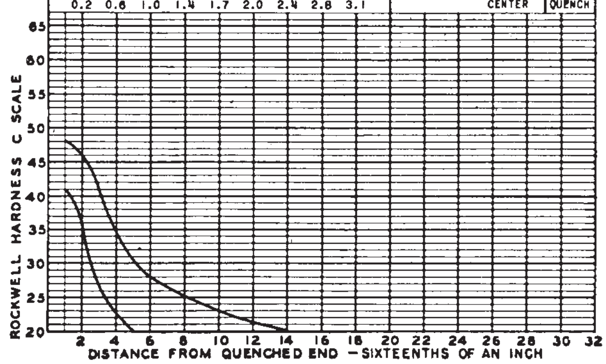
HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F

*For forged or rolled specimens only.

HARDENABILITY BAND 4118 H

C	Mn	Si		Cr	Mo	
0.17/0.23	0.60/1.00	0.15/0.35		0.30/0.70	0.08/0.15	

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD WATER QUENCH
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD OIL QUENCH
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	



NOTE—1 in. = 25.4 mm.

FIG. 11 Limits for Hardenability Band 4118 H

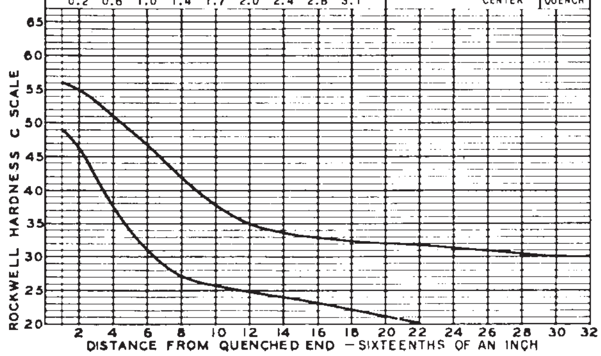
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4130 H	
	MAX	MIN
1	56	49
2	55	46
3	53	42
4	51	38
5	49	34
6	47	31
7	44	29
8	42	27
9	40	26
10	38	26
11	36	25
12	35	25
13	34	24
14	34	24
15	33	23
16	33	23
18	32	22
20	32	21
22	32	20
24	31	-
26	31	-
28	30	-
30	30	-
32	29	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 4130 H

C	Mn	Si		Cr	Mo	
0.27/0.33	0.30/0.70	0.15/0.35		0.75/1.20	0.15/0.25	

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD WATER QUENCH
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD OIL QUENCH
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	



NOTE— 1 in. = 25.4 mm.

FIG. 12 Limits for Hardenability Band 4130 H

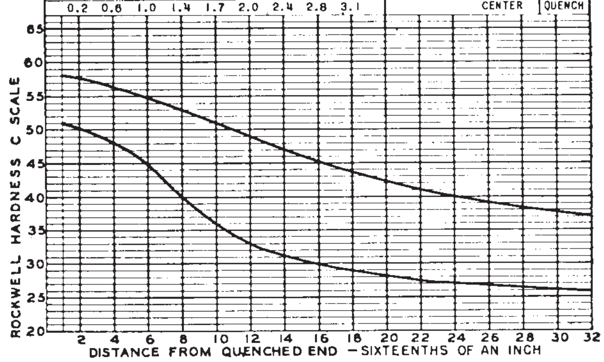
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4135 H	
	MAX	MIN
1	58	51
2	58	50
3	57	49
4	56	48
5	56	47
6	55	45
7	54	42
8	53	40
9	52	38
10	51	36
11	50	34
12	49	33
13	48	32
14	47	31
15	46	30
16	45	30
18	44	29
20	42	28
22	41	27
24	40	27
26	39	27
28	38	26
30	38	26
32	37	26

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 4135 H

C	Mn	Si		Cr	Mo	
0.32/0.38	0.60/1.00	0.15/0.35		0.75/1.20	0.15/0.25	

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD WATER QUENCH
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD OIL QUENCH
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	



NOTE— 1 in. = 25.4 mm.

FIG. 13 Limits for Hardenability Band 4135 H

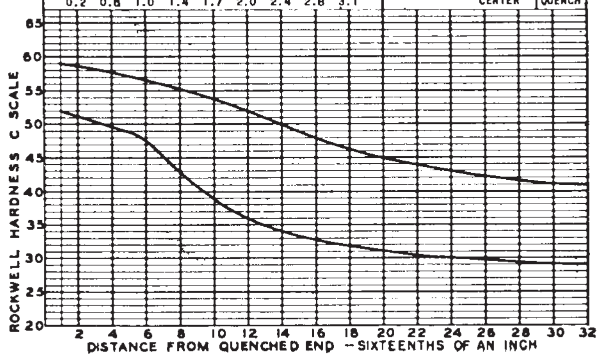
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4137 H	
	MAX	MIN
1	59	52
2	59	51
3	58	50
4	58	49
5	57	49
6	57	48
7	56	45
8	55	43
9	55	40
10	54	39
11	53	37
12	52	36
13	51	35
14	50	34
15	49	33
16	48	33
18	46	32
20	45	31
22	44	30
24	43	30
26	42	30
28	42	29
30	41	29
32	41	29

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 4137 H

C	Mn	Si		Cr	Mo
0.34/0.41	0.60/1.00	0.15/0.35		0.75/1.20	0.15/0.25

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	WATER
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	QUENCH
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	OIL
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	QUENCH



NOTE—1 in. = 25.4 mm.

FIG. 14 Limits for Hardenability Band 4137 H

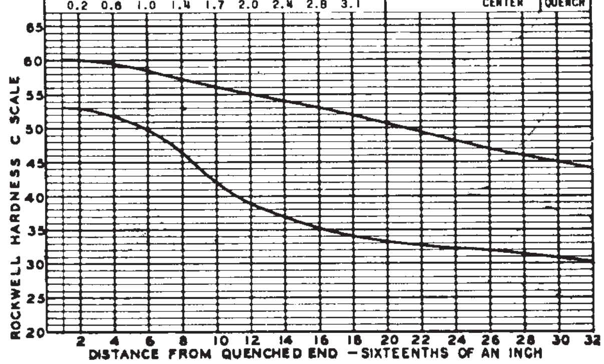
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4140 H	
	MAX	MIN
1	60	53
2	60	53
3	60	52
4	59	51
5	59	51
6	58	50
7	58	48
8	57	47
9	57	44
10	56	42
11	56	40
12	55	39
13	55	38
14	54	37
15	54	36
16	53	35
18	52	34
20	51	33
22	49	33
24	48	32
26	47	32
28	46	31
30	45	31
32	44	30

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 4140 H

C	Mn	Si		Cr	Mo
0.37/0.44	0.65/1.10	0.15/0.35		0.75/1.20	0.15/0.25

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	WATER
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	QUENCH
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	OIL
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	QUENCH



NOTE—1 in. = 25.4 mm.

FIG. 15 Limits for Hardenability Band 4140 H

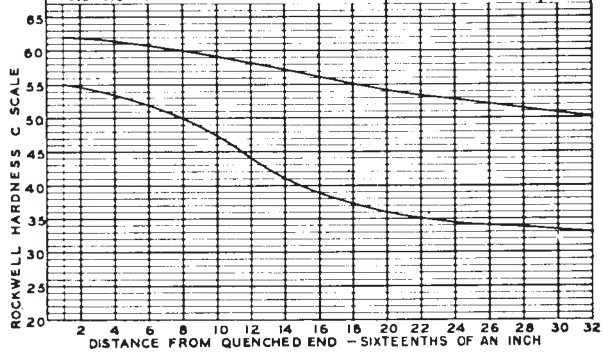
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4142 H MAX	MIN
1	62	55
2	62	55
3	62	54
4	61	53
5	61	53
6	61	52
7	60	51
8	60	50
9	60	49
10	59	47
11	59	46
12	58	44
13	58	42
14	57	41
15	57	40
16	56	39
18	55	37
20	54	36
22	53	35
24	53	34
26	52	34
28	51	34
30	51	33
32	50	33

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 4142 H

C	Mn	Si		Cr	Mo	
0.39/0.46	0.65/1.10	0.15/0.35		0.75/1.20	0.15/0.25	

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	WATER
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	QUENCH
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	OIL
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	QUENCH



NOTE—1 in. = 25.4 mm.

FIG. 16 Limits for Hardenability Band 4142 H

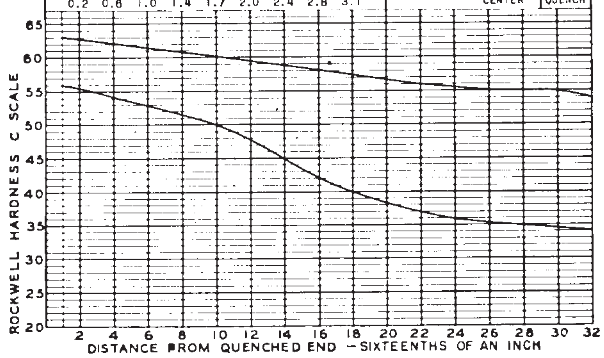
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4145 H MAX	MIN
1	63	56
2	63	55
3	62	55
4	62	54
5	62	53
6	61	53
7	61	52
8	61	52
9	60	51
10	60	50
11	60	49
12	59	48
13	59	46
14	59	45
15	58	43
16	58	42
18	57	40
20	57	38
22	56	37
24	55	36
26	55	35
28	55	35
30	55	34
32	54	34

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 4145 H

C	Mn	Si		Cr	Mo	
0.42/0.49	0.65/1.10	0.15/0.35		0.75/1.20	0.15/0.25	

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	WATER
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	QUENCH
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	OIL
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	QUENCH



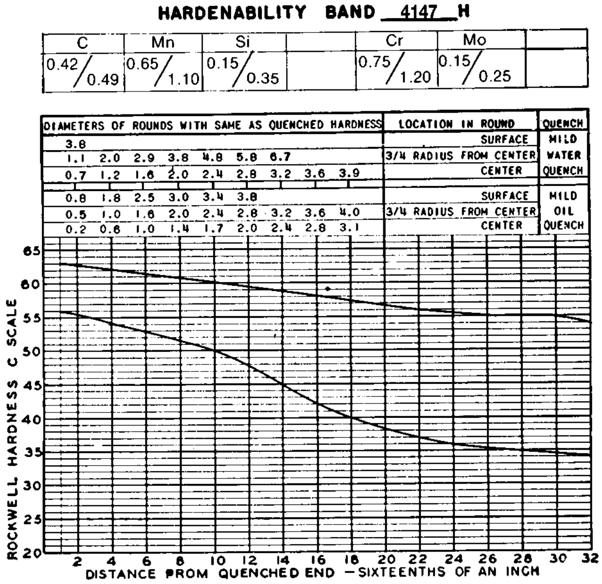
NOTE—1 in. = 25.4 mm.

FIG. 17 Limits for Hardenability Band 4145 H

"J" DISTANCE SIXTEENTHS OF AN INCH	4145 H MAX	MIN
1	63	56
2	63	55
3	62	55
4	62	54
5	62	53
6	61	53
7	61	52
8	61	52
9	60	51
10	60	50
11	60	49
12	59	48
13	59	46
14	59	45
15	58	43
16	58	42
18	57	40
20	57	38
22	56	37
24	55	36
26	55	35
28	55	35
30	55	34
32	54	34

HARDNESS LIMITS FOR SPECIFICATION PURPOSES

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.



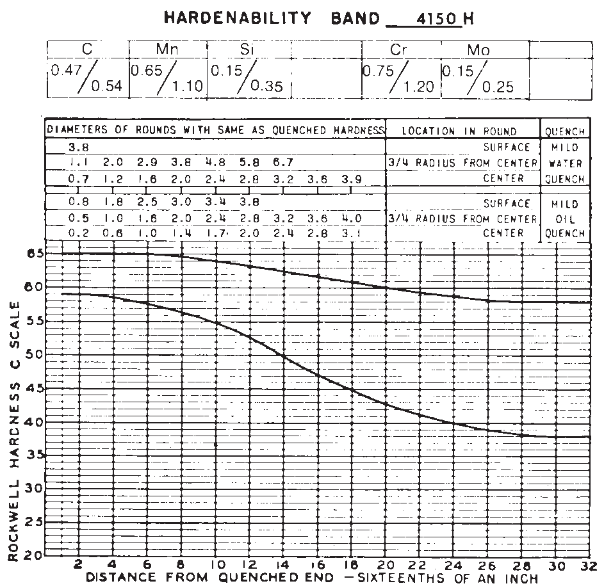
NOTE—1 in. = 25.4 mm.

FIG. 18 Limits for Hardenability Band 4147 H

"J" DISTANCE SIXTEENTHS OF AN INCH	4150 H MAX	MIN
1	65	59
2	65	59
3	65	59
4	65	58
5	65	58
6	65	57
7	65	57
8	64	56
9	64	56
10	64	55
11	64	54
12	63	53
13	63	51
14	62	50
15	62	48
16	62	47
18	61	45
20	60	43
22	59	41
24	59	40
26	58	39
28	58	38
30	58	38
32	58	38

HARDNESS LIMITS FOR SPECIFICATION PURPOSES

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.



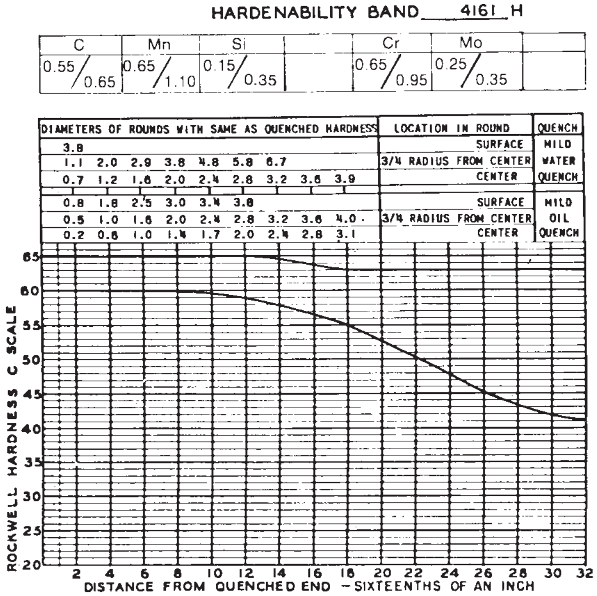
NOTE—1 in. = 25.4 mm.

FIG. 19 Limits for Hardenability Band 4150 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE, SIXTEENTHS OF AN INCH	4161 H	
	MAX.	MIN.
1	65	60
2	65	60
3	65	60
4	65	60
5	65	60
6	65	60
7	65	60
8	65	60
9	65	59
10	65	59
11	65	59
12	64	59
13	64	58
14	64	58
15	64	57
16	64	56
18	64	55
20	63	53
22	63	50
24	63	48
26	63	45
28	63	43
30	63	42
32	63	41

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F

*For forged or rolled specimens only.



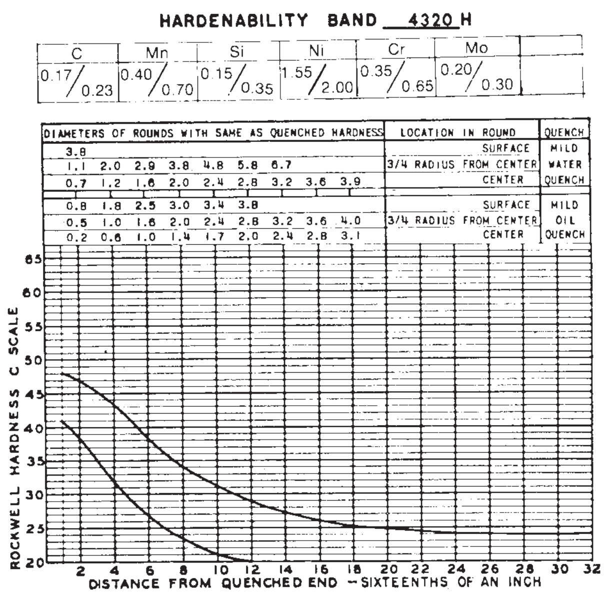
NOTE—1 in. = 25.4 mm.

FIG. 20 Limits for Hardenability Band 4161 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4320 H	
	MAX	MIN
1	48	41
2	47	38
3	45	35
4	43	32
5	41	29
6	38	27
7	36	25
8	34	23
9	33	22
10	31	21
11	30	20
12	29	20
13	28	-
14	27	-
15	27	-
16	26	-
18	25	-
20	25	-
22	24	-
24	24	-
26	24	-
28	24	-
30	24	-
32	24	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F

*For forged or rolled specimens only.

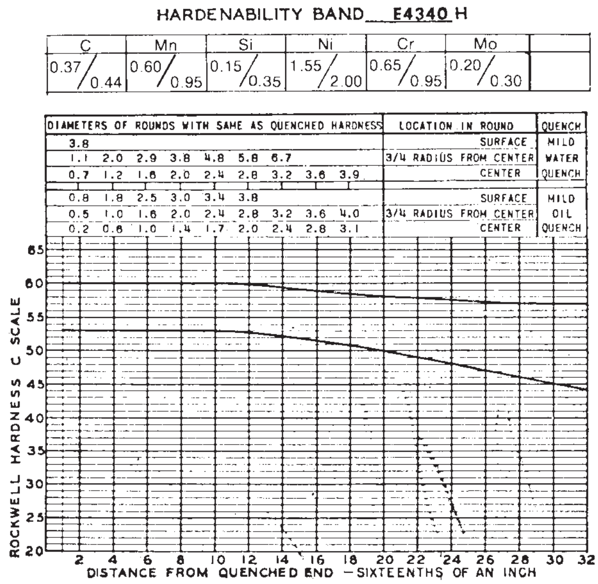


NOTE—1 in. = 25.4 mm.

FIG. 21 Limits for Hardenability Band 4320 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	E4340 H	
	MAX	MIN
1	30	53
2	60	53
3	60	53
4	60	53
5	60	53
6	60	53
7	60	53
8	60	53
9	60	53
10	60	53
11	60	53
12	60	52
13	60	52
14	59	52
15	59	52
16	59	51
18	58	51
20	58	50
22	58	49
24	57	48
26	57	47
28	57	46
30	57	45
32	57	44

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only

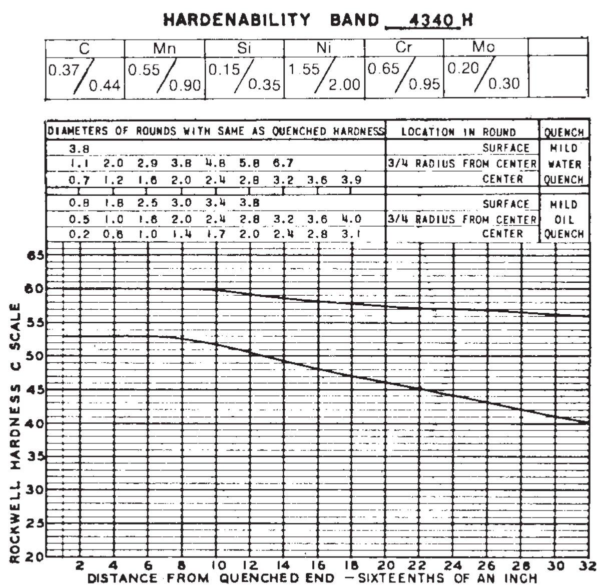


NOTE—1 in. = 25.4 mm.

FIG. 22 Limits for Hardenability Band E 4340 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4340 H	
	MAX	MIN
1	60	53
2	60	53
3	60	53
4	60	53
5	60	53
6	60	53
7	60	53
8	60	52
9	60	52
10	60	52
11	59	51
12	59	51
13	59	50
14	58	49
15	58	49
16	58	48
18	58	47
20	57	46
22	57	45
24	57	44
26	57	43
28	56	42
30	56	41
32	56	40

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.



NOTE—1 in. = 25.4 mm.

FIG. 23 Limits for Hardenability Band 4340 H

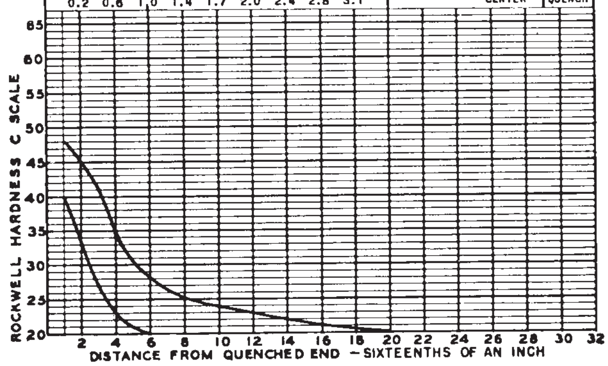
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4520 H	
	MAX.	MIN.
1	48	40
2	45	33
3	41	27
4	34	23
5	30	21
6	28	20
7	27	-
8	25	-
9	25	-
10	24	-
11	24	-
12	23	-
13	23	-
14	22	-
15	22	-
16	21	-
18	21	-
20	20	-
22	-	-
24	-	-
26	-	-
28	-	-
30	-	-
32	-	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 4419H

C	Mn	Si			Mo	
0.17/0.23	0.35/0.75	0.15/0.35			0.45/0.60	

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	WATER
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	QUENCH
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	OIL
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	QUENCH



NOTE—1 in. = 25.4 mm.

FIG. 24 Limits for Hardenability Band 4419 H

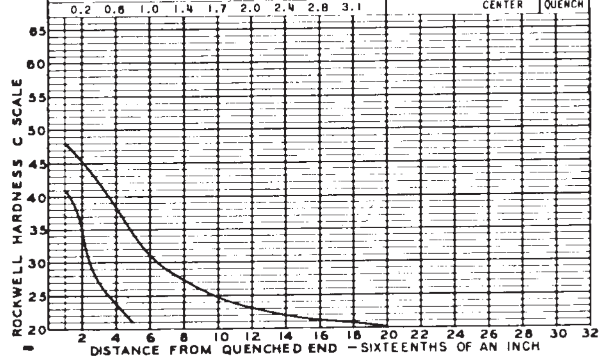
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4620 H	
	MAX	MIN
1	48	41
2	45	35
3	42	27
4	39	24
5	34	21
6	31	-
7	29	-
8	27	-
9	26	-
10	25	-
11	24	-
12	23	-
13	22	-
14	22	-
15	22	-
16	21	-
18	21	-
20	20	-
22	-	-
24	-	-
26	-	-
28	-	-
30	-	-
32	-	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 4620 H

C	Mn	Si	Ni		Mo	
0.17/0.23	0.35/0.75	0.15/0.35	1.55/2.00		0.20/0.30	

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	WATER
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	QUENCH
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	OIL
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	QUENCH

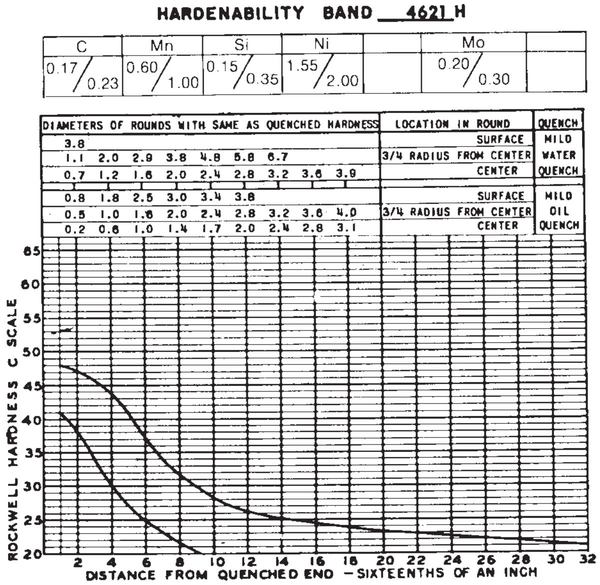


NOTE—1 in. = 25.4 mm.

FIG. 25 Limits for Hardenability Band 4620 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4621 H MAX	MIN
1	48	41
2	47	38
3	46	34
4	44	30
5	41	27
6	37	25
7	34	23
8	32	22
9	30	20
10	28	-
11	27	-
12	26	-
13	26	-
14	25	-
15	25	-
16	24	-
18	24	-
20	23	-
22	23	-
24	22	-
26	22	-
28	22	-
30	21	-
32	21	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F
*For forged or rolled specimens only.

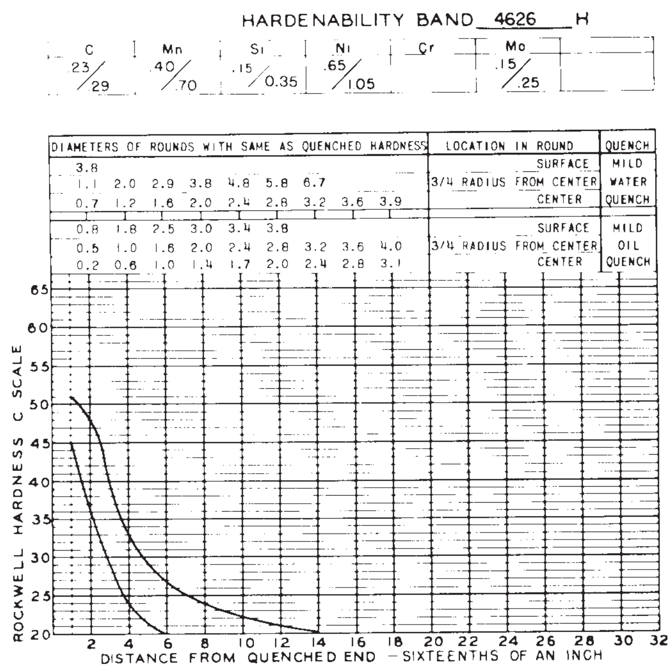


NOTE—1 in. = 25.4 mm.

FIG. 26 Limits for Hardenability Band 4621 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4626 H MAX.	MIN.
1	51	45
2	48	36
3	41	29
4	33	24
5	29	21
6	27	-
7	25	-
8	24	-
9	23	-
10	22	-
11	22	-
12	21	-
13	21	-
14	20	-
15	-	-
16	-	-
18	-	-
20	-	-
22	-	-
24	-	-
26	-	-
28	-	-
30	-	-
32	-	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F
*For forged or rolled specimens only.



NOTE—1 in. = 25.4 mm.

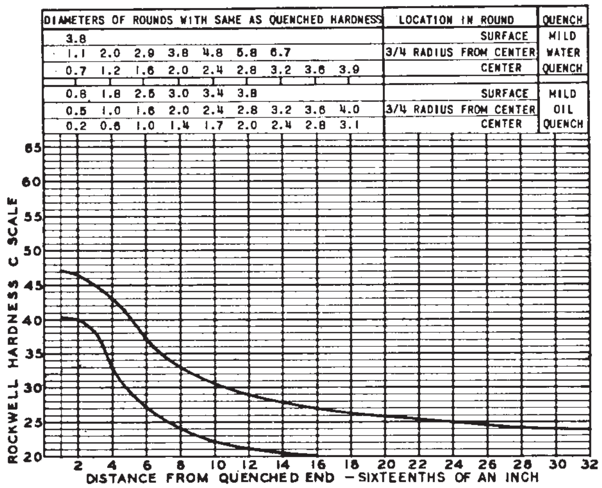
FIG. 27 Limits for Hardenability Band 4626 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4718 H MAX.	4718 H MIN.
1	47	40
2	47	40
3	46	38
4	43	33
5	40	29
6	37	27
7	35	25
8	33	24
9	32	23
10	31	22
11	30	22
12	29	21
13	29	21
14	28	21
15	27	20
16	27	20
18	27	-
20	26	-
22	26	-
24	25	-
26	25	-
28	24	-
30	24	-
32	24	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 4718H

C	Mn	Si	Ni	Cr	Mo
0.15/0.21	0.60/0.95	0.15/0.35	0.85/1.25	0.30/0.60	0.30/0.40



NOTE—1 in. = 25.4 mm.

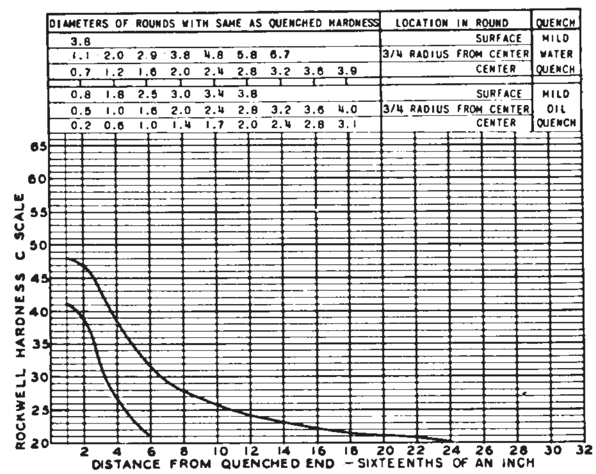
FIG. 28 Limits for Hardenability Band 4718 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4720 H MAX	4720 H MIN
1	48	41
2	47	39
3	43	31
4	39	27
5	35	23
6	32	21
7	29	-
8	28	-
9	27	-
10	26	-
11	26	-
12	24	-
13	24	-
14	23	-
15	23	-
16	22	-
18	21	-
20	21	-
22	21	-
24	20	-
26	-	-
28	-	-
30	-	-
32	-	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 4720H

C	Mn	Si	Ni	Cr	Mo
0.17/0.23	0.45/0.75	0.15/0.35	0.85/1.25	0.30/0.60	0.15/0.25



NOTE—1 in. = 25.4 mm.

FIG. 29 Limits for Hardenability Band 4720 H

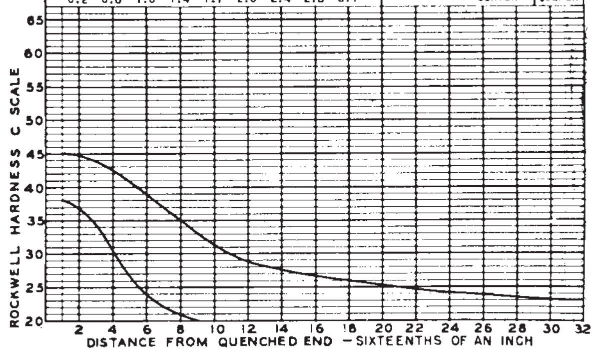
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4815 H	
	MAX	MIN
1	45	38
2	44	37
3	44	34
4	42	30
5	41	27
6	39	24
7	37	22
8	35	21
9	33	20
10	31	-
11	30	-
12	29	-
13	28	-
14	28	-
15	27	-
16	27	-
18	26	-
20	25	-
22	24	-
24	24	-
26	24	-
28	23	-
30	23	-
32	23	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 4815 H

C	Mn	Si	Ni		Mo	
0.12/0.18	0.30/0.70	0.15/0.35	3.20/3.80		0.20/0.30	

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	WATER
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	QUENCH
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	OIL
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	QUENCH



NOTE—1 in. = 25.4 mm.

FIG. 30 Limits for Hardenability Band 4815 H

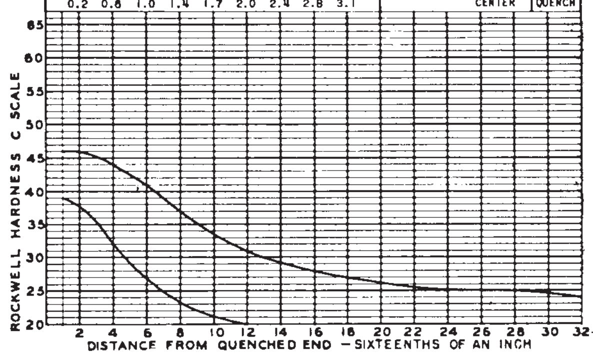
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4817 H	
	MAX	MIN
1	46	39
2	46	38
3	45	35
4	44	32
5	42	29
6	41	27
7	39	25
8	37	23
9	35	22
10	33	21
11	32	20
12	31	20
13	30	-
14	29	-
15	28	-
16	28	-
18	27	-
20	26	-
22	25	-
24	25	-
26	25	-
28	25	-
30	24	-
32	24	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 4817 H

C	Mn	Si	Ni		Mo	
0.14/0.20	0.30/0.70	0.15/0.35	3.20/3.80		0.20/0.30	

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	WATER
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	QUENCH
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RIDIUS FROM CENTER	OIL
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	QUENCH

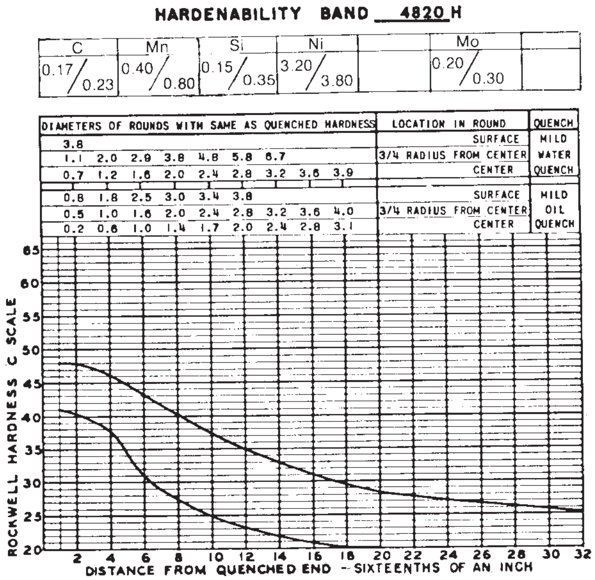


NOTE—1 in. = 25.4 mm.

FIG. 31 Limits for Hardenability Band 4817 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	4820 H	
	MAX	MIN
1	48	41
2	48	40
3	47	39
4	46	38
5	45	34
6	43	31
7	42	29
8	40	27
9	39	26
10	37	25
11	36	24
12	35	23
13	34	22
14	33	22
15	32	21
16	31	21
18	29	20
20	28	20
22	28	-
24	27	-
26	27	-
28	26	-
30	26	-
32	25	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

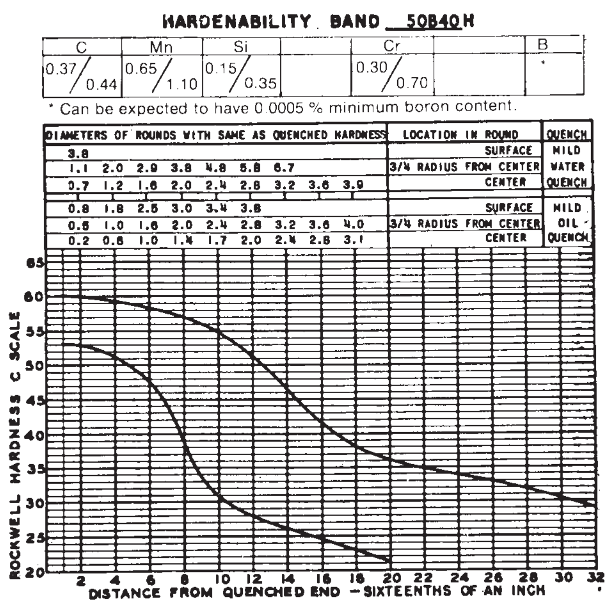


NOTE—1 in. = 25.4 mm.

FIG. 32 Limits for Hardenability Band 4820 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	50B40 H	
	MAX	MIN
1	60	53
2	60	53
3	59	52
4	59	51
5	58	50
6	58	48
7	57	44
8	57	39
9	56	34
10	55	31
11	53	29
12	51	28
13	49	27
14	47	26
15	44	25
16	41	25
18	38	23
20	36	21
22	35	-
24	34	-
26	33	-
28	32	-
30	30	-
32	29	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.



NOTE—1 in. = 25.4 mm.

FIG. 33 Limits for Hardenability Band 50B40 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	50B44 H MAX	MIN
1	63	56
2	63	56
3	62	55
4	62	55
5	61	54
6	61	52
7	60	48
8	60	43
9	59	38
10	58	34
11	57	31
12	56	30
13	54	29
14	52	29
15	50	28
16	48	27
18	44	26
20	40	24
22	38	23
24	37	21
26	36	20
28	35	-
30	34	-
32	33	-

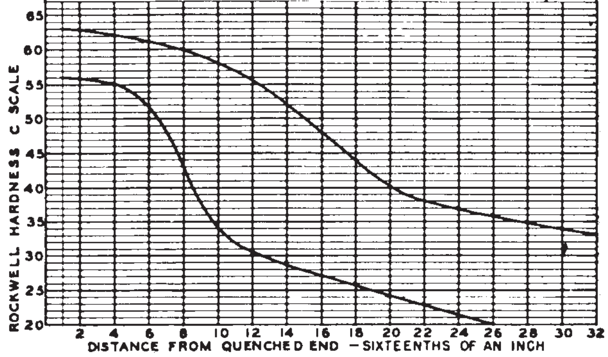
HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600°F
AUSTENITIZE 1550°F
*For forged or rolled specimens only.

HARDENABILITY BAND 50B44H

C	Mn	Si	Cr	B
0.42/0.49	0.65/1.10	0.15/0.35	0.30/0.70	*

* Can be expected to have 0.0005 % minimum boron content.

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD WATER QUENCH
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD OIL QUENCH
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	



NOTE—1 in. = 25.4 mm.

FIG. 34 Limits for Hardenability Band 50B44 H

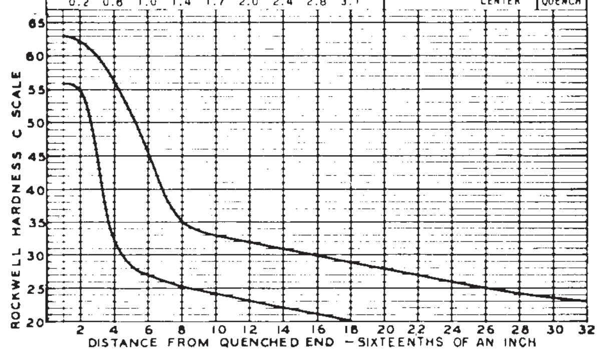
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	5046 H MAX	MIN
1	63	56
2	62	55
3	60	45
4	56	32
5	52	28
6	46	27
7	39	26
8	35	25
9	34	24
10	33	24
11	33	23
12	32	23
13	32	22
14	31	22
15	31	21
16	30	21
18	29	20
20	28	-
22	27	-
24	26	-
26	25	-
28	24	-
30	23	-
32	23	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 5046H

C	Mn	Si	Cr
0.43/0.50	0.65/1.10	0.15/0.35	0.13/0.43

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD WATER QUENCH
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD OIL QUENCH
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	

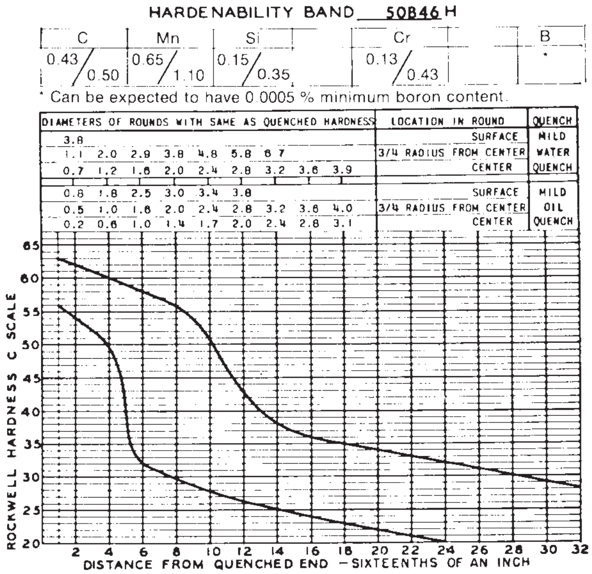


NOTE—1 in. = 25.4 mm.

FIG. 35 Limits for Hardenability Band 5046 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	50B46 H	
	MAX	MIN
1	63	56
2	62	54
3	61	52
4	60	50
5	59	41
6	58	32
7	57	31
8	56	30
9	54	29
10	51	28
11	47	27
12	43	26
13	40	26
14	38	25
15	37	25
16	36	24
18	35	23
20	34	22
22	33	21
24	32	20
26	31	-
28	30	-
30	29	-
32	28	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

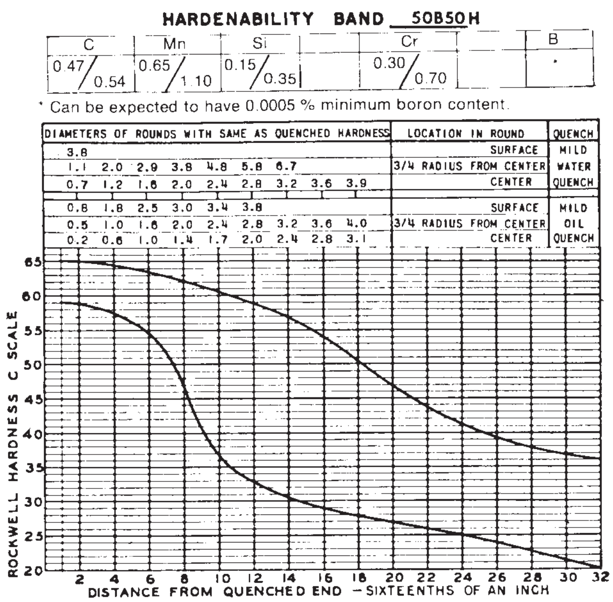


NOTE—1 in. = 25.4 mm.

FIG. 36 Limits for Hardenability Band 50B46 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	50B50 H	
	MAX	MIN
1	65	59
2	65	59
3	64	58
4	64	57
5	63	56
6	63	55
7	62	52
8	62	47
9	61	42
10	60	37
11	60	35
12	59	33
13	58	32
14	57	31
15	56	30
16	54	29
18	50	28
20	47	27
22	44	26
24	41	25
26	39	24
28	38	22
30	37	21
32	36	20

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.



NOTE—1 in. = 25.4 mm.

FIG. 37 Limits for Hardenability Band 50B50 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	50B60 H	
	MAX	MIN
1	-	60
2	-	60
3	-	60
4	-	60
5	-	60
6	-	59
7	-	57
8	65	53
9	65	47
10	64	42
11	64	39
12	64	37
13	63	36
14	63	35
15	63	34
16	62	34
18	60	33
20	58	31
22	55	30
24	53	29
26	51	28
28	49	27
30	47	26
32	44	25

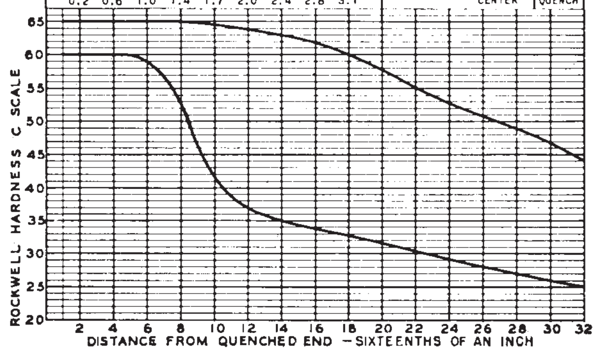
HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 50B60 H

C	Mn	Si	Cr	B
0.55/0.65	0.65/1.10	0.15/0.35	0.30/0.70	*

* Can be expected to have 0.0005 % minimum boron content.

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	WATER
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	QUENCH
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	OIL
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	QUENCH



NOTE—1 in. = 25.4 mm.

FIG. 38 Limits for Hardenability Band 50B60 H

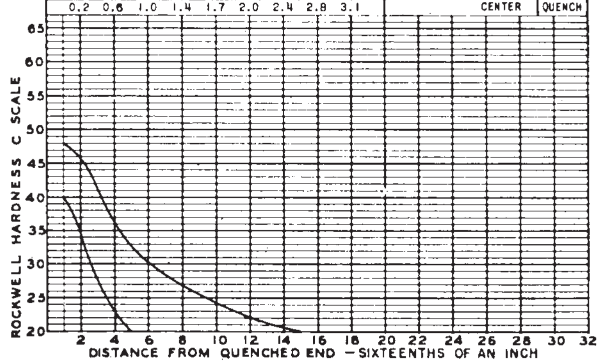
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	5120H	
	MAX	MIN
1	48	40
2	46	34
3	41	28
4	36	23
5	33	20
6	30	-
7	28	-
8	27	-
9	25	-
10	24	-
11	23	-
12	22	-
13	21	-
14	21	-
15	20	-
16	-	-
18	-	-
20	-	-
22	-	-
24	-	-
26	-	-
28	-	-
30	-	-
32	-	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 5120 H

C	Mn	Si	Cr
0.17/0.23	0.60/1.00	0.15/0.35	0.60/1.00

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	WATER
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	QUENCH
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	OIL
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	QUENCH

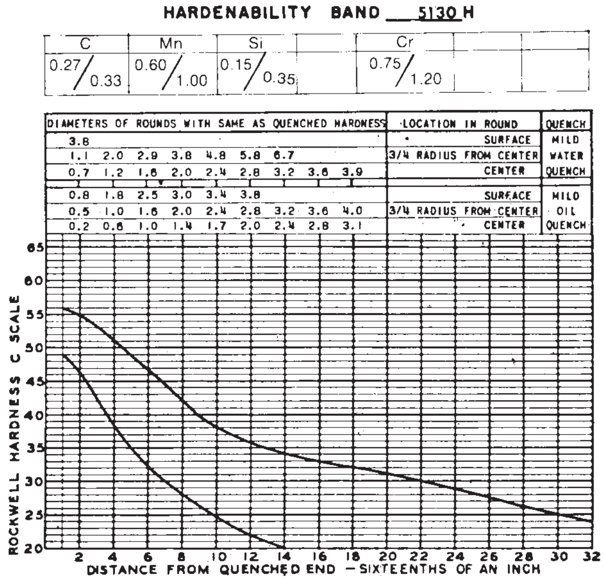


NOTE—1 in. = 25.4 mm.

FIG. 39 Limits for Hardenability Band 5120 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	5130H	
	MAX	MIN
1	56	49
2	55	46
3	53	42
4	51	39
5	49	35
6	47	32
7	45	30
8	42	28
9	40	26
10	38	25
11	37	23
12	36	22
13	35	21
14	34	20
15	34	–
16	33	–
18	32	–
20	31	–
22	30	–
24	29	–
26	27	–
28	26	–
30	25	–
32	24	–

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F
*For forged or rolled specimens only.

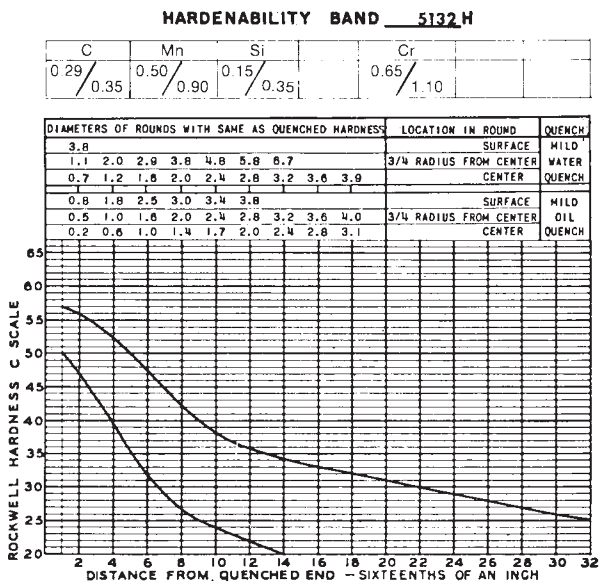


NOTE—1 in. = 25.4 mm.

FIG. 40 Limits for Hardenability Band 5130 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	5132H	
	MAX	MIN
1	57	50
2	56	47
3	54	43
4	52	40
5	50	35
6	48	32
7	45	29
8	42	27
9	40	25
10	38	24
11	37	23
12	36	22
13	35	21
14	34	20
15	34	–
16	33	–
18	32	–
20	31	–
22	30	–
24	29	–
26	28	–
28	27	–
30	26	–
32	25	–

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F
*For forged or rolled specimens only.

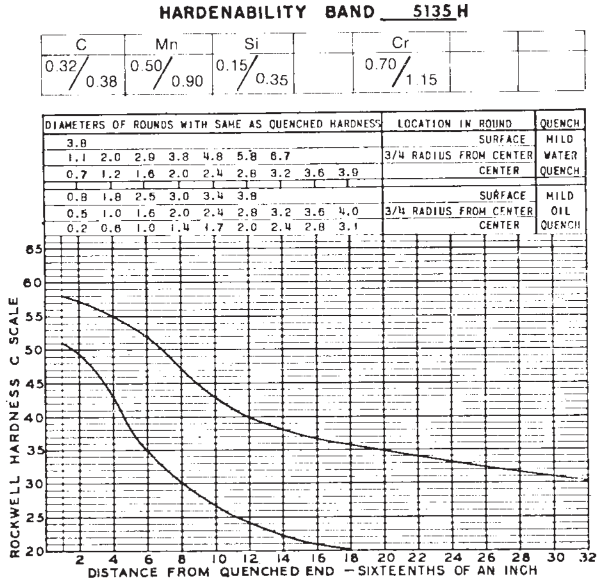


NOTE—1 in. = 25.4 mm.

FIG. 41 Limits for Hardenability Band 5132 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	5135H	
	MAX	MIN
1	58	51
2	57	49
3	56	47
4	55	43
5	54	38
6	52	35
7	50	32
8	47	30
9	45	28
10	43	27
11	41	25
12	40	24
13	39	23
14	38	22
15	37	21
16	37	21
18	36	20
20	35	-
22	34	-
24	33	-
26	32	-
28	32	-
30	31	-
32	30	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE.
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F
*For forged or rolled specimens only.

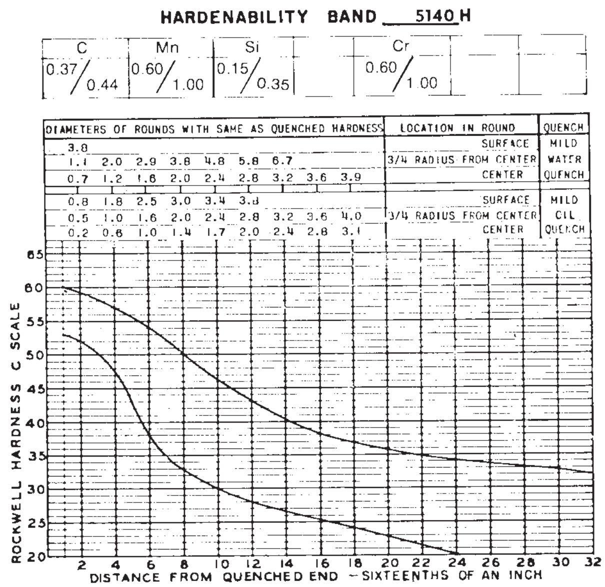


NOTE—1 in. = 25.4 mm.

FIG. 42 Limits for Hardenability Band 5135 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	5140H	
	MAX	MIN
1	60	53
2	59	52
3	58	50
4	57	48
5	56	43
6	54	38
7	52	35
8	50	33
9	48	31
10	46	30
11	45	29
12	43	28
13	42	27
14	40	27
15	39	26
16	38	25
18	37	24
20	36	23
22	35	21
24	34	20
26	34	-
28	33	-
30	33	-
32	32	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.



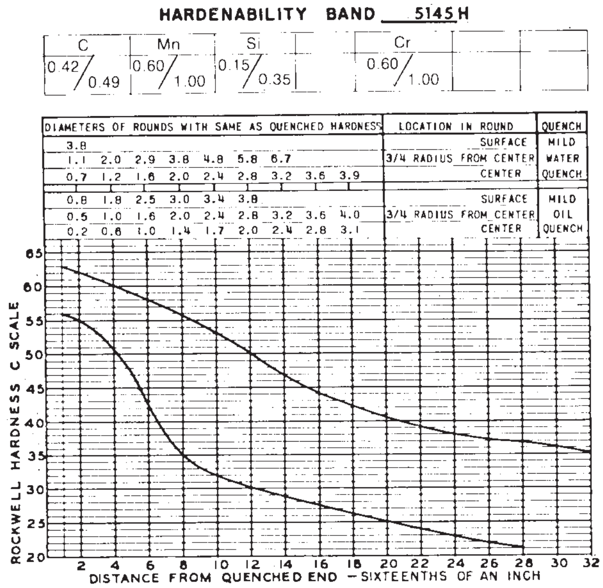
NOTE—1 in. = 25.4 mm.

FIG. 43 Limits for Hardenability Band 5140 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	5145H MAX	5145H MIN
1	63	56
2	62	55
3	61	53
4	60	51
5	59	48
6	58	42
7	57	38
8	56	35
9	55	33
10	53	32
11	52	31
12	50	30
13	48	30
14	47	29
15	45	28
16	44	28
18	42	26
20	41	25
22	39	24
24	38	23
26	37	22
28	37	21
30	36	-
32	35	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.



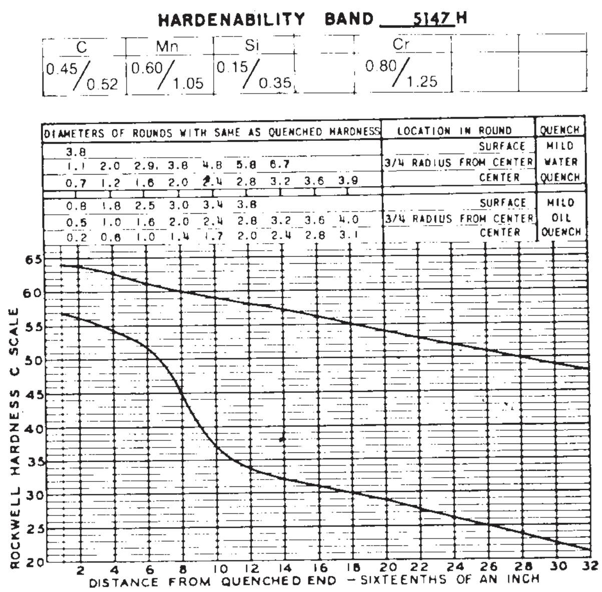
NOTE—1 in. = 25.4 mm.

FIG. 44 Limits for Hardenability Band 5145 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	5147H MAX	5147H MIN
1	64	57
2	64	56
3	63	55
4	62	54
5	62	53
6	61	52
7	61	49
8	60	45
9	60	40
10	59	37
11	59	35
12	58	34
13	58	33
14	57	32
15	57	32
16	56	31
18	55	30
20	54	29
22	53	27
24	52	26
26	51	25
28	50	24
30	49	22
32	48	21

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.



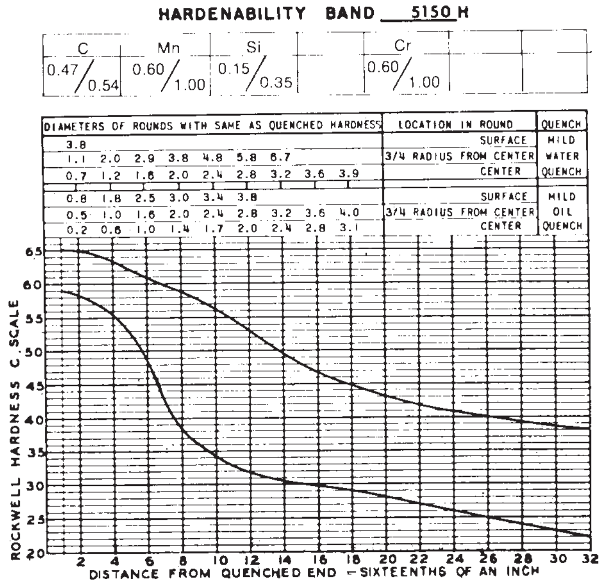
NOTE—1 in. = 25.4 mm.

FIG. 45 Limits for Hardenability Band 5147 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	5150H	
	MAX	MIN
1	65	59
2	65	58
3	64	57
4	63	56
5	62	53
6	61	49
7	60	42
8	59	38
9	58	36
10	56	34
11	55	33
12	53	32
13	51	31
14	50	31
15	48	30
16	47	30
18	45	29
20	43	28
22	42	27
24	41	26
26	40	25
28	39	24
30	39	23
32	38	22

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F

*For forged or rolled specimens only.



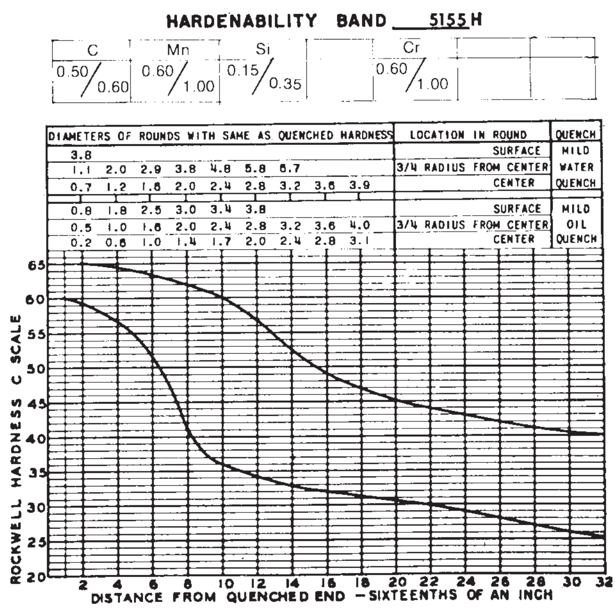
NOTE—1 in. = 25.4 mm.

FIG. 46 Limits for Hardenability Band 5150 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	5155 H	
	MAX	MIN
1	-	60
2	65	59
3	64	58
4	64	57
5	63	55
6	63	52
7	62	47
8	62	41
9	61	37
10	60	36
11	59	35
12	57	34
13	55	34
14	52	33
15	51	33
16	49	32
18	47	31
20	45	31
22	44	30
24	43	29
26	42	28
28	41	27
30	41	26
32	40	25

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F

*For forged or rolled specimens only.

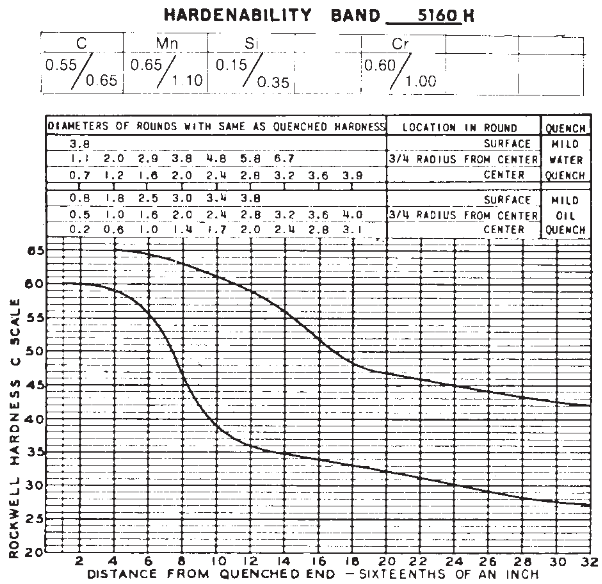


NOTE—1 in. = 25.4 mm.

FIG. 47 Limits for Hardenability Band 5155 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	5160H MAX	MIN
1	-	60
2	-	60
3	-	60
4	65	59
5	65	58
6	64	56
7	64	52
8	63	47
9	62	42
10	61	39
11	60	37
12	59	36
13	58	35
14	56	35
15	54	34
16	52	34
18	48	33
20	47	32
22	46	31
24	45	30
26	44	29
28	43	28
30	43	28
32	42	27

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

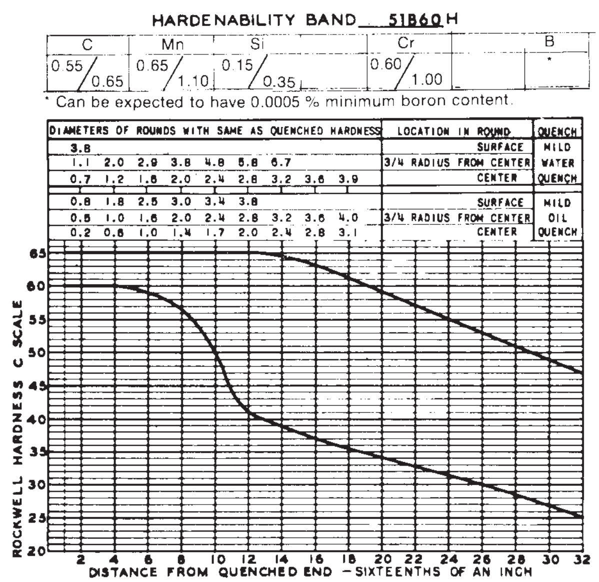


NOTE—1 in. = 25.4 mm.

FIG. 48 Limits for Hardenability Band 5160 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	51B60 H MAX	MIN
1	-	60
2	-	60
3	-	60
4	-	60
5	-	60
6	-	59
7	-	58
8	-	57
9	-	54
10	-	50
11	-	44
12	65	41
13	65	40
14	64	39
15	64	38
16	63	37
18	61	36
20	59	34
22	57	33
24	55	31
26	53	30
28	51	28
30	49	27
32	47	25

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

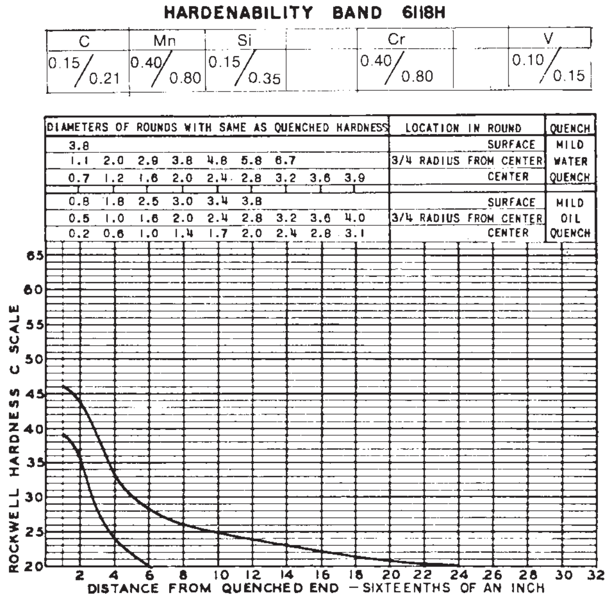


NOTE—1 in. = 25.4 mm.

FIG. 49 Limits for Hardenability Band 51B60 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	6118 H MAX.	6118 H MIN.
1	46	39
2	44	36
3	38	28
4	33	24
5	30	22
6	28	20
7	27	–
8	26	–
9	26	–
10	25	–
11	25	–
12	24	–
13	24	–
14	23	–
15	23	–
16	22	–
18	22	–
20	21	–
22	21	–
24	20	–
26	–	–
28	–	–
30	–	–
32	–	–

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F
*For forged or rolled specimens only.

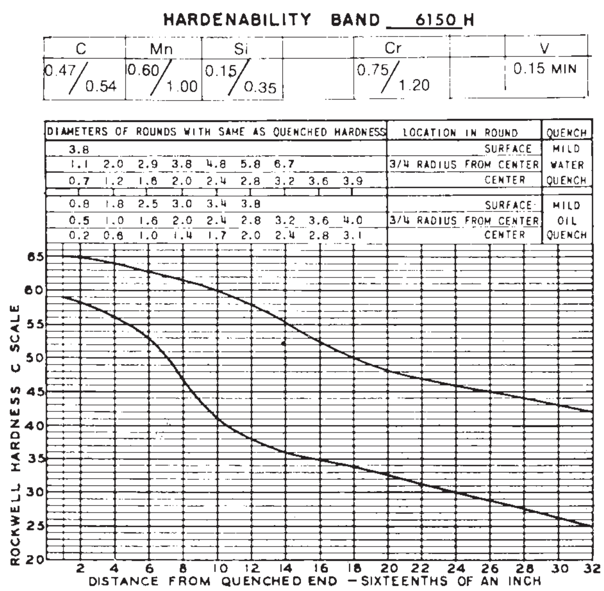


NOTE—1 in. = 25.4 mm.

FIG. 50 Limits for Hardenability Band 6118 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	6150H MAX	6150H MIN
1	65	59
2	65	58
3	64	57
4	64	56
5	63	55
6	63	53
7	62	50
8	61	47
9	61	43
10	60	41
11	59	39
12	58	38
13	57	37
14	55	36
15	54	35
16	52	35
18	50	34
20	48	32
22	47	31
24	46	30
26	45	29
28	44	27
30	43	26
32	42	25

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F
*For forged or rolled specimens only.



NOTE—1 in. = 25.4 mm.

FIG. 51 Limits for Hardenability Band 6150 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	81B45 H	
	MAX	MIN
1	63	58
2	63	58
3	63	58
4	63	58
5	63	55
6	63	54
7	62	53
8	62	51
9	61	48
10	60	44
11	60	41
12	59	39
13	58	38
14	57	37
15	57	36
16	56	35
18	55	34
20	53	32
22	52	31
24	50	30
26	49	29
28	47	28
30	45	28
32	43	27

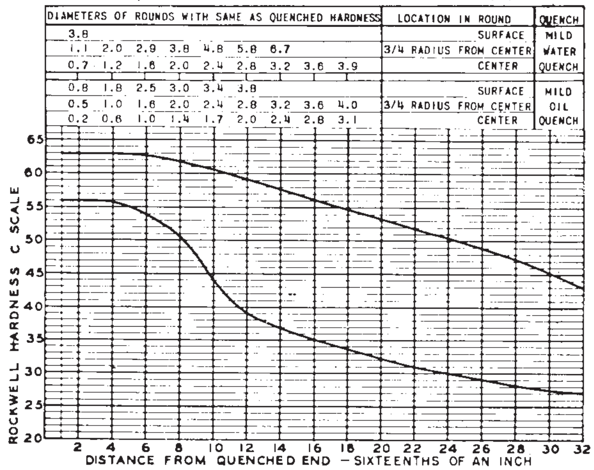
HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F

*For forged or rolled specimens only.

HARDENABILITY BAND 81B45 H

C	Mn	Si	Ni	Cr	Mo	B
0.42/0.49	0.70/1.05	0.15/0.35	0.15/0.45	0.30/0.60	0.08/0.15	*

* Can be expected to have 0.0005 % minimum boron content.



NOTE—1 in. = 25.4 mm.

FIG. 52 Limits for Hardenability Band 81B45 H

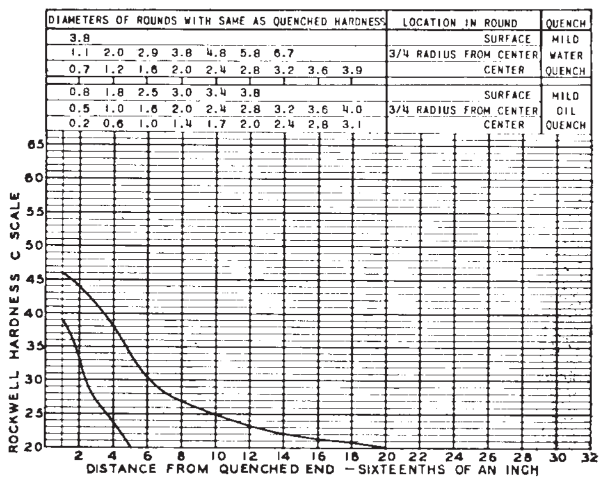
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	8617 H	
	MAX	MIN
1	46	39
2	44	33
3	41	27
4	38	24
5	34	20
6	31	-
7	28	-
8	27	-
9	26	-
10	25	-
11	24	-
12	23	-
13	23	-
14	22	-
15	22	-
16	21	-
18	21	-
20	20	-
22	-	-
24	-	-
26	-	-
28	-	-
30	-	-
32	-	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F

*For forged or rolled specimens only.

HARDENABILITY BAND 8617 H

C	Mn	Si	Ni	Cr	Mo
0.14/0.20	0.60/0.95	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25



NOTE—1 in. = 25.4 mm.

FIG. 53 Limits for Hardenability Band 8617 H

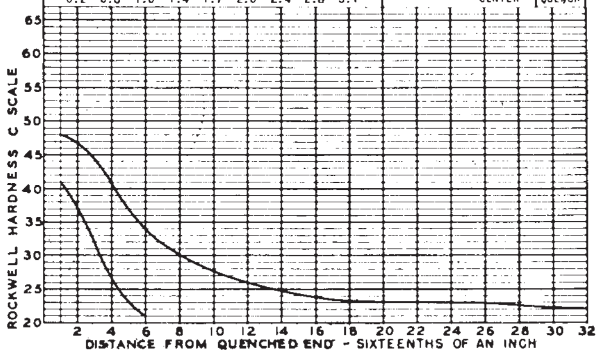
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	8620H	
	MAX	MIN
1	48	41
2	47	37
3	44	32
4	41	27
5	37	23
6	34	21
7	32	-
8	30	-
9	29	-
10	28	-
11	27	-
12	26	-
13	25	-
14	25	-
15	24	-
16	24	-
18	23	-
20	23	-
22	23	-
24	23	-
26	23	-
28	22	-
30	22	-
32	22	-

HEAT TREATING TEMPERATURES
RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 8620 H

C	Mn	Si	Ni	Cr	Mo
0.17/0.23	0.60/0.95	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD WATER QUENCH
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD OIL QUENCH
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	



NOTE—1 in. = 25.4 mm.

FIG. 54 Limits for Hardenability Band 8620 H

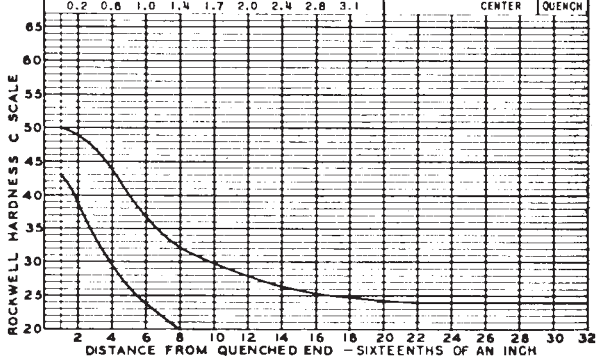
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	8622H	
	MAX	MIN
1	50	43
2	49	39
3	47	34
4	44	30
5	40	26
6	37	24
7	34	22
8	32	20
9	31	-
10	30	-
11	29	-
12	28	-
13	27	-
14	26	-
15	26	-
16	25	-
18	25	-
20	24	-
22	24	-
24	24	-
26	24	-
28	24	-
30	24	-
32	24	-

HEAT TREATING TEMPERATURES
RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 8622 H

C	Mn	Si	Ni	Cr	Mo
0.19/0.25	0.60/0.95	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD WATER QUENCH
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD OIL QUENCH
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	



NOTE—1 in. = 25.4 mm.

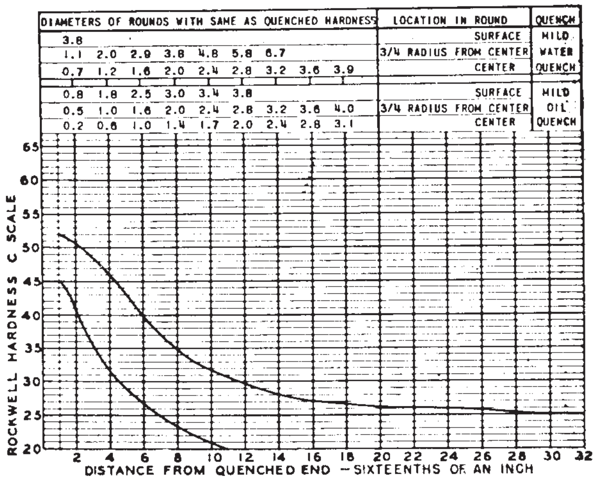
FIG. 55 Limits for Hardenability Band 8622 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	8625 H	
	MAX	MIN
1	52	45
2	51	41
3	48	36
4	46	32
5	43	29
6	40	27
7	37	25
8	35	23
9	33	22
10	32	21
11	31	20
12	30	-
13	29	-
14	28	-
15	28	-
16	27	-
18	27	-
20	26	-
22	26	-
24	26	-
26	26	-
28	25	-
30	25	-
32	25	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 8625 H

C	Mn	Si	Ni	Cr	Mo
0.22/0.28	0.60/0.95	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25



NOTE—1 in. = 25.4 mm.

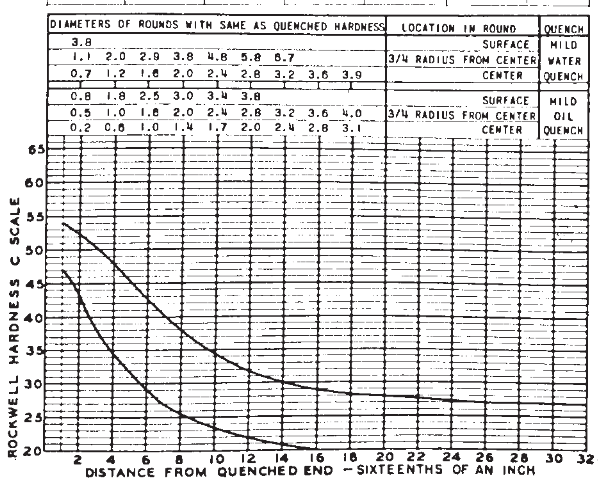
FIG. 56 Limits for Hardenability Band 8625 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	8627 H	
	MAX	MIN
1	54	47
2	52	43
3	50	38
4	48	35
5	45	32
6	43	29
7	40	27
8	38	26
9	36	24
10	34	24
11	33	23
12	32	22
13	31	21
14	30	21
15	30	20
16	29	20
18	28	-
20	28	-
22	28	-
24	27	-
26	27	-
28	27	-
30	27	-
32	27	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 8627 H

C	Mn	Si	Ni	Cr	Mo
0.24/0.30	0.60/0.95	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25

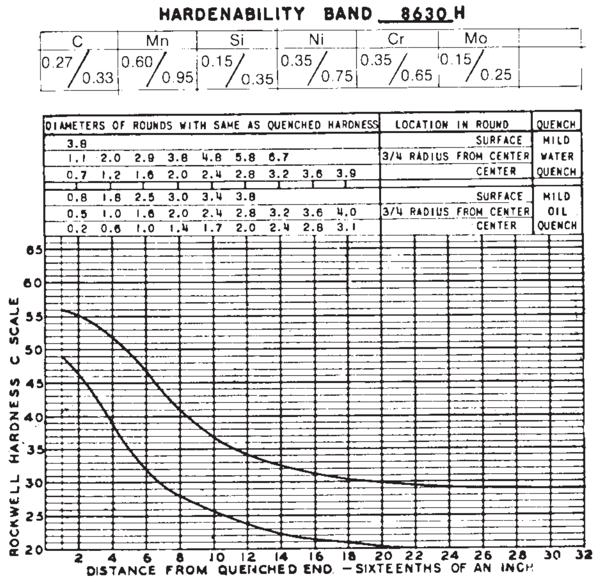


NOTE—1 in. = 25.4 mm.

FIG. 57 Limits for Hardenability Band 8627 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	8630H MAX	MIN
1	56	49
2	55	46
3	54	43
4	52	39
5	50	35
6	47	32
7	44	29
8	41	28
9	39	27
10	37	26
11	35	25
12	34	24
13	33	23
14	33	22
15	32	22
16	31	21
18	30	21
20	30	20
22	29	20
24	29	-
26	29	-
28	29	-
30	29	-
32	29	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F
*For forged or rolled specimens only.

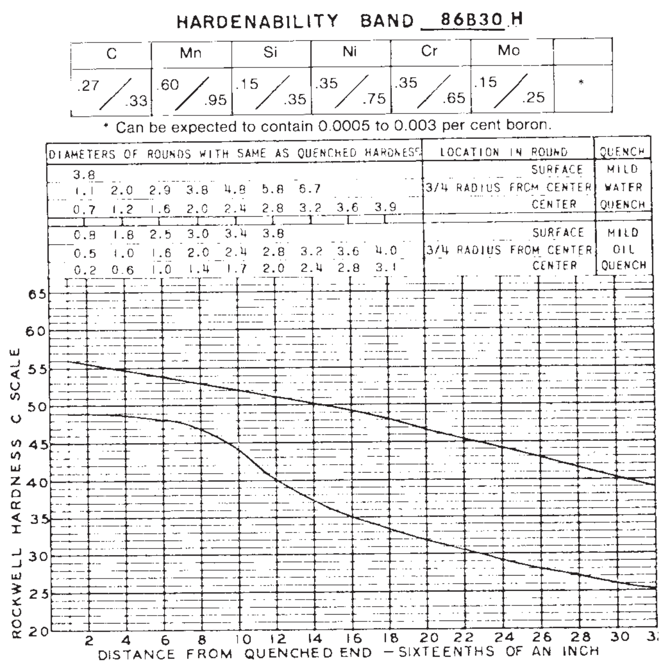


NOTE—1 in. = 25.4 mm.

FIG. 58 Limits for Hardenability Band 8630 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	86B30H MAX.	MIN.
1	56	49
2	55	49
3	55	48
4	55	48
5	54	48
6	54	48
7	53	48
8	53	47
9	52	46
10	52	44
11	52	42
12	51	40
13	51	39
14	50	38
15	50	36
16	49	35
18	48	34
20	47	32
22	45	31
24	44	29
26	43	28
28	41	27
30	40	26
32	39	25

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F
*For forged or rolled specimens only.

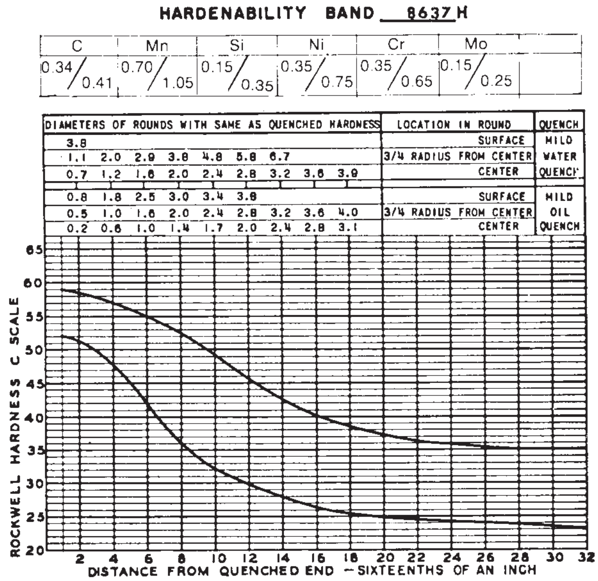


NOTE—1 in. = 25.4 mm.

FIG. 59 Limits for Hardenability Band 86B30 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	8637H	
	MAX	MIN
1	59	52
2	58	51
3	58	50
4	57	48
5	56	45
6	55	42
7	54	39
8	53	36
9	51	34
10	49	32
11	47	31
12	46	30
13	44	29
14	43	28
15	41	27
16	40	26
18	39	25
20	37	25
22	36	24
24	36	24
26	35	24
28	35	24
30	35	23
32	35	23

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

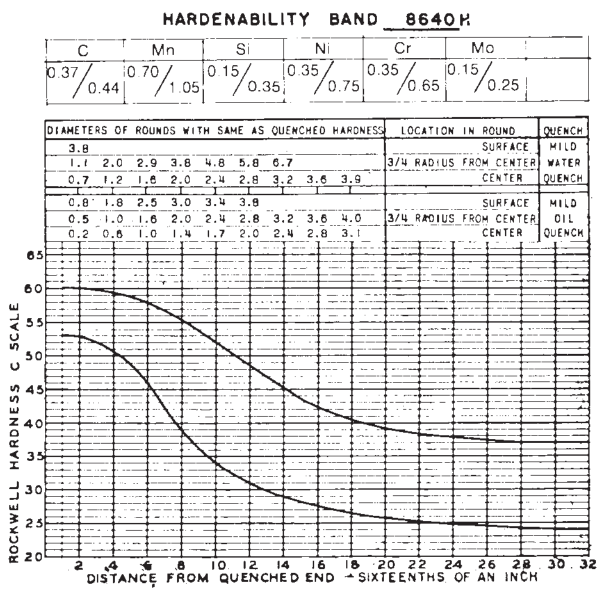


NOTE—1 in. = 25.4 mm.

FIG. 60 Limits for Hardenability Band 8637 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	8640H	
	MAX	MIN
1	60	53
2	60	53
3	60	52
4	59	51
5	59	49
6	58	46
7	57	42
8	55	39
9	54	36
10	52	34
11	50	32
12	49	31
13	47	30
14	45	29
15	44	28
16	42	28
18	41	26
20	39	26
22	38	25
24	38	25
26	37	24
28	37	24
30	37	24
32	37	24

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.



NOTE—1 in. = 25.4 mm.

FIG. 61 Limits for Hardenability Band 8640 H

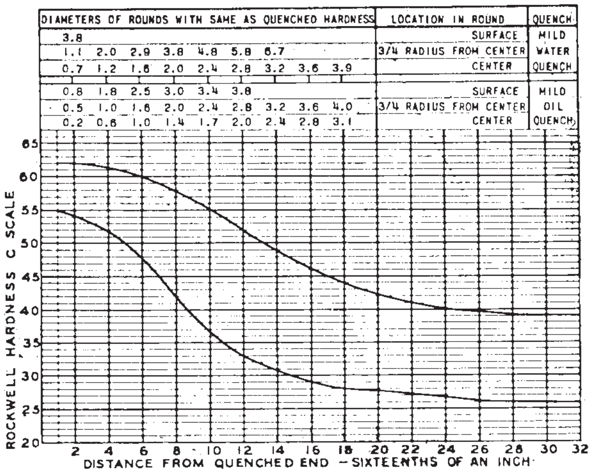
"J" DISTANCE SIXTEENTHS OF AN INCH	8642H	
	MAX	MIN
1	62	55
2	62	54
3	62	53
4	61	52
5	61	50
6	60	48
7	59	45
8	58	42
9	57	39
10	55	37
11	54	34
12	52	33
13	50	32
14	49	31
15	48	30
16	46	29
18	44	28
20	42	28
22	41	27
24	40	27
26	40	26
28	39	26
30	39	26
32	39	26

HARDNESS LIMITS FOR SPECIFICATION PURPOSES

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
*AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 8642 H

C	Mn	Si	Ni	Cr	Mo
0.39/0.46	0.70/1.05	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25



NOTE—1 in. = 25.4 mm.

FIG. 62 Limits for Hardenability Band 8642 H

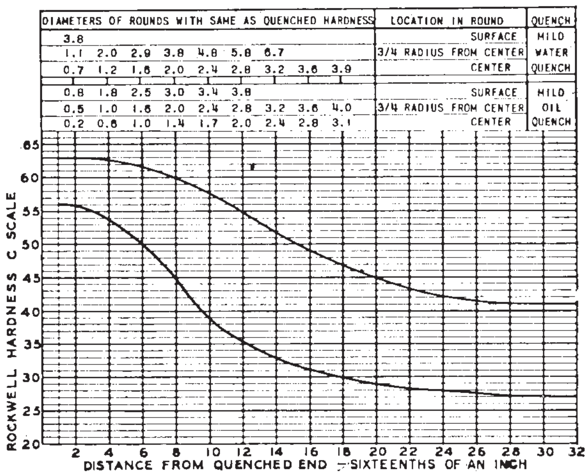
"J" DISTANCE SIXTEENTHS OF AN INCH	8645H	
	MAX	MIN
1	63	56
2	63	56
3	63	55
4	63	54
5	62	52
6	61	50
7	61	48
8	60	45
9	59	41
10	58	39
11	56	37
12	55	35
13	54	34
14	52	33
15	51	32
16	49	31
18	47	30
20	45	29
22	43	28
24	42	28
26	42	27
28	41	27
30	41	27
32	41	27

HARDNESS LIMITS FOR SPECIFICATION PURPOSES

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 8645 H

C	Mn	Si	Ni	Cr	Mo
0.42/0.49	0.70/1.05	0.15/0.35	0.35/0.75	0.35/0.65	0.15/0.25

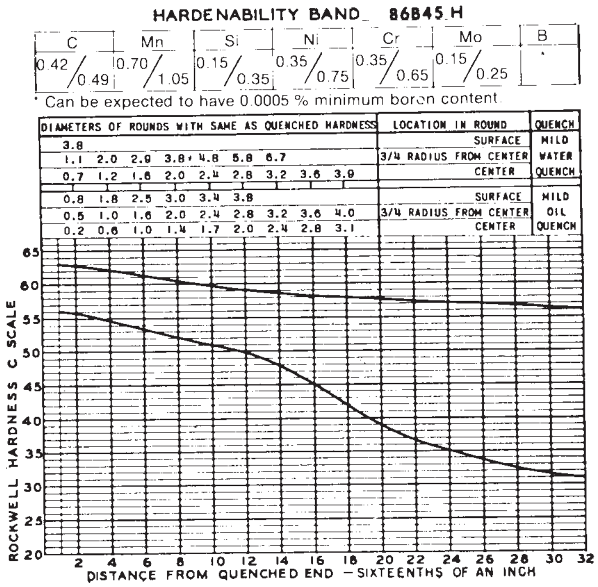


NOTE—1 in. = 25.4 mm.

FIG. 63 Limits for Hardenability Band 8645 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	86B45 H	
	MAX	MIN
1	63	56
2	63	56
3	62	55
4	62	54
5	62	54
6	61	53
7	61	52
8	60	52
9	60	51
10	60	51
11	59	50
12	59	50
13	59	49
14	59	48
15	58	46
16	58	45
18	58	42
20	58	39
22	57	37
24	57	35
26	57	34
28	57	32
30	56	32
32	56	31

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

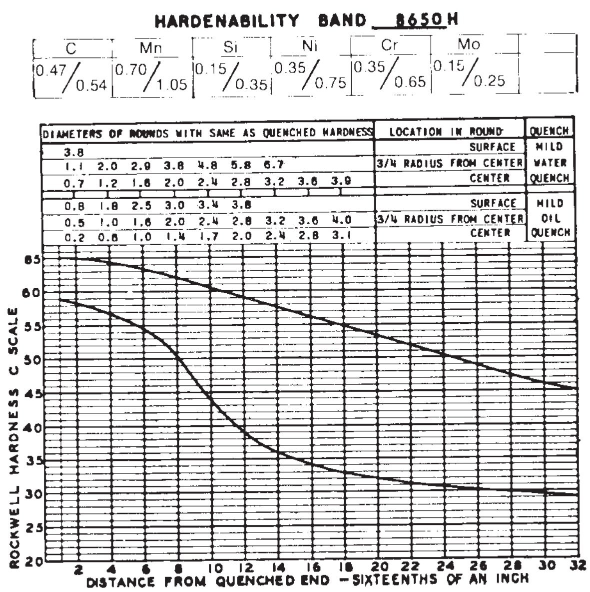


NOTE—1 in. = 25.4 mm.

FIG. 64 Limits for Hardenability Band 86B45 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	8650H	
	MAX	MIN
1	65	59
2	65	58
3	65	57
4	64	57
5	64	56
6	63	54
7	63	53
8	62	50
9	61	47
10	60	44
11	60	41
12	59	39
13	58	37
14	58	36
15	57	35
16	56	34
18	55	33
20	53	32
22	52	31
24	50	31
26	49	30
28	47	30
30	46	29
32	45	29

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.



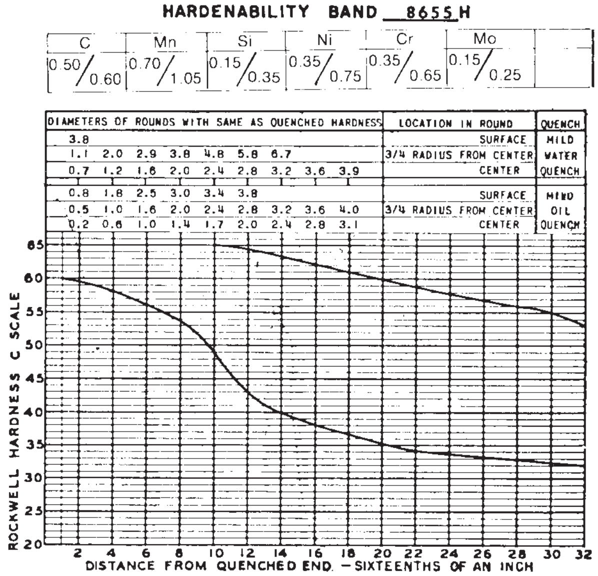
NOTE—1 in. = 25.4 mm.

FIG. 65 Limits for Hardenability Band 8650 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	8655H	
	MAX	MIN
1	–	60
2	–	59
3	–	59
4	–	58
5	–	57
6	–	56
7	–	55
8	–	54
9	–	52
10	65	49
11	65	46
12	64	43
13	64	41
14	63	40
15	63	39
16	62	38
18	61	37
20	60	35
22	59	34
24	58	34
26	57	33
28	56	33
30	55	32
32	53	32

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
NORMALIZE 1600 °F
AUSTENITIZE 1550 °F

*For forged or rolled specimens only.



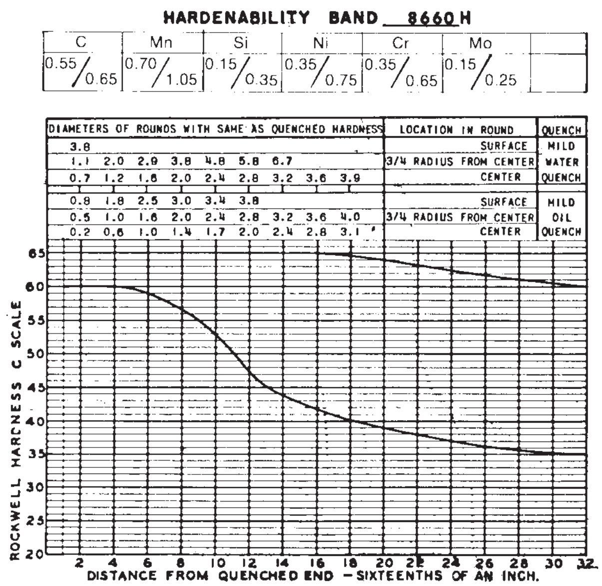
NOTE—1 in. = 25.4 mm.

FIG. 66 Limits for Hardenability Band 8655 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	8660H	
	MAX	MIN
1	–	60
2	–	60
3	–	60
4	–	60
5	–	60
6	–	59
7	–	58
8	–	57
9	–	55
10	–	53
11	–	50
12	–	47
13	–	45
14	–	44
15	–	43
16	65	42
18	64	40
20	64	39
22	63	38
24	62	37
26	62	36
28	61	35
30	60	35
32	60	35

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F

*For forged or rolled specimens only.

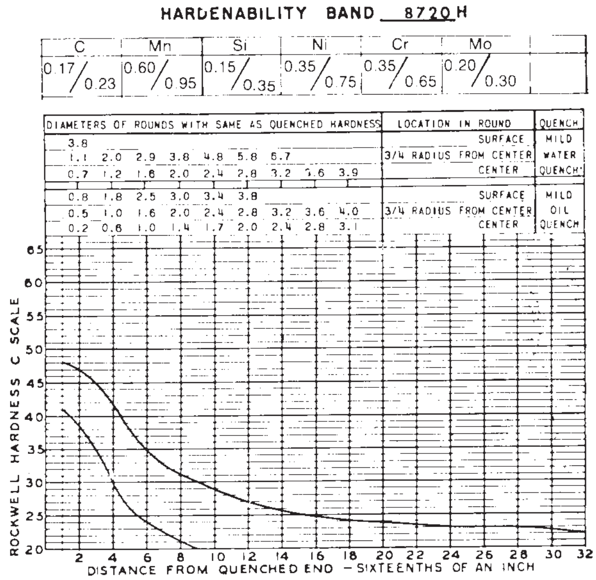


NOTE—1 in. = 25.4 mm.

FIG. 67 Limits for Hardenability Band 8660 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	8720H	
	MAX	MIN
1	48	41
2	47	38
3	45	35
4	42	30
5	38	26
6	35	24
7	33	22
8	31	21
9	30	20
10	29	-
11	28	-
12	27	-
13	26	-
14	26	-
15	25	-
16	25	-
18	24	-
20	24	-
22	23	-
24	23	-
26	23	-
28	23	-
30	22	-
32	22	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F
*For forged or rolled specimens only.

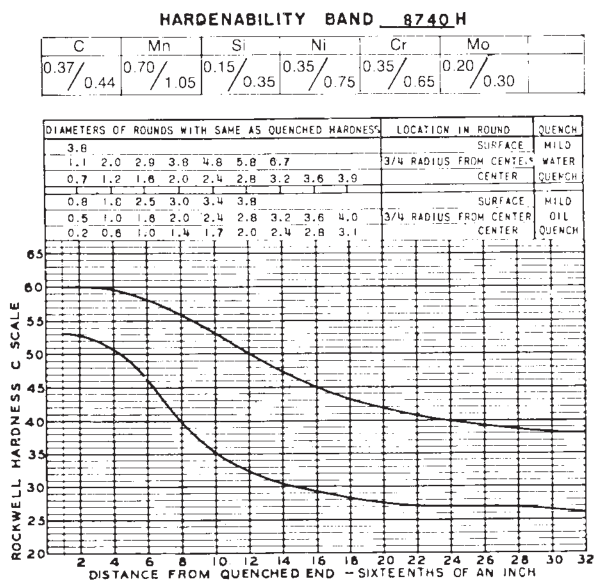


NOTE—1 in. = 25.4 mm.

FIG. 68 Limits for Hardenability Band 8720 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	8740H	
	MAX	MIN
1	60	53
2	60	53
3	60	52
4	60	51
5	59	49
6	58	46
7	57	43
8	56	40
9	55	37
10	53	35
11	52	34
12	50	32
13	49	31
14	48	31
15	46	30
16	45	29
18	43	28
20	42	28
22	41	27
24	40	27
26	39	27
28	39	27
30	38	26
32	38	26

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.



NOTE—1 in. = 25.4 mm.

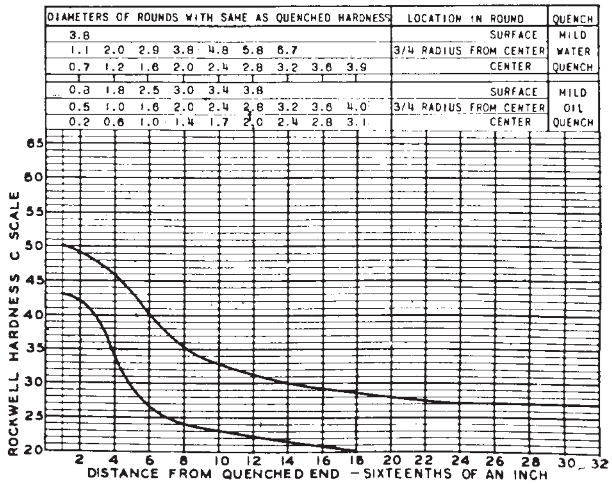
FIG. 69 Limits for Hardenability Band 8740 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	8822 H	
	MAX	MIN
1	50	43
2	49	42
3	48	39
4	46	33
5	43	29
6	40	27
7	37	25
8	35	24
9	34	24
10	33	23
11	32	23
12	31	22
13	31	22
14	30	22
15	30	21
16	29	21
18	29	20
20	28	-
22	27	-
24	27	-
26	27	-
28	27	-
30	27	-
32	27	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 8822H

C	Mn	Si	Ni	Cr	Mo
0.19/0.25	0.70/1.05	0.15/0.35	0.35/0.75	0.35/0.65	0.30/0.40



NOTE—1 in. = 25.4 mm.

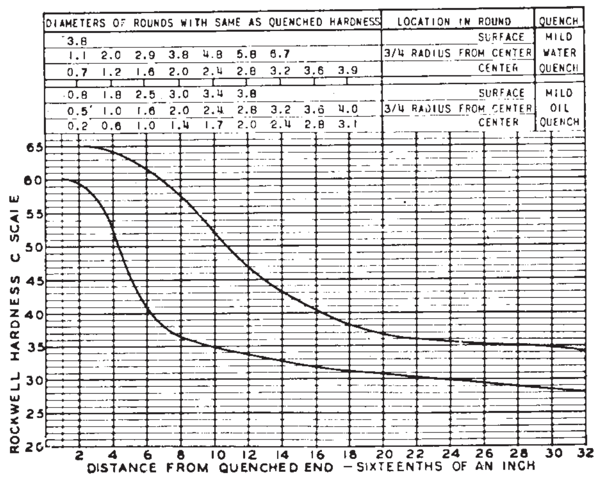
FIG. 70 Limits for Hardenability Band 8822 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	9260H	
	MAX	MIN
1	-	60
2	-	60
3	65	57
4	64	53
5	63	46
6	62	41
7	60	38
8	58	36
9	55	36
10	52	35
11	49	34
12	47	34
13	45	33
14	43	33
15	42	32
16	40	32
18	38	31
20	37	31
22	36	30
24	35	30
26	35	29
28	35	29
30	35	28
32	34	28

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 9260H

C	Mn	Si
0.55/0.65	0.65/1.10	1.70/2.20



NOTE—1 in. = 25.4 mm.

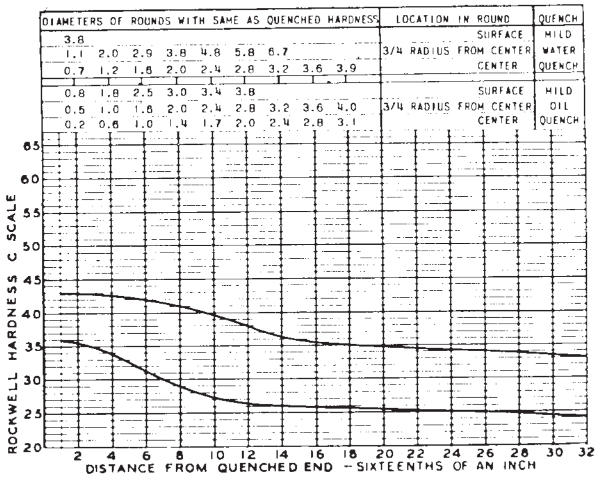
FIG. 71 Limits for Hardenability Band 9260 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	9310H	
	MAX	MIN
1	43	36
2	43	35
3	43	35
4	42	34
5	42	32
6	42	31
7	42	30
8	41	29
9	40	28
10	40	27
11	39	27
12	38	26
13	37	26
14	36	26
15	36	26
16	35	26
18	35	26
20	35	25
22	34	25
24	34	25
26	34	25
28	34	25
30	33	24
32	33	24

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 9310 H

C	Mn	Si	Ni	Cr	Mo	
0.07/0.13	0.40/0.70	0.15/0.35	2.95/3.55	1.00/1.45	0.08/0.15	



NOTE—1 in. = 25.4 mm.

FIG. 72 Limits for Hardenability Band 9310 H

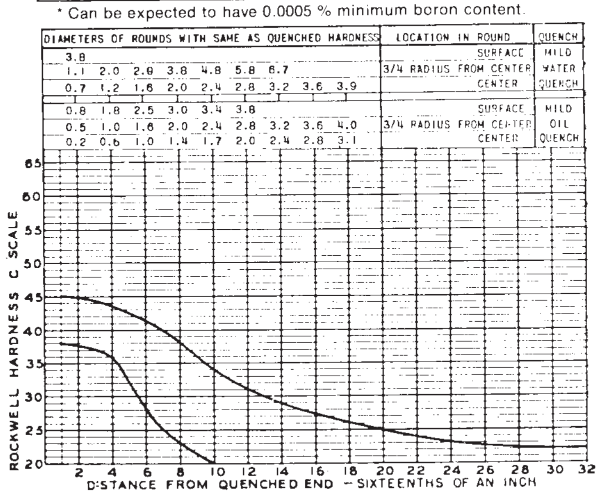
HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	94B15H	
	MAX	MIN
1	45	38
2	45	38
3	44	37
4	44	36
5	43	32
6	42	28
7	40	25
8	38	23
9	36	21
10	34	20
11	33	-
12	31	-
13	30	-
14	29	-
15	28	-
16	27	-
18	26	-
20	25	-
22	24	-
24	23	-
26	23	-
28	22	-
30	22	-
32	22	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F
*For forged or rolled specimens only.

HARDENABILITY BAND 94B15 H

C	Mn	Si	Ni	Cr	Mo	B
0.12/0.18	0.70/1.05	0.15/0.35	0.25/0.65	0.25/0.55	0.08/0.15	*

* Can be expected to have 0.0005 % minimum boron content.



NOTE—1 in. = 25.4 mm.

FIG. 73 Limits for Hardenability Band 94B15 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	94B17H	
	MAX	MIN
1	46	39
2	46	39
3	45	38
4	45	37
5	44	34
6	43	29
7	42	26
8	41	24
9	40	23
10	38	21
11	36	20
12	34	-
13	33	-
14	32	-
15	31	-
16	30	-
18	28	-
20	27	-
22	26	-
24	25	-
26	24	-
28	24	-
30	23	-
32	23	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F

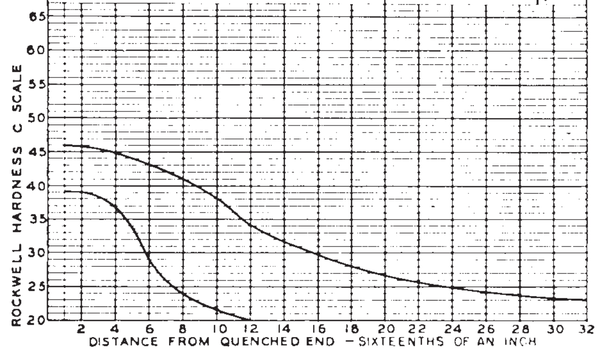
*For forged or rolled specimens only.

HARDENABILITY BAND 94B17H

C	Mn	Si	Ni	Cr	Mo	B
0.14/0.20	0.70/1.05	0.15/0.35	0.25/0.65	0.25/0.55	0.08/0.15	*

* Can be expected to have 0.0005 % minimum boron content.

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD WATER QUENCH
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD OIL QUENCH
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	



NOTE—1 in. = 25.4 mm.

FIG. 74 Limits for Hardenability Band 94B17 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	94B30 H	
	MAX	MIN
1	56	49
2	56	49
3	55	48
4	55	48
5	54	47
6	54	46
7	53	44
8	53	42
9	52	39
10	52	37
11	51	34
12	51	32
13	50	30
14	49	29
15	48	28
16	46	27
18	44	25
20	42	24
22	40	23
24	38	23
26	37	22
28	35	21
30	34	21
32	34	20

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F

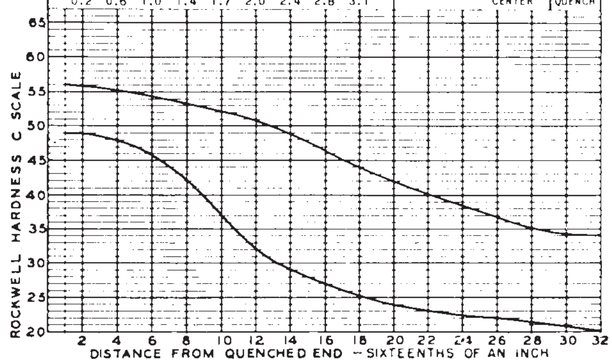
*For forged or rolled specimens only.

HARDENABILITY BAND 94B30H

C	Mn	Si	Ni	Cr	Mo	B
0.27/0.33	0.70/1.05	0.15/0.35	0.25/0.65	0.25/0.55	0.08/0.15	*

* Can be expected to have 0.0005 % minimum boron content.

DIAMETERS OF ROUNDS WITH SAME AS QUENCHED HARDNESS	LOCATION IN ROUND	QUENCH
3.8	SURFACE	MILD WATER QUENCH
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 RADIUS FROM CENTER	
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	CENTER	
0.8 1.8 2.5 3.0 3.4 3.8	SURFACE	MILD OIL QUENCH
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 RADIUS FROM CENTER	
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	CENTER	



NOTE—1 in. = 25.4 mm.

FIG. 75 Limits for Hardenability Band 94B30 H

"J" Distance Sixteenths of an Inch	H Max.	H Min.
1	58	51
1.5	56	42
2	55	34
2.5	53	29
3	49	26
3.5	43	24
4	37	23
4.5	33	22
5	30	22
5.5	29	21
6	28	21
6.5	27	20
7	27	-
7.5	26	-
8	26	-
9	25	-
10	25	-
12	24	-
14	23	-
16	21	-

HARDNESS LIMITS FOR SPECIFICATION PURPOSES

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE

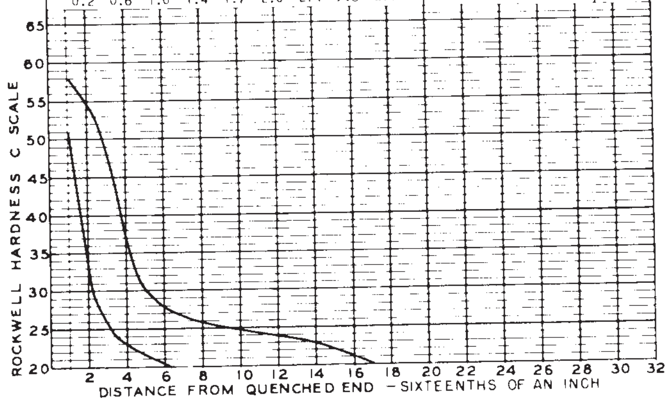
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F

*For forged or rolled specimens only.

HARDENABILITY BAND 1038 H

C	Mn	Si	Ni	Cr	Mo	
0.34/0.43	0.50/1.00	0.15/0.35				

Diameters of Rounds with Same as Quenched Hardness	Location in Round	Quench
3.8	Surface	Mild Water Quench
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 Radius from Center	
0.7 1.2 1.6 2.0 2.4 2.8 3.2 3.6 3.9	Center	
0.8 1.8 2.5 3.0 3.4 3.8	Surface	Mild Oil Quench
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 Radius from Center	
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	Center	



NOTE—1 in. = 25.4 mm.

FIG. 76 Limits for Hardenability Band 1038 H

"J" Distance Sixteenths of an Inch	H Max.	H Min.
1	62	55
1.5	61	52
2	59	42
2.5	56	34
3	52	31
3.5	46	29
4	38	28
4.5	34	27
5	33	26
5.5	32	26
6	32	25
6.5	31	25
7	31	25
7.5	30	24
8	30	24
9	29	23
10	29	22
12	28	21
14	27	20
16	26	-
18	25	—
20	23	—
22	22	—
24	21	—

HARDNESS LIMITS FOR SPECIFICATION PURPOSES

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE

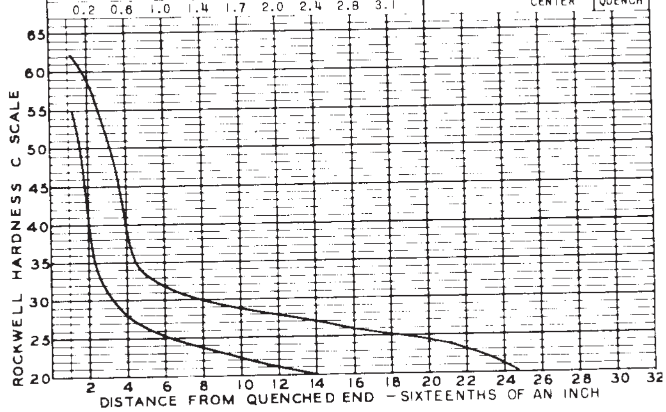
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F

*For forged or rolled specimens only.

HARDENABILITY BAND 1045 H

C	Mn	Si	Ni	Cr	Mo	
0.42/0.51	0.50/1.00	0.15/0.35				

Diameters of Rounds with Same as Quenched Hardness	Location in Round	Quench
3.8	Surface	Mild Water Quench
1.1 2.0 2.9 3.8 4.8 5.8 6.7	3/4 Radius from Center	
0.7 1.2 1.8 2.0 2.4 2.8 3.2 3.6 3.9	Center	
0.8 1.8 2.5 3.0 3.4 3.8	Surface	Mild Oil Quench
0.5 1.0 1.6 2.0 2.4 2.8 3.2 3.6 4.0	3/4 Radius from Center	
0.2 0.6 1.0 1.4 1.7 2.0 2.4 2.8 3.1	Center	

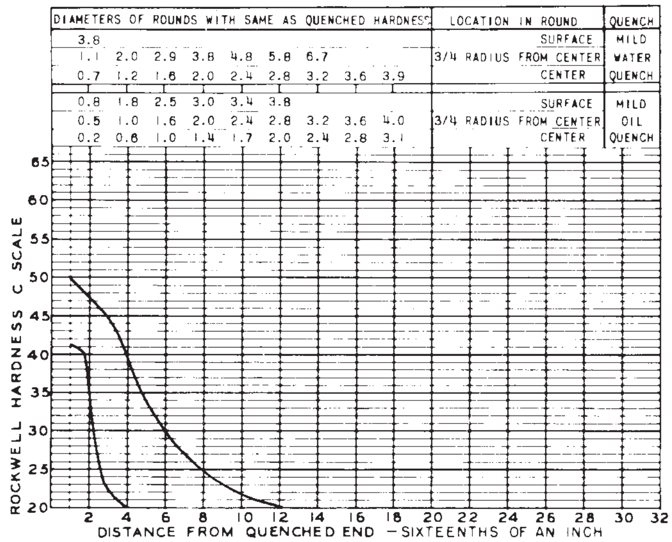


NOTE—1 in. = 25.4 mm.

FIG. 77 Limits for Hardenability Band 1045 H

HARDENABILITY BAND 1522H

C	Mn	Si	Ni	Cr	Mo	
0.17/0.25	1.00/1.50	0.15/0.35				



NOTE—1 in. = 25.4 mm.

FIG. 78 Limits for Hardenability Band 1522 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	H MAX.	H MIN.
1	51	42
1.5	49	42
2	48	38
2.5	47	34
3	45	29
3.5	43	25
4	39	22
4.5	38	20
5	35	-
5.5	34	-
6	32	-
6.5	30	-
7	29	-
7.5	28	-
8	27	-
9	26	-
10	25	-
12	23	-
14	22	-
16	20	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE

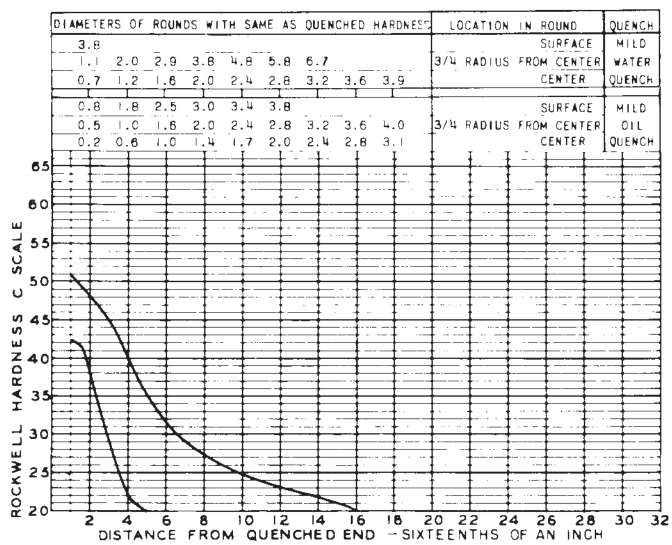
*NORMALIZE 1650 °F

AUSTENITIZE 1600 °F

*For forged or rolled specimens only.

HARDENABILITY BAND 1524H

C	Mn	Si	Ni	Cr	Mo	
0.18/0.26	1.25/1.75	0.15/0.35				

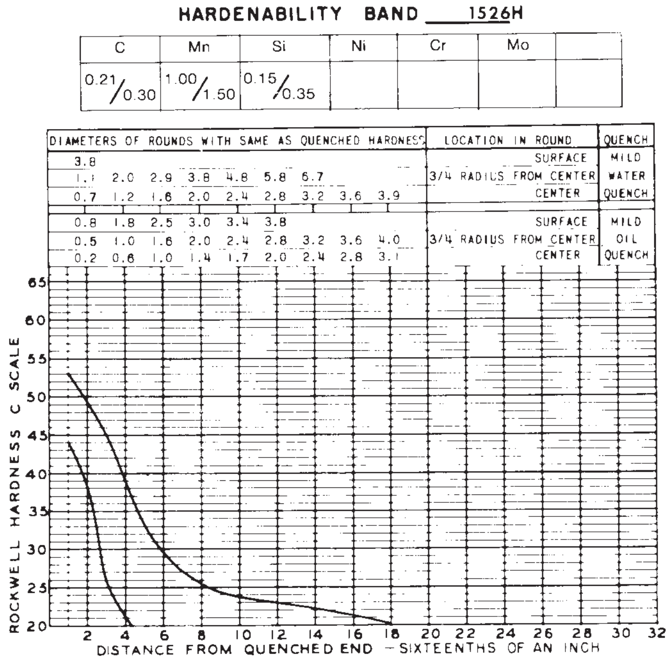


NOTE—1 in. = 25.4 mm.

FIG. 79 Limits for Hardenability Band 1524 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	H MAX.	H MIN.
1	53	44
1.5	50	42
2	49	38
2.5	47	33
3	46	26
3.5	42	25
4	39	21
4.5	37	20
5	33	-
5.5	31	-
6	30	-
6.5	28	-
7	27	-
7.5	26	-
8	26	-
9	24	-
10	24	-
12	23	-
14	22	-
16	21	-
18	20	

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F
*For forged or rolled specimens only.

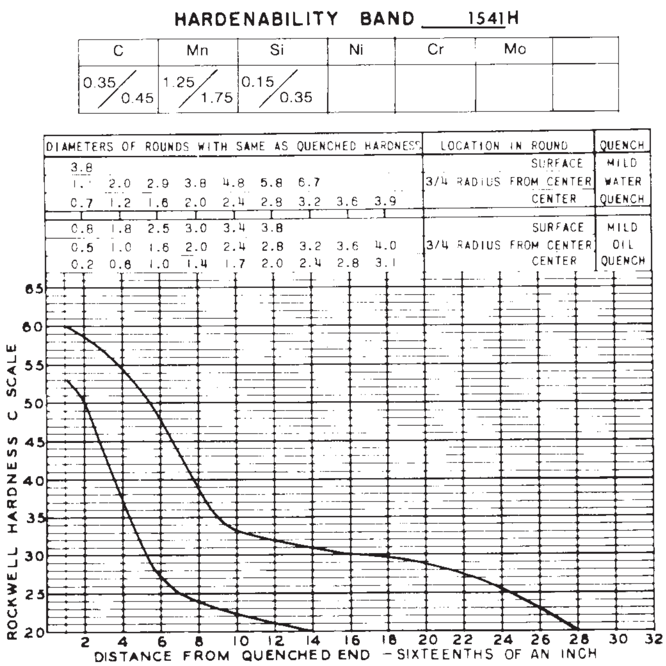


NOTE—1 in. = 25.4 mm.

FIG. 80 Limits for Hardenability Band 1526 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	H MAX.	H MIN.
1	60	53
1.5	59	52
2	59	50
2.5	58	47
3	57	44
3.5	56	41
4	55	38
4.5	53	35
5	52	32
5.5	50	29
6	48	27
6.5	46	26
7	44	25
7.5	41	24
8	39	23
9	35	23
10	33	22
12	32	21
14	31	20
16	30	-
18	30	-
20	29	-
22	28	-
24	26	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F
*For forged or rolled specimens only.



NOTE—1 in. = 25.4 mm.

FIG. 81 Limits for Hardenability Band 1541 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	H	
	MAX.	MIN.
1	48	41
1.5	48	41
2	47	40
2.5	47	39
3	46	38
3.5	45	36
4	44	30
4.5	42	23
5	40	20
5.5	38	-
6	35	-
6.5	32	-
7	27	-
7.5	22	-
8	20	-
9	-	-
10	-	-
12	-	-
14	-	-
16	-	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE

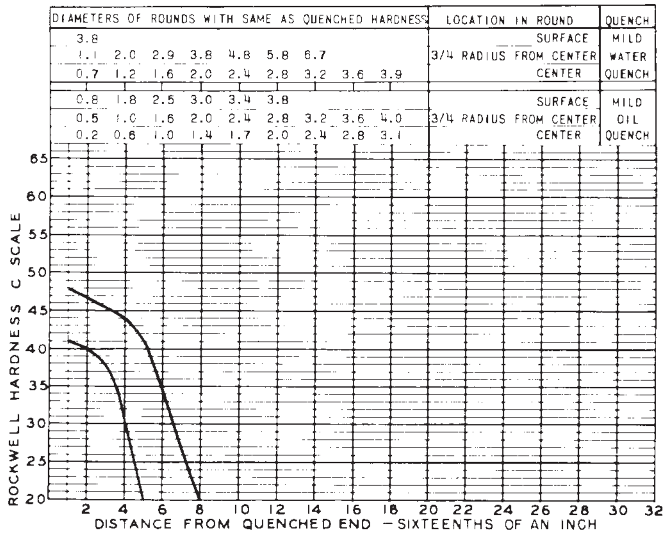
*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F

*For forged or rolled specimens only.

HARDENABILITY BAND 15B21 H

C	Mn	Si	Ni	Cr	Mo	
0.17/0.24	0.70/1.20	0.15/0.35				

Can be expected to contain 0.0005 to 0.003 per cent boron



NOTE—1 in. = 25.4 mm.

FIG. 82 Limits for Hardenability Band 15B21 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	H	
	MAX.	MIN.
1	58	51
2	56	50
3	55	49
4	54	48
5	53	39
6	51	28
7	47	24
8	41	22
9	-	-
10	30	20
11	-	-
12	27	-
13	-	-
14	26	-
15	-	-
16	25	-
18	-	-
20	24	-
22	-	-
24	22	-
26	-	-
28	20	-
30	-	-
32	-	-

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE

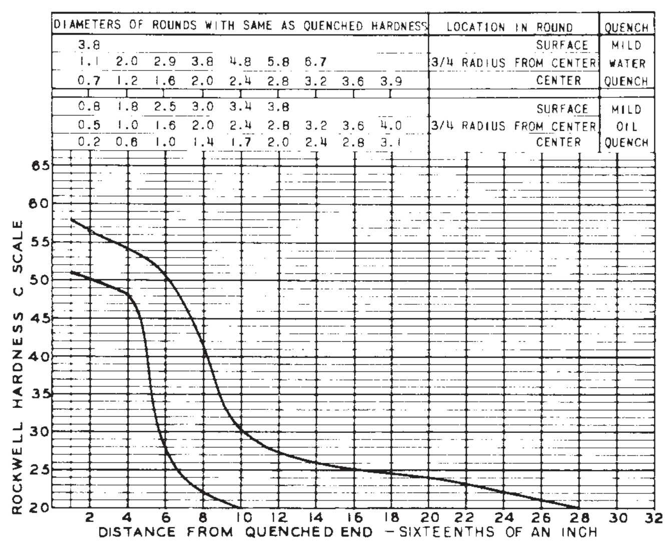
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F

*For forged or rolled specimens only.

HARDENABILITY BAND 15B35H

C	Mn	Si	Ni	Cr	Mo	B
0.31/0.39	0.70/1.20	0.15/0.35				*

Can be expected to contain 0.0005 to 0.003 per cent boron.



NOTE—1 in. = 25.4 mm.

FIG. 83 Limits for Hardenability Band 15B35 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	H MAX.	H MIN.
1	58	50
2	56	50
3	55	49
4	54	48
5	53	43
6	52	37
7	51	33
8	50	26
9	-	-
10	45	22
11	-	-
12	40	21
13	-	-
14	33	20
15	-	-
16	29	-
18	-	-
20	27	-
22	-	-
24	25	-
26	-	-
28	23	-
30	-	-
32	21	-

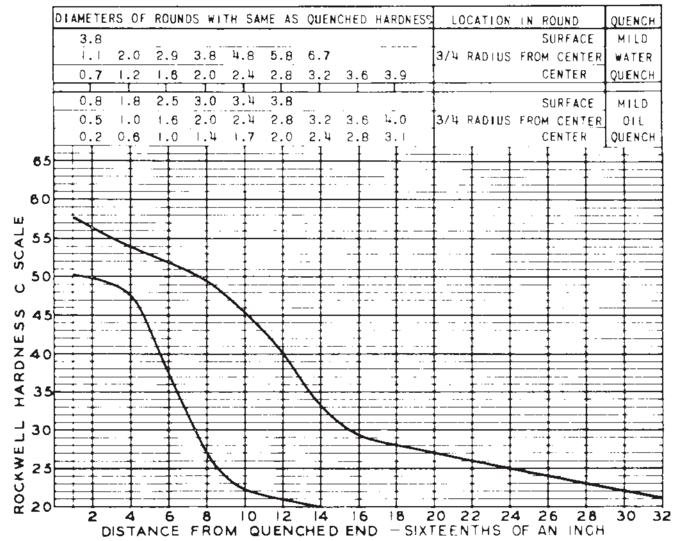
HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F

*For forged or rolled specimens only.

HARDENABILITY BAND 15B37H

C	Mn	Si	Ni	Cr	Mo	B
0.30/0.39	1.00/1.50	0.15/0.35				*

*Can be expected to contain 0.0005 to 0.003 per cent boron.



NOTE—1 in. = 25.4 mm.

FIG. 84 Limits for Hardenability Band 15B37 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	H MAX.	H MIN.
1	60	53
2	59	52
3	59	52
4	58	51
5	58	51
6	57	50
7	57	49
8	56	48
9	55	44
10	55	37
11	54	32
12	53	28
13	52	26
14	51	25
15	50	25
16	49	24
18	46	23
20	42	22
22	39	21
24	36	21
26	34	20
28	33	-
30	31	
32	31	

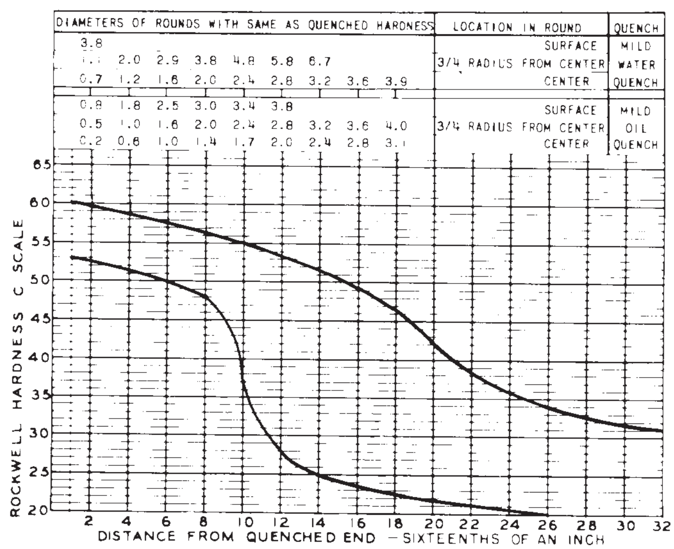
HEAT TREATING TEMPERATURES RECOMMENDED BY SAE
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F

*For forged or rolled specimens only.

HARDENABILITY BAND 15B41 H

C	Mn	Si	Ni	Cr	Mo	
0.35/0.45	1.25/1.75	0.15/0.35				

Can be expected to contain 0.0005 to 0.003 per cent boron



NOTE—1 in. = 25.4 mm.

FIG. 85 Limits for Hardenability Band 15B41 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	H MAX.	H MIN.
1	63	56
2	62	56
3	62	55
4	61	54
5	60	53
6	59	52
7	58	42
8	57	34
9	56	31
10	55	30
11	53	29
12	51	28
13	48	27
14	45	27
15	41	26
16	38	26
18	34	25
20	32	24
22	31	23
24	30	22
26	29	21
28	29	20
30	28	
32	28	

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE

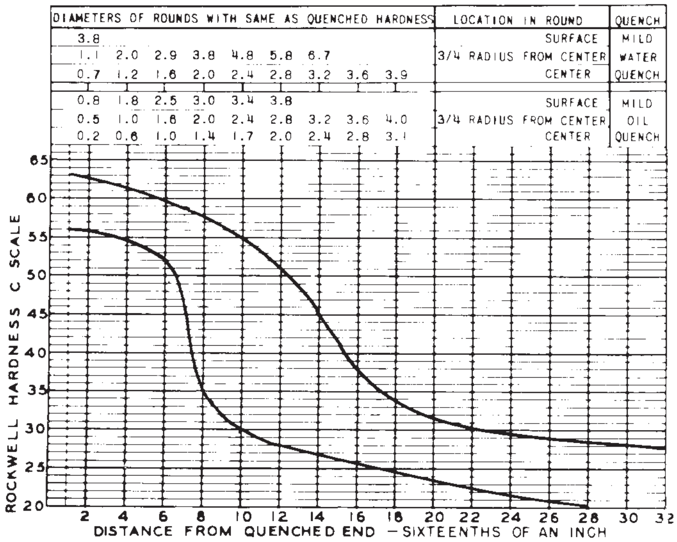
*NORMALIZE	1600 °F
AUSTENITIZE	1550 °F

*For forged or rolled specimens only

HARDENABILITY BAND 15B48 H

C	Mn	Si	Ni	Cr	Mo	
0.43/0.53	1.00/1.50	0.15/0.35				

Can be expected to contain 0.0005 to 0.003 per cent boron.



NOTE—1 in. = 25.4 mm.

FIG. 86 Limits for Hardenability Band 15B48 H

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	H	
	MAX.	MIN.
1	-	60
2	-	60
3	-	60
4	-	60
5	65	59
6	65	58
7	64	57
8	64	52
9	64	43
10	63	39
11	63	37
12	63	35
13	62	35
14	62	34
15	61	33
16	60	33
18	58	32
20	54	31
22	48	30
24	43	30
26	40	29
28	37	28
30	35	27
32	34	26

HEAT TREATING TEMPERATURES RECOMMENDED BY SAE

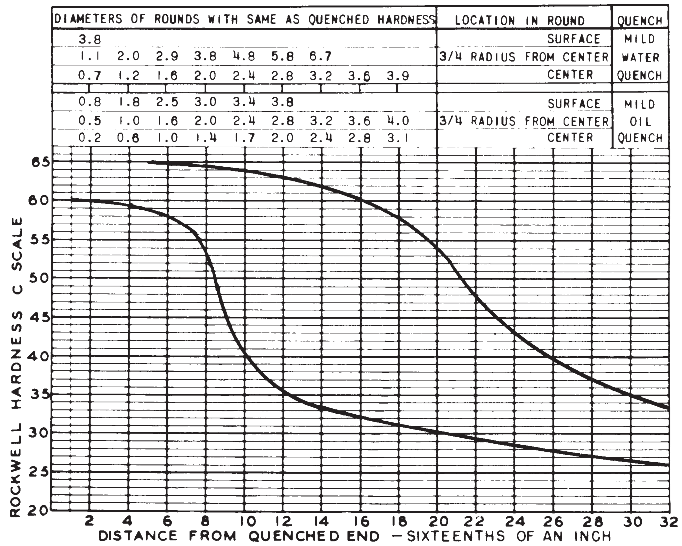
*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F

*For forged or rolled specimens only.

HARDENABILITY BAND 15B62 H

C	Mn	Si	Ni	Cr	Mo	
0.54/0.67	1.00/1.50	0.40/0.60				

Can be expected to contain 0.0005 to 0.003 per cent boron.



NOTE—1 in. = 25.4 mm.

FIG. 87 Limits for Hardenability Band 15B62 H

Designation: A 311/A 311M – 04

Standard Specification for Cold-Drawn, Stress-Relieved Carbon Steel Bars Subject to Mechanical Property Requirements[1]

This standard is issued under the fixed designation A 311/A 311M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers two classes, nine grades, and four conditions of stress-relieved cold-drawn carbon steel bars produced to mechanical property requirements. One class, B, is cold drawn with higher than normal (heavy) drafts to provide higher strength levels, and four grades provide improved machinability.

1.2 Supplementary Requirements, S1 through S6, of an optional nature are provided.

1.3 The values stated in inch-pound units or SI units are to be regarded as the standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents, therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for

A 108 Specification for Steel Bar, Carbon and Alloy, Cold-Finished

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

E 527 Practice for Numbering Metals and Alloys (UNS)

3. Terminology

3.1 *Definitions:*

3.1.1 *stress relieving*—heating to a suitable temperature, holding long enough to reduce residual stresses, and then cooling slowly enough to minimize the development of new residual stresses.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *heavy draft*—Using higher than normal drafts (approximately 10 % through 35 % reduction), followed by stress relieving, produces higher tensile and yield strengths provided an appropriate composition is used; for example, medium carbon with normal or higher manganese content.

4. Classification

4.1 The bars are furnished in the following classes and grades, and in the conditions shown in 6.4.

4.1.1 *Class A*—Normal-draft cold-drawn and stress-relieved rounds, squares, hexagons, and flats in the following grades:[3]

Grades	UNS Designations[3]
1018	G10180
1035	G10350
1045	G10450
1050	G10500
1541	G15410
1117	G11170
1137	G11370
1141	G11410
1144	G11440

4.1.2 *Class B*—Heavy-draft cold-drawn and stress-relieved rounds and hexagons in the following grades:

Grade	UNS Designations[3]
1045	G10450
1050	G10500
1541	G15410
1141	G11410
1144	G11440

5. Ordering Information

5.1 Orders for material under this specification should include the following information as required to adequately describe the desired material:

5.1.1 Quantity (weight [mass] or number of pieces),

5.1.2 Name of material (carbon steel bars, cold drawn, stress relieved),

5.1.3 Condition 8.3,

5.1.4 Cross-sectional shape,

5.1.5 Size,

5.1.6 Length,

5.1.7 Class and grade,

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

Current edition approved March 1, 2004. Published April 2004. Originally approved in 1947. Last previous edition approved in 2000 as A 311/A 311M–95 (2000).

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] New designation established in accordance with Practice E 527 and SAE J 1086.

***A Summary of Changes section appears at the end of this standard.**

5.1.8 Report of heat analysis, tensile properties Section 11,
5.1.9 ASTM designation A 311 or A 311M,
5.1.10 Application,
5.1.11 Leaded steel, when required (see Table 1, footnote A),
5.1.12 Supplementary requirements, if any, and
5.1.13 Additional requirements, if any.

NOTE 1—A typical ordering description is as follows: 10 000 lb carbon steel bars, cold drawn, stress relieved turned and polished, round 2.0 in. (50.8 mm) Diameter, 10 to 12 ft (3048 to 3658 mm) long, Class B, Grade 1050, (UNS G 10500), fine grain, test reports required, ASTM A 311/ A 311M dated____ , hydraulic cylinder piston rods. [5000 kg carbon steel bars, cold drawn, stress relieved turned and polished round 50 mm diameter, 3050 to 3650 mm long, Class B, Grade 1050 (UNS G 10500), fine grain, test reports required, ASTM A 311M dated ____ , hydraulic cylinder piston rods.]

6. Materials and Manufacture

6.1 *Melting Practice*—The steel shall be made by one or more of the following primary processes: open-hearth, basic-oxygen, or electric-furnace. The primary melting may incorporate separate degassing or refining and may be followed by secondary melting using electroslag remelting or vacuum arc remelting. Where secondary melting is employed, the heat shall be defined as all of the ingots remelted from a single primary heat.

6.2 *Cold Working*:

6.2.1 Class A bars shall be cold drawn using normal drafting practices.

6.2.2 Class B bars shall be cold drawn using heavy (higher than normal) drafting practices.

6.3 *Thermal Treatment*—After cold drawing, the bars shall be stress relieved at a temperature of not less than 550°F [288°C] to meet the mechanical requirements specified in Table 2.

6.4 *Condition*—The bars shall be furnished in the following cold finish conditions, as specified:

6.4.1 Cold drawn, stress relieved;
6.4.2 Cold drawn, stress relieved, turned, and polished;
6.4.3 Cold drawn, stress relieved, turned, ground, and polished; and
6.4.4 Cold drawn, stress relieved, ground, and polished.

NOTE 2—When turned bars are specified, turning may be performed prior to cold-drawing.

7. Chemical Composition

7.1 *Composition*—The cast or heat analysis shall conform to the chemical composition requirements specified in Table 1 for the grade ordered.

8. Mechanical Properties

8.1 *Requirements*—The bars shall conform to the requirements listed in Table 2.

8.2 *Number of Tests*—At least one tension test shall be made on each lot. A lot shall consist of bars of the same size from the same heat which have been stress relieved in the same stationary furnace charge. For continuous type of treatment, a lot shall consist of 25 tons [25 Mg] or less of the same size of each heat, treated in the same cycle.

8.3 *Specimens*—Tension test specimens shall be taken longitudinally in accordance with and from the locations specified in Test Methods and Definitions A 370.

8.4 *Test Methods*—Tension tests shall be made in accordance with Test Methods and Definitions A 370. The yield strength shall be determined at 0.2 % offset or at 0.005 in./in. [0.005 mm/mm] of gage length, total extension under load.

9. Workmanship, Finish, and Appearance

9.1 *Surface Finish*—Unless otherwise specified, the bars shall have a commercial bright smooth surface finish consistent with the cold finishing operations specified in 6.4.

9.2 Bars that are thermal treated after cold finishing may have a discolored or oxidized surface.

9.3 *Oiling*—The bars shall be given a surface coating of oil or other rust inhibitor to protect against rust during shipment.

9.4 *Workmanship*—The bars shall be free of pipe, cracks, and flakes. Within the limits of good manufacturing and inspection practices, the bars shall be free of injurious seams, laps, segregation, or other imperfections that, due to their nature, degree, or extent, will interfere with the use of the material in machining or fabrication of suitable parts.

10. General Requirements

10.1 Material furnished under this specification shall conform to the requirements of the current edition of Specification A 29/A 29M and/or Specification A 108 unless otherwise stated.

11. Certification and Test Reports

11.1 A manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the heat analysis and tension test results shall be furnished at the time of shipment (if requested). The report shall include the name of the manufacturer, ASTM designation and year date and revision letter, if any, class and grade, heat number, size, and grain size (if requested).

12. Keywords

12.1 carbon steel bars; cold finished steel bars; steel bars

TABLE 1 Chemical Requirements (Cast or Heat Analysis)[A]

UNS Designation	Grade	Carbon, %	Manganese, %	Phosphorus, max %	Sulfur, %
G10180	1018	0.15-0.20	0.60-0.90	0.040	0.050 max
G10350	1035	0.32-0.38	0.60-0.90	0.040	0.050 max
G10450	1045	0.43-0.50	0.60-0.90	0.040	0.050 max
G10500	1050	0.48-0.55	0.60-0.90	0.040	0.050 max
G15410	1541	0.36-0.44	1.35-1.65	0.040	0.050 max
G11170	1117	0.14-0.20	1.00-1.30	0.040	0.08-0.13
G11370	1137	0.32-0.39	1.35-1.65	0.040	0.08-0.13
G11410	1141	0.37-0.45	1.35-1.65	0.040	0.08-0.13
G11440	1144	0.40-0.48	1.35-1.65	0.040	0.24-0.33

[A] When lead is required as an added element to a standard steel, a range from 0.15 to 0.35 % inclusive, is specified. Such a steel is identified by inserting the letter "L" between the second and third numerals of the grade designation, for example, 10L45. A cast or heat analysis is not determinable when lead is added to the ladle stream.

TABLE 2 Mechanical Requirements

Class A—Normal Draft Cold Drawn and Stress Relief Annealed						
UNS No.	Grade Designation	Diameter, Thickness, or Distance Between Parallel Faces, in. [mm]	Tensile Strength, min, ksi [MPa]	Yield Strength, min, ksi [MPa]	Elongation in 2 in. [50 mm], min, %	Reduction of Area, min, %
G10180	1018	Up to ⅞ [20], incl	70 [485]	60 [415]	18	40
		Over ⅞ [20] to 1¼ [30], incl	65 [450]	55 [380]	16	40
		Over 1¼ [30] to 2 [50], incl	60 [415]	50 [345]	15	35
		Over 2 [50] to 3 [75], incl	55 [380]	45 [310]	15	35
G10350	1035	Up to ⅞ [20], incl	85 [590]	75 [520]	13	35
		Over ⅞ [20] to 1¼ [30], incl	80 [550]	70 [485]	12	35
		Over 1¼ [30] to 2 [50], incl	75 [520]	65 [450]	12	35
		Over 2 [50] to 3 [75], incl	70 [485]	60 [415]	10	30
G10450	1045	Up to ⅞ [20], incl	95 [655]	85 [585]	12	35
		Over ⅞ [20] to 1¼ [30], incl	90 [620]	80 [550]	11	30
		Over 1¼ [30] to 2 [50], incl	85 [585]	75 [520]	10	30
		Over 2 [50] to 3 [75], incl	80 [550]	70 [485]	10	30
G10500	1050	Up to ⅞ [20], incl	100 [690]	90 [620]	11	35
and	and	Over ⅞ [20] to 1¼ [30], incl	95 [655]	85 [585]	11	30
G15410	G1541	Over 1¼ [30] to 2 [50], incl	90 [620]	80 [550]	10	30
		Over 2 [50] to 3 [75], incl	85 [585]	75 [520]	10	30
G11170	1117	Up to ⅞ [20], incl	75 [520]	65 [450]	15	40
		Over ⅞ [20] to 1¼ [30], incl	70 [485]	60 [415]	15	40
		Over 1¼ [30] to 2 [50], incl	65 [450]	55 [380]	13	35
		Over 2 [50] to 3 [75], incl	60 [415]	50 [345]	12	30
G11370	1137	Up to ⅞ [20], incl	95 [655]	90 [620]	11	35
and	and	Over ⅞ [20] to 1¼ [30], incl	90 [620]	85 [585]	11	30
G11410	1141	Over 1¼ [30] to 2 [50], incl	85 [585]	80 [550]	10	30
		Over 2 [50] to 3 [70], incl	80 [550]	75 [520]	10	30
G11440	1144	Up to ⅞ [20], incl	105 [725]	95 [655]	10	30
		Over ⅞ [20] to 1¼ [30], incl	100 [690]	90 [620]	10	30
		Over 1¼ [30] to 2 [50], incl	95 [655]	85 [585]	10	25
		Over 2 [50] to 3 [70], incl	90 [620]	80 [550]	10	20
		Over 3 [70] to 4½ [115], incl	85 [585]	75 [520]	10	20
Class B—Heavy Draft Cold Drawn and Stress Relieved Annealed						
UNS No.	Grade Designation	in. [mm], Round or Hexagon[A]	Tensile Strength, min, ksi [MPa]	Yield Strength, min, ksi [MPa]	Elongation in 2 in. [50 mm], min, %	Reduction of Area, min, %
G10450	1045	Up to ⅞ [20] incl	115 [795]	100 [690]	10	25
		Over ⅞ [20] to 1¼ [30], incl	115 [795]	100 [690]	10	25
		Over 1¼ [30] to 2 [50], incl	115 [795]	100 [690]	10	25
		Over 2 [50] to 3 [75], incl	115 [795]	100 [690]	9	25
		Over 3 [75] to 4 [102], incl	105 [725]	90 [620]	7	20
G10500	1050	Up to ⅞ [20], incl	115 [795]	100 [690]	8	25
G15410	1541	Over ⅞ [20] to 1¼ [30], incl	115 [795]	100 [690]	8	25
G11410	1141	Over 1¼ [30] to 2 [50], incl	115 [795]	100 [690]	8	25
and	and	Over 2 [50] to 3 [75], incl	115 [795]	100 [690]	8	20
G11440	1144	Over 3 [75] to 4½ [115], incl	115 [795]	100 [690]	7	20

[A] Maximum size for hexagons is 1½ in. [40 mm].

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry or order. Details of these requirements shall be agreed upon between the manufacturer and the purchaser.

S1. Special Surface

S1.1 When inspection standards more restrictive than visual inspection are required, special surface may be specified.

S2. Restricted Cast or Heat Analysis

S2.1 When required, the purchaser may specify restrictive cast or heat analysis limits on one or more elements. The degree of restriction and the number of elements so restricted are both subject to agreement between the manufacturer and the purchaser.

S3. Restricted Decarburization

S3.1 The purchaser may specify a maximum affected depth of decarburization when required for special applications, subject to agreement between the manufacturer and the purchaser.

S4. Nonmetallic Inclusion Requirements (Microscopical)

S4.1 When nonmetallic inclusion requirements are specified, the samples for testing shall be taken on a longitudinal direction midway between the center and the surface of the material. The area of the sample to be examined should be agreed upon between the purchaser and the manufacturer, and the test specimen should be hardened by heating and quenched before being polished to avoid pits. The rating of the inclusion count should also be agreed upon and be based upon examination at a magnification of 100 diameters. Resulfurized steels are not subject to inclusion ratings.

S5. Restricted Incidental Elements

S5.1 The purchaser may specify limiting maximum requirements for copper, nickel, chromium, or molybdenum subject to agreement between the manufacturer and the purchaser.

S6. Grain Size

S6.1 The steel shall conform to either the coarse austenitic grain size (except as stated in S6.2), or the fine austenitic grain size requirement of Specification A 29/A 29M.

S6.2 Certain elements, or combinations of elements, such as manganese, sulfur, and lead tend to produce grain refinement and it is technically inappropriate to ensure coarse grain size as measured by the McQuaid-Ehn test on high manganese, high sulfur, and leaded steels such as 1144, 1151, and 11L41.

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 311/A 311–95 (2000) that may impact the use of this standard.

(1) Added Specification A 108 to Referenced Documents.

Designation: A 321 – 90 (Reapproved 2001)

Standard Specification for Steel Bars, Carbon, Quenched and Tempered[1]

This standard is issued under the fixed designation A 321; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers hot-rolled, quenched, and tempered carbon steel bars, of the following sections and size ranges:

1.1.1 *Rounds*, ¼ to 9½ in. (6.35 to 241.3 mm) incl, in diameter.

1.1.2 *Squares*, ¼ to 5½ in. (6.35 to 139.7 mm) incl, between parallel surfaces.

1.1.3 *Hexagons*, ¼ in. (6.35 mm) and over between parallel surfaces.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

3. Ordering Information

3.1 Orders for material under this specification should include the following information:

3.1.1 Quantity (weight or number of pieces),

3.1.2 Name of material,

3.1.3 Stress relief anneal (if required),

3.1.4 Finish (specify descaled and oiled if required),

3.1.5 Dimensions (cross sectional shape, size, and length),

3.1.6 Straightness (if other than standard is required),

3.1.7 Leaded steel (if required),

3.1.8 Heat analysis or test report (if required),

3.1.9 ASTM designation and date of issue, and

3.1.10 Additional requirements, if any.

NOTE 1—A typical ordering description is as follows: 10 000 lb, hot-rolled bars quenched and tempered, straightened, stress relieved, descaled, 1.000 in. diameter by 10 ft long, heat analysis required, ASTM A 321, dated____.

4. Manufacture

4.1 *Melting Practice*—The steel shall be made by one or more of the following primary processes: open-hearth, basic-oxygen, or electric-furnace. The primary melting may incorporate separate degassing or refining and may be followed by secondary melting using electroslag remelting or vacuum arc remelting. Where secondary melting is employed, the heat shall be defined as all of the ingots remelted from a single primary heat.

4.2 *Discard*—A sufficient discard shall be made (from each ingot, when ingot cast) to secure freedom from injurious piping and undue segregation.

4.3 *Heat Treatment*:

4.3.1 *Cooling*—Immediately after rolling, the bars shall be allowed to cool to a temperature below the critical range under suitable conditions to prevent injury by too rapid cooling.

4.3.2 *Quenching and Tempering*—The material shall be uniformly heated to the austenitizing temperature, soaked for a sufficient length of time to produce the desired change in structure (a group thus heated being known as a "quenching charge"), and quenched in some medium under substantially uniform conditions for each quenching charge. The material shall then be uniformly reheated to the proper temperature for tempering (a group thus reheated being known as a "tempering charge"), and allowed to cool uniformly. The temperature selected for tempering shall not be less than 800°F (427°C).

4.3.3 *Stress Relieving*—When it is desirable to minimize internal stresses introduced by straightening, the purchaser may specify a stress relief anneal as a final operation.

5. Chemical Composition

5.1 *Chemical Composition*—The steel shall conform to the requirements for chemical composition specified in Table 1.

5.2 *Leaded Steel*—When required, lead may be specified as an added element. A range from 0.15 to 0.35 %, inclusive, is commonly specified. Heat analysis for lead is not determinable since lead is added to the ladle stream while each ingot is poured.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

Current edition approved Jan. 26, 1990. Published March 1990. Originally published as A 321 – 49 T. Last previous edition A 321 – 89.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

TABLE 1 Chemical Requirements (Heat Analysis)

Element	Composition, %
Carbon, max	0.55
Manganese	0.60 to 0.90
Phosphorus, max	0.040
Sulfur, max	0.050
Silicon	0.15 to 0.35
Lead	[A]

[A] When required, lead may be specified as an added element. See 6.2.

6. Grain Size Requirements

6.1 The steel shall conform to the fine austenitic grain size requirement of Specification A 29/A 29M.

7. Mechanical Properties

7.1 *Tensile Properties*—The material, after final heat treatment and straightening, shall conform to the requirements as to tensile properties specified in Table 2.

7.2 *Test Specimens*:

7.2.1 Test specimens shall be prepared for testing from the material in the quenched and tempered condition.

7.2.2 Specimens shall be taken longitudinally and may be tested in full thickness or section, or they may be machined to the dimensions shown in Figs. 4 or Figs. 6 of Test Methods and Definitions A 370. If test specimens are selected conforming to the dimensions of Fig. 6 for sizes 1½ in. (38.1 mm) and larger in diameter or distance between parallel faces, they shall be machined from a position midway between the center and the surface of the bar. If test specimens are selected conforming to the dimensions of Fig. 6 for sizes under 1½ in. in diameter or distance between parallel faces, they shall be machined from the center of the bar.

TABLE 2 Tensile Requirements

Diameter or Distance Between Parallel Faces, in. (mm)	Yield Point, min, ksi (MPa)	Tensile Strength, min, ksi (MPa)	Elongation in 2 in. or 50 mm, min, %	Reduction of Area, min, %
1 (25.4) and under	75 (520)	110 (760)	18	45
Over 1 to 2½ (25.4 to 63.5), incl	70 (485)	105 (720)	18	45
Over 2½ to 4 (63.5 to 101.6), incl	65 (450)	95 (660)	18	45
Over 4 to 6 (101.6 to 152.4), incl	60 (415)	90 (620)	18	40
Over 6 to 9½ (152.4 to 241.3), incl	50 (345)	85 (590)	18	35

7.3 *Number of Tests*—One tension test shall be made from each tempering or stress-relieving charge. If more than one quenching charge is represented, one tension test shall be made from each quenching charge. If more than one heat is represented in a quenching charge, one tension test shall be made from each heat and size. For continuous type of treatment, one tension test shall be made for each 25 tons (23 Mg) of each heat or size.

7.4 *Test Methods*—Tension tests shall be made in accordance with Test Methods and Definitions A 370. The yield point shall be determined by the drop of the beam or halt in the gage of the testing machine, or by the use of dividers, as covered in Section 12 of Test Methods and Definitions A 370.

8. Permissible Variations of Dimensions

8.1 *Straightness*—Unless otherwise specified, all material shall be supplied to a straightness tolerance of ⅛ in. (3.2 mm) in any 5 ft (1.52 m) but it may not exceed the following:

Maximum straightness deviation, in. (mm) =
⅛ (3.2 mm) × length in feet (or metres)/5 (or 1.52)

9. Workmanship, Finish, and Appearance

9.1 *Descaling*—Unless otherwise specified, the bars shall be furnished not descaled. When required, the bars may be specified to be descaled and shall be oiled as a protection from rust during shipment.

10. General Requirements

10.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 29/A 29M unless otherwise provided herein.

11. Keywords

11.1 carbon steel bars; quenched and tempered steel bars; steel bars

Designation: A 322 – 91 (Reapproved 2001)$^{\epsilon 1}$

Standard Specification for Steel Bars, Alloy, Standard Grades[1]

This standard is issued under the fixed designation A 322; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

ϵ^1 NOTE—A correction was made to Table 1 in May 2004.

1. Scope

1.1 This specification covers hot-wrought alloy steel bars. Bar applications include forging, heat treating, cold drawing, machining and many structural components (Note 1).

NOTE 1—A guide for the selection of steel bars is contained in Practice A 400.

1.2 The bars shall be furnished in the grades specified in Table 1. Sections and sizes of bar steel available are covered in Specification A 29/A 29M. Hot-wrought alloy steel bars are produced in cut lengths and coils; the manufacturer should be consulted regarding sections and sizes available in coils, produced to a chemical composition.

1.3 Some applications may require superior surface quality, or special chemical restrictions, metallurgical characteristics, heat treatment, or surface finishes which the purchaser may obtain by designating one or more of the available Supplementary Requirements.

1.4 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 304 Specification for Steel Bars, Alloy, Subject to End-Quench Hardenability Requirements[2]

A 400 Practice for Steel Bars, Selection Guide, Composition, and Mechanical Properties[2]

E 112 Test Methods for Determining Average Grain Size[3]

E 381 Method of Macroetch Testing, Inspection, and Rating Steel Products, Comprising Bars, Billets, Blooms, and Forgings[3]

E 527 Practice for Numbering Metals and Alloys (UNS)[4]

3. Ordering Information

3.1 Orders under this specification should include the following as required to describe adequately the desired material:

3.1.1 Quantity (weight or number of bars),

3.1.2 Name of material (hot-wrought alloy steel bars),

3.1.3 Dimensions,

3.1.4 ASTM designation,

3.1.5 Deoxidation practice (see 5.3),

3.1.6 Grade designation or chemical composition limits (see 6.1 and Table 1),

3.1.7 Grain size if required,

3.1.8 Test reports, if required (Section 8),

3.1.9 Additions to the specification and Supplementary Requirements, if required, and

3.1.10 Application.

4. General Requirements

4.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 29/A 29M, unless otherwise provided herein.

5. Materials and Manufacture

5.1 The steel shall be made by one or more of the following primary processes: open-hearth, basic-oxygen, or electric-furnace. The primary melting may incorporate separate degassing or refining and may be followed by secondary melting using electro-slag remelting or vacuum arc remelting. Where secondary melting is employed, the heat shall be defined as all of the ingots remelted from a single primary heat.

5.2 The steel shall be furnished as strand cast or ingot cast, unless otherwise specified.

5.3 *Deoxidation*—Killed steel is required.

5.3.1 The purchaser may designate that the steel be made to coarse or fine austenitic grain size. (See Supplementary Requirement S9 or S10.)

5.4 *Slow Cooling*—Immediately after hot forming, the bars shall be allowed to cool to a temperature below the critical

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] *Annual Book of ASTM Standards*, Vol 01.01.

range under suitable conditions to prevent imperfections caused by too rapid cooling.

5.5 *Thermal Treatment*—Various thermal treatments such as annealing, stress relief, quench and temper, normalize, etc., are available. Such treatments must be specified as a Supplementary Requirement.

6. Chemical Composition

6.1 The heat analysis shall conform to the requirements for chemical composition in Table 1 for the grade specified.

TABLE 1 Grade Designations and Chemical Compositions of Hot-Wrought Alloy Steel Bars[A,B]

UNS Designation[C]	Grade[D] Designations	Chemical Composition, Ranges and Limits, %							
		Carbon	Manganese	Phosphorus, max	Sulfur,[E] max	Silicon[F]	Nickel	Chromium	Molybdenum
G13300	1330	0.28–0.33	1.60–1.90	0.035	0.040	0.15–0.35	...	...	...
G13350	1335	0.33–0.38	1.60–1.90	0.035	0.040	0.15–0.35	...	...	...
G13400	1340	0.38–0.43	1.60–1.90	0.035	0.040	0.15–0.35	...	...	...
G13450	1345	0.43–0.48	1.60–1.90	0.035	0.040	0.15–0.35	...	...	...
G40230	4023	0.20–0.25	0.70–0.90	0.035	0.040	0.15–0.35	...	...	0.20–0.30
G40240	4024	0.20–0.25	0.70–0.90	0.035	0.035–0.050	0.15–0.35	...	...	0.20–0.30
G40270	4027	0.25–0.30	0.70–0.90	0.035	0.040	0.15–0.35	...	...	0.20–0.30
G40280	4028	0.25–0.30	0.70–0.90	0.035	0.035–0.050	0.15–0.35	...	...	0.20–0.30
G40370	4037	0.35–0.40	0.70–0.90	0.035	0.040	0.15–0.35	..	...	0.20–0.30
G40470	4047	0.45–0.50	0.70–0.90	0.035	0.040	0.15–0.35	...	...	0.20–0.30
G41180	4118	0.18–0.23	0.70–0.90	0.035	0.040	0.15–0.35	...	0.40–0.60	0.08–0.15
G41200		0.18–0.23	0.90–1.20	0.035	0.040	0.15–0.35	...	0.40–0.60	0.13–0.20
G41210		0.18–0.23	0.75–1.00	0.035	0.040	0.15–0.35	...	0.45–0.65	0.20–0.30
G41300	4130	0.28–0.33	0.40–0.60	0.035	0.040	0.15–0.35	...	0.80–1.10	0.15–0.25
G41370	4137	0.35–0.40	0.70–0.90	0.035	0.040	0.15–0.35	...	0.80–1.10	0.15–0.25
G41400	4140	0.38–0.43	0.75–1.00	0.035	0.040	0.15–0.35	...	0.80–1.10	0.15–0.25
G41420	4142	0.40–0.45	0.75–1.00	0.035	0.040	0.15–0.35	...	0.80–1.10	0.15–0.25
G41450	4145	0.43–0.48	0.75–1.00	0.035	0.040	0.15–0.35	...	0.80–1.10	0.15–0.25
G41470	4147	0.45–0.50	0.75–1.00	0.035	0.040	0.15–0.35	...	0.80–1.10	0.15–0.25
G41500	4150	0.48–0.53	0.75–1.00	0.035	0.040	0.15–0.35	...	0.80–1.10	0.15–0.25
G41610	4161	0.56–0.64	0.75–1.00	0.035	0.040	0.15–0.35	...	0.70–0.90	0.25–0.35
G43200	4320	0.17–0.22	0.45–0.65	0.035	0.040	0.15–0.35	1.65–2.00	0.40–0.60	0.20–0.30
G43400	4340	0.38–0.43	0.60–0.80	0.035	0.040	0.15–0.35	1.65–2.00	0.70–0.90	0.20–0.30
G43406	E4340	0.38–0.43	0.65–0.85	0.025	0.025	0.15–0.35	1.65–2.00	0.70–0.90	0.20–0.30
G46150	4615	0.13–0.18	0.45–0.65	0.035	0.040	0.15–0.35	1.65–2.00	...	0.20–0.30
G46200	4620	0.17–0.22	0.45–0.65	0.035	0.040	0.15–0.35	1.65–2.00	...	0.20–0.30
G46210	4621	0.18–0.23	0.70–0.90	0.035	0.040	0.15–0.35	1.65–2.00	...	0.20–0.30
G46260	4626	0.24–0.29	0.45–0.65	0.035	0.040	0.15–0.35	0.70–1.00	...	0.15–0.25
G47150		0.13–0.18	0.70–0.90	0.035	0.040	0.15–0.35	0.70–1.00	0.45–0.65	0.45–0.60
G47200	4720	0.17–0.22	0.50–0.70	0.035	0.040	0.15–0.35	0.90–1.20	0.35–0.55	0.15–0.25
G48150	4815	0.13–0.18	0.40–0.60	0.035	0.040	0.15–0.35	3.25–3.75	...	0.20–0.30
G48170	4817	0.13–0.20	0.40–0.60	0.035	0.040	0.15–0.35	3.25–3.75	...	0.20–0.30
G48200	4820	0.18–0.23	0.50–0.70	0.035	0.040	0.15–0.35	3.25–3.75	...	0.20–0.30
G51170	5117	0.15–0.20	0.70–0.90	0.035	0.040	0.15–0.35	...	0.70–0.90	...
G51200	5120	0.17–0.22	0.70–0.90	0.035	0.040	0.15–0.35	...	0.70–0.90	...
G51300	5130	0.28–0.33	0.70–0.90	0.035	0.040	0.15–0.35	...	0.80–1.10	...
G51320	5132	0.30–0.35	0.60–0.80	0.035	0.040	0.15–0.35	...	0.75–1.00	...
G51350	5135	0.33–0.38	0.60–0.80	0.035	0.040	0.15–0.35	...	0.80–1.05	...
G51400	5140	0.38–0.43	0.70–0.90	0.035	0.040	0.15–0.35	...	0.70–0.90	...
G51500	5150	0.48–0.53	0.70–0.90	0.035	0.040	0.15–0.35	...	0.70–0.90	...
G51550	5155	0.51–0.59	0.70–0.90	0.035	0.040	0.15–0.35	...	0.70–0.90	...
G51600	5160	0.56–0.64	0.75–1.00	0.035	0.040	0.15–0.35	...	0.70–0.90	...
G51986	E51100	0.98–1.10	0.25–0.45	0.025	0.025	0.15–0.35	...	0.90–1.15	...
G52986	E52100	0.98–1.10	0.25–0.45	0.025	0.025	0.15–0.35	...	1.30–1.60	...
									Vanadium
G61180	6118	0.16–0.21	0.50–0.70	0.035	0.040	0.15–0.35	...	0.50–0.70	0.10–0.15
G61500	6150	0.48–0.53	0.70–0.90	0.035	0.040	0.15–0.35	...	0.80–1.10	0.15 min
									Molybdenum
G86150	8615	0.13–0.18	0.70–0.90	0.035	0.04	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25
G86170	8617	0.15–0.20	0.70–0.90	0.035	0.040	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25
G86200	8620	0.18–0.23	0.70–0.90	0.035	0.04	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25
G86220	8622	0.20–0.25	0.70–0.90	0.035	0.040	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25
G86250	8625	0.23–0.28	0.70–0.90	0.035	0.040	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25
G86270	8627	0.25–0.30	0.70–0.90	0.035	0.040	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25
G86300	8630	0.28–0.33	0.70–0.90	0.035	0.040	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25
G86370	8637	0.35–0.40	0.75–1.00	0.035	0.040	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25
G86400	8640	0.38–0.43	0.75–1.00	0.035	0.040	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25
G86420	8642	0.40–0.45	0.75–1.00	0.035	0.040	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25

TABLE 1 *Continued*

UNS Designation[C]	Grade[D] Designations	Chemical Composition, Ranges and Limits, %							
		Carbon	Manganese	Phosphorus, max	Sulfur,[E] max	Silicon[F]	Nickel	Chromium	Molybdenum
G86450	8645	0.43–0.48	0.75–1.00	0.035	0.040	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25
G86550	8655	0.51–0.59	0.75–1.00	0.035	0.040	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25
G87200	8720	0.18–0.23	0.70–0.90	0.035	0.040	0.15–0.35	0.40–0.70	0.40–0.60	0.20–0.30
G87400	8740	0.38–0.43	0.75–1.00	0.035	0.040	0.15–0.35	0.40–0.70	0.40–0.60	0.20–0.30
G88220	8822	0.20–0.25	0.75–1.00	0.035	0.040	0.15–0.35	0.40–0.70	0.40–0.60	0.30–0.40
G92590	9259	0.56–0.64	0.75–1.00	0.035	0.040	0.70–1.10	...	0.45–0.65	...
G92600	9260	0.56–0.64	0.75–1.00	0.035	0.040	1.80–2.20	...	...	...
				Standard Boron Steels[G]					
G50441	50B44	0.43–0.48	0.75–1.00	0.035	0.040	0.15–0.35	...	0.20–0.60	...
G50461	50B46	0.44–0.49	0.75–1.00	0.035	0.040	0.15–0.35	...	0.20–0.35	...
G50501	50B50	0.48–0.53	0.75–1.00	0.035	0.040	0.15–0.35	...	0.40–0.60	...
G50601	50B60	0.56–0.64	0.75–1.00	0.035	0.040	0.15–0.35	...	0.40–0.60	...
G51601	51B60	0.56–0.64	0.75–1.00	0.035	0.040	0.15–0.35	...	0.70–0.90	...
G81451	81B45	0.43–0.48	0.75–1.00	0.035	0.040	0.15–0.35	0.20–0.40	0.35–0.55	0.08–0.15
G94171	94B17	0.15–0.20	0.75–1.00	0.035	0.040	0.15–0.35	0.30–0.60	0.30–0.50	0.08–0.15
G94301	94B30	0.28–0.33	0.75–1.00	0.035	0.040	0.15–0.35	0.30–0.60	0.30–0.50	0.08–0.15

[A] Small quantities of certain elements are present in alloy steels which are not specified or required. These elements are considered as incidental and may be present to the following maximum amounts: copper 0.35 %, nickel 0.25 %, chromium 0.20 %, and molybdenum 0.06 %.

[B] Standard alloy steels can be produced with a lead range of 0.15 to 0.35 %. Such steels are identified by inserting the letter "L" between the second and third numerals of the number, that is, 41L40. A cast or heat analysis is not determinable when lead is added to the ladle stream

[C] New designation established in accordance with Practice E 527

[D] Grade designations correspond to the respective AISI and SAE designations. Grade compositions correspond to the respective AISI compositions.

[E] Where minimum and maximum sulfur contents are shown, it is indicative of resulfurized steel

[F] Silicon may be specified by the purchaser as 0.10 % maximum. The need for 0.10 % maximum generally relates to severely cold-formed parts.

[G] These steels can be expected to contain 0.0005 to 0.003 boron %. If the usual titanium additive is not permitted, the steels can be expected to contain up to 0.005% boron.

6.2 The composition of the steel furnished under this specification may be other than listed in Table 1 when agreed upon between the manufacturer and the purchaser as out-lined in Specification A 29/A 29M (Table on Heat Analysis Chemical Ranges and Limits of Alloy Steel Bars).

7. Workmanship, Finish, and Appearance

7.1 *Workmanship*—The bars shall be free of pipe, cracks, and flakes. Within the limits of good manufacturing and inspection practices, the bars shall be free of injurious seams, laps, segregation, or other imperfections which due to their nature, degree, or extent, will interfere with the use of the material in machining or fabrication of suitable parts.

7.2 *Descaling*—When descaled bars are required, Supplementary Requirement S12 on Pickling or S13 on Blast Cleaning must be specified.

8. Certification and Test Reports

8.1 When specified by the purchaser, a manufacturer's certification that the material was manufactured and tested in accordance with this specification, together with a report of the cast or heat analysis test results for the specified elements, shall be furnished. The report shall include the name of the manufacturer, ASTM designation and year date and revision letter, if any, type and grade, heat number, and size.

8.2 When Supplementary Requirements are specified, the report shall include a statement of compliance with the requirement of the results of tests when the requirement involves measured test values.

SUPPLEMENTARY REQUIREMENTS

One or more of the following Supplementary Requirements shall apply when specified by the purchaser.

S1. Axle Shaft Quality

S1.1 Axle shaft quality applies to hot-rolled steel bars intended for the manufacture of power-driven axle shafts of the automotive or truck type, which by their design or method of manufacture are not machined all over or have less than recommended stock removed for the proper clean-up of normal surface imperfections.

S2. Ball and Roller Bearing Quality and Bearing Quality

S2.1 This quality applies to steel intended for antifriction bearings.

S3. Cold Shearing Quality

S3.1 When the bar size exceeds certain limits, it is recommended that cold shearing quality steel be ordered. This quality will provide characteristics which permit cold shearing without cracking. The producer should be consulted in establishing the proper practice.

S4. Cold Working Quality

S4.1 This classification encompasses bars subject to severe cold plastic deformation such as, but not limited to, upsetting, heading, forging, forward or backward extrusion.

S4.2 If the type of steel or chemical composition does not have adequate cold working characteristics, appropriate thermal treatments should be specified.

S4.3 When Supplementary Requirement S1 is specified, the bars shall be produced by manufacturing practices and subjected to mill tests and inspection and freedom from injurious surface imperfections to the extent that the bars shall be suitable for the manufacture of identified parts. The quality requirements of individual application vary.

S5. Aircraft Quality or Magnaflux Quality

S5.1 These quality designations apply to alloy steels for important or highly stressed parts of aircraft and for other similar or corresponding purposes involving additional stringent requirements, such as: magnetic particle inspection; additional discard; macroetch tests (see Method E 381); and hardenability control (see Specification A 304).

S6. Annealing

S6.1 The steel shall be furnished annealed.

S7. Spheroidize Annealing

S7.1 The steel shall be spheroidize annealed.

S8. Stress Relieving

S8.1 The steel shall be stress relieved by heating to a temperature specified by the purchaser or to a temperature selected by the manufacturer.

S9. Grain Size (Coarse)

S9.1 The steel shall conform to the coarse austenitic grain size requirement of Specification A 29/A 29M.

S10. Grain Size (Fine)

S10.1 The steel shall be killed and shall have austenitic grain size of 5 to 8 and finer (fine grain), to be determined in accordance with the comparison procedure in Test Methods E 112. The grain structure shall be considered satisfactory when a minimum of the rated grains are 70 % within the specified size limits.

S11. Special Straightness

S11.1 The bars shall be produced with special straightness (see Specification A 29/A 29M for tolerances).

S12. Pickling

S12.1 The surface of the bars shall be descaled by pickling.

S13. Cleaning

S13.1 The surface of the bars shall be descaled by blast cleaning or other mechanical methods.

S14. Coating

S14.1 The bars shall be oiled, limed, or phosphate-coated as specified by the purchaser. The purchaser shall also specify the method of cleaning (Supplementary Requirement S12 or S13); otherwise, the bars shall be descaled by pickling or blasting at the manufacturer's option.

Designation: A 336/A 336M – 03

Standard Specification for Alloy Steel Forgings for Pressure and High-Temperature Parts[1]

This standard is issued under the fixed designation A 336/A 336M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification[2] covers ferritic steel forgings for boilers, pressure vessels, high-temperature parts, and associated equipment.

1.2 Forgings made of steel grades listed in Specification A 335/A 335M, may also be ordered under this specification. The chemical, tensile, heat treatment, and marking requirements of Specification A 335/A 335M shall apply, except the forging shall conform to the chemical requirements of Tables 1 and 2 of Specification A 335/A 335M only with respect to heat analysis. On check analysis they may deviate from these limits to the extent permitted in Table 1 of this specification.

Current	Formerly
Grade F1	Class F1
Grade F11, Class 2	Class F11
Grade F11, Class 3	Class F11A
Grade F11, Class 1	Class F11B
Grade F12	Class F12
Grade F5	Class F5
Grade F5A	Class F5A
Grade F9	Class F9
Grade F6	Class F6
Grade F21 Class 1	Class F21A
Grade F21, Class 3	Class F21
Grade F22, Class 1	Class F22A
Grade F22, Class 3	Class F22
Grade F91	Class F91
Grade F3V	Class F3V
Grade F22V	Class F22V

1.3 Supplementary Requirements S1 to S9 are provided for use when additional testing or inspection is desired. These shall apply only when specified individually by the purchaser in the order.

1.4 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch-pound units.

1.5 A 336/A 336M formerly included austenitic steel forgings, which are now found in A 965/A 965M.

1.6 The values stated in either inch-pound units or SI (metric) units are to be regarded separately as standards. Within the text and tables, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independent of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings[3]

A 335/A 335M Specification for Seamless Ferritic Alloy Steel Pipe for High-Temperature Service[4]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[5]

A 788 Specification for Steel Forgings, General Requirements[3]

A 965 Specification for Steel Forgings, Austenitic, for Pressure and High Temperature Parts[3]

E 165 Test Method for Liquid Penetrant Examination[6]

2.2 *Other Standard:*

ASME Boiler and Pressure Vessel Code, Section IX, Welding Qualifications[7]

3. Ordering Information and General Requirements

3.1 In addition to the ordering information required by Specification A 788, the purchaser should include with the inquiry and order the following information:

3.1.1 A drawing or sketch that shows test locations when the testing is in accordance with 8.1.1.3.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved April 10, 2003. Published June 2003. Originally approved in 1955. Last previous edition approved in 1999 as A 336/A 336M – 99[1].

[2] For ASME Boiler and Pressure Vessel Code applications, see related Specification SA-336/SA-336M in Section II of that Code.

[3] *Annual Book of ASTM Standards*, Vol 01.05.

[4] *Annual Book of ASTM Standards*, Vol 01.01.

[5] *Annual Book of ASTM Standards*, Vol 01.03.

[6] *Annual Book of ASTM Standards*, Vol 03.03.

[7] Available from the American Society of Mechanical Engineers, 345 East 47th St., New York, NY 10017.

***A Summary of Changes section appears at the end of this standard.**

TABLE 1 Tensile Requirements

	Ferritic Steels																	
	Grade																	
	F1	F11, Class 2	F11, Class 3	F11, Class 1	F12	F5	F5A	F9	F6	F21, Class 3	F21, Class 1	F22, Class 3	F22, Class 1	F91	F911	F3V	F3VCb	F22V
Tensile strength, psi [MPa]	70 000-95 000 [485-660]	70 000-95 000 [485-660]	75 000-100 000 [515-690]	60 000-85 000 [415-585]	70 000-95 000 [485-660]	60 000-85 000 [415-585]	80 000-105 000 [550-725]	85 000-110 000 [585-760]	85 000-110 000 [585-760]	75 000-100 000 [515-690]	60 000-85 000 [415-585]	75 000-100 000 [515-690]	60 000-85 000 [415-585]	85 000-110 000 [585-760]	90 000-120 000 [620-830]	85 000-110 000 [585-760]	85 000-110 000 [585-760]	85 000-110 000 [585-760]
Yield strength, min, psi [MPa]	40 000 [275]	40 000 [275]	45 000 [310]	30 000 [205]	40 000 [275]	36 000 [250]	50 000 [345]	55 000 [380]	55 000 [380]	45 000 [310]	30 000 [205]	45 000 [310]	30 000 [205]	60 000 [415]	64 000 [440]	60 000 [415]	60 000 [415]	60 000 [415]
Elongation in 2 in. or 50 mm, min, %	20	20	18	20	20	20	19	20	18	19	20	19	20	20	20	18	18	18
Reduction of area, min, %	40	40	40	45	40	40	35	40	35	40	45	40	45	40	40	45	45	45

3.1.2 The intended use of forgings if 5.1 is applicable.

3.2 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

3.3 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

3.4 For hubbed flanges and tube sheets ordered for ASME Boiler and Pressure Vessel Code application, Supplementary Requirement S12 of Specification A 788 should be specified.

4. Melting and Forging

4.1 In addition to the melting and forging requirements of Specification A 788 which may be supplemented by Supplementary Requirement S8, the following conditions apply:

4.1.1 A sufficient discard shall be made to secure freedom from injurious pipe and undue segregation.

5. Machining

5.1 Forged pressure vessels for steam power service shall have the inner surface machined or ground. Unfired pressure vessels shall have the inner surfaces sufficiently free of scale to permit inspection.

5.2 When rough machining is performed, it may be done either before or after heat treatment.

6. Heat Treatment

6.1 The steel forgings shall be annealed or normalized and tempered but alternatively may be liquid quenched and tempered when mutually agreed upon between the manufacturer and the purchaser. Grade F22V forgings shall be normalized and tempered or liquid quenched and tempered. For Grade F22V forgings the minimum austenizing temperature shall be 1650°F [900°C]. For Grade F91 and F911 forgings the austenitizing temperature shall be in the range of 1900 to 2000°F [1040 to 1095°C]. Normalizing or liquid quenching shall be followed by tempering at a subcritical temperature. The minimum tempering temperature shall be 1100°F [595°C], except for the following grades:

Grade	Minimum Tempering Temperature, °F [°C]
F6	1150 [620]
F11, Class 2	1150 [620]
F11, Class 3	1150 [620]
F11, Class 1	1150 [620]
F5	1250 [675]
F9	1250 [675]
F21, Class 1	1250 [675]
F3V, F3VCb	1250 [675]
F22, Class 1	1250 [675]
F22V	1250 [675]
F91	1350 [730]
F911	1350 [730]

7. Chemical Composition

7.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 and shall comply with Table 2.

7.2 *Product Analysis*—The manufacturer shall use the product analysis provision of Specification A 788 to obtain a product analysis from a forging representing each heat or multiple heat. The product analysis for columbium and calcium for Grade F22V shall conform to the requirements of Table 2 of this specification. Boron is not subject to product analysis. The purchaser may also make this determination in accordance with Specification A 788.

8. Mechanical Properties

8.1 *General Requirements*—The material shall conform to the requirements for mechanical properties prescribed in Table 1. The largest obtainable tension test specimen as specified in Test Methods and Definitions A 370 shall be used.

8.1.1 For annealed, normalized, and tempered steels not tested per 8.1.1.3, the longitudinal axis of the specimens shall be parallel to the direction of major working of the forging, except when Supplementary Requirement S2 is specified. For upset disk forgings, the longitudinal axis of the test specimen shall be in the tangential direction.

8.1.1.1 The longitudinal axis of the specimen shall be located midway between the parallel surfaces of the test extension if added to the periphery of disks or midway between the center and surface of solid forgings. For hollow forgings, the longitudinal axis of the specimens shall be located midway between the center and outer surfaces of the wall. When separately forged test blocks are employed, as defined in 8.1.3, the tension test specimens shall be taken from a location which represents the midwall of the heaviest section of the production forgings. When specimens are required from opposite ends, they shall be taken from the diagonal corners of an axial plane. Alternatively, and when specified, the specimens shall be taken in accordance with Supplementary Requirement S3.

8.1.1.2 For liquid quenched and tempered forgings, the test specimens shall have their longitudinal axis at least ¼ T of the maximum heat-treated thickness from any surface and with the mid-length of the specimens at least one T from any second surface. This is normally referred to as ¼ $T \times T$, where T is the maximum heat-treated thickness. A thermal buffer may be used to adhere to the above condition.

8.1.1.3 For normalized and tempered and liquid quenched and forgings. With prior purchaser approval, test specimens may be taken at a depth (t) corresponding to the distance from the area of significant stress to the nearest heat-treated surface and at least twice this distance (2 t) from any second surface. However, the test depth shall not be nearer to one heat-treated surface than ¾ in. [19 mm] and to the second treated surface than 1½ in. [38 mm]. This method of test specimen location normally applies to thick and complex pressure vessel components where the testing in 8.1.1.2 is not practical. Sketches showing the exact test locations shall be approved by the purchaser when this method is used.

8.1.2 Except as specified herein, tests for acceptance shall be made after heat treatment has been completed in accordance with Section 6. When the ends of the cylindrical forgings are closed in by reforging, the cylindrical forgings may be normalized and tempered or annealed and tested before reforging. After reforging, the entire forging shall be reheat-treated in the

TABLE 2 Chemical Requirements

Composition, %								
	Grade							
Element	F1	F11, Classes 2 and 3	F11, Class 1	F12	F5[A]	F5A[A]	F9	F6
Carbon	0.20–0.30	0.10–0.20	0.05–0.15	0.10–0.20	0.15 max	0.25 max	0.15 max	0.12 max
Manganese	0.60–0.80	0.30–0.80	0.30–0.60	0.30–0.80	0.30–0.60	0.60 max	0.30–0.60	1.00 max
Phosphorus, max	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Sulfur, max	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Silicon	0.20–0.35	0.50–1.00	0.50–1.00	0.10–0.60	0.50 max	0.50 max	0.50–1.00	1.00 max
Nickel	. . .	. . .	. . .	. . .	0.50 max	0.50 max	. . .	0.50 max
Chromium	. . .	1.00–1.50	1.00–1.50	0.80–1.10	4.0–6.0	4.0–6.0	8.0–10.0	11.5–13.5
Molybdenum	0.40–0.60	0.45–0.65	0.44–0.65	0.45–0.65	0.45–0.65	0.45–0.65	0.90–1.10	. . .

Grade		
Element	F21, Classes 1 and 3	F22, Classes 1 and 3
Carbon	0.05–0.15	0.05–0.15
Manganese	0.30–0.60	0.30–0.60
Phosphorus, max†	0.025	0.025
Sulfur, max†	0.025	0.025
Silicon†	0.50 max	0.50 max
Nickel†	. . .	. . .
Chromium	2.7–3.3	2.00–2.50
Molybdenum	0.80–1.06	0.90–1.10
Vanadium	. . .	. . .
Copper	. . .	. . .
Nitrogen	. . .	. . .
Columbium	. . .	. . .

Element	Grade F 91	Grade F911	F3V	F3VCb	F22V
Carbon	0.08–0.12	0.09–0.13	0.10–0.15	0.10–0.15	0.11–0.15
Manganese	0.30–0.60	0.30–0.60	0.30–0.60	0.30–0.60	0.30–0.60
Phosphorus, max	0.025	0.020	0.020	0.020	0.015
Sulfur, max	0.025	0.010	0.020	0.010	0.010
Silicon	0.20–0.50	0.10–0.50	0.10 max	0.10 max	0.10 max
Nickel	0.40 max	0.40 max	. . .	0.25 max	0.25 max
Chromium	8.0–9.5	8.5–10.5	2.7–3.3	2.7–3.3	2.00–2.50
Molybdenum	0.85–1.05	0.90–1.10	0.90–1.10	0.90–1.10	0.90–1.10
Vanadium	0.18–0.25	0.18–0.25	0.20–0.30	0.20–0.30	0.25–0.35
Columbium	0.06–0.10	0.06–0.10	. . .	0.015–0.070	0.07 max
Nitrogen	0.03–0.07	0.04–0.09	. . .	. . .	. . .
Aluminum	0.04 max	0.04 max	. . .	. . .	. . .
Boron	. . .	0.0003–0.006	0.001–0.003	. .	0.0020 max
Tungsten	. . .	0.90–1.10	. . .	. . .	. . .
Titanium	. . .	. . .	0.015–0.035	0.015 max	0.030 max
Copper	. . .	. . .	. . .	0.25 max	0.20 max
Calcium	. . .	. . .	. . .	0.0005–0.0150	0.015 max[B]

[A] The present Grade F 5A (0.25 %, maximum carbon) previous to 1955 was assigned the identification symbol F 5. Identification symbol F 5 has been assigned to the 0.15 %, maximum, carbon grade to be consistent with ASTM specifications for other products such as pipe, tubing, bolting, welding, fittings, etc.
[B] For Grade F 22V, rare earth metals (REM may be added in place of calcium subject to agreement between the producer and the purchaser. In that case the total amount of REM shall be determined and reported.
† Editorially corrected.

same manner and at the same temperature range as employed when the forging was heat-treated before certification testing.

8.1.3 When mutually agreed upon between the manufacturer and the purchaser, test specimens may be machined from a specially forged block suitably worked and heat treated with the production forgings. Such a special block shall be obtained from an ingot, slab, or billet from the same heat used to make the forgings it represents. This block shall receive essentially the same type of hot-working and forging reduction as the production forgings; however, a longitudinally forged bar with dimensions not less than T by T by 3 T may be used to represent a ring forging. The dimension T shall be representative of the heaviest effective cross section of the forging. For quenched and tempered forgings for which tests are required at both ends by 8.2.2.3 and 8.2.2.4, separately forged test blocks are not allowed.

NOTE 1—In using separately forged test blocks attention is drawn to the effect of mass differences between the production forgings and the test blocks. This can be particularly significant when forgings are normalized and tempered or quenched and tempered.

8.2 *Number and Location of Tests*—The number and location of tests are based on forging length, weight, and heat treatment and shall be as prescribed below. The length and weight to be used for this purpose shall be the shipped length and weight of forgings produced individually or the aggregate shipped length and weight of all pieces cut from a multiple forging.

8.2.1 *Annealed or Normalized and Tempered Forgings*:

8.2.1.1 For forgings weighing 5000 lb [2250 kg] or less at the time of heat treatment, one tension test shall be taken from one forging per heat, per heat treatment charge. When heat treatment is performed in continuous type furnaces with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a tempering charge may be considered as any continuous run not exceeding an 8 h period.

8.2.1.2 For forgings and forged bars weighing over 5000 lb [2250 kg] at the time of heat treatment, one tension test shall be taken from each forging.

8.2.2 *Quenched and Tempered Forgings*:

8.2.2.1 For quenched and tempered forgings weighing 5000 lb [2250 kg] or less at the time of heat treatment, but not exceeding 12 ft [3.7 m] in length, one tension test shall be taken from one forging per heat, per heat treatment charge. When heat treatment is performed in continuous type furnaces with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a tempering charge may be considered as any continuous run not exceeding an 8 h period.

8.2.2.2 For quenched and tempered forgings and forged bars weighing over 5000 to 10 000 lb [2250 to 4500 kg] at the time of heat treatment, but not exceeding 12 ft [3.7 m] in length, one tension test shall be taken from each forging.

8.2.2.3 Quenched and tempered forgings that exceed 12 ft [3.7 m] in length shall be tension tested at both ends of the forging under test.

8.2.2.4 For quenched and tempered forgings and forged bars weighing more than 10 000 lb [4500 kg] at the time of heat treatment, two tension test specimens shall be taken from each forging. These shall be offset 180° from each other except that if the length of the forging, excluding test prolongations, exceeds 12 ft [3.7 m], then one specimen shall be taken from each end of the forging.

8.3 *Notch Toughness Requirements–Grades F3V, F3VCb, and F22V*:

8.3.1 Impact test specimens shall be charpy V-notch Type A, as shown in Fig. 11 of Test Methods and Definitions A 370. The usage of subsize specimens due to material limitations must have prior purchaser approval.

8.3.2 The charpy V-notch test specimens shall be obtained as required for tension tests in 8.1 and 8.2. One set of three charpy V-notch specimens shall be taken from each tensile specimen location.

8.3.3 The longitudinal axis and mid-length of impact specimen shall be located similarly to the longitudinal axis of the tension test specimens. The axis of the notch shall be normal to the nearest heat treated surface of the forging.

8.3.4 The charpy V-notch tests shall meet a minimum energy absorption value of 40 ft·lbf [54 J] average of three specimens. One specimen only in one set may be below 40 ft·lbf [54 J] and it shall meet a minimum value of 35 ft·lbf [48 J].

8.3.5 The impact test temperature shall be 0°F [−18°C].

9. Workmanship, Finish, and Appearance

9.1 When forgings have been heat treated by quenching and tempering, all accessible surfaces shall subsequently be examined for quench cracks by the magnetic particle method in accordance with Test Method A 275/A 275M.

10. Repair Welding

10.1 Repair welding of forgings may be permitted but only at the option of the purchaser. Such repair welds shall be made in accordance with Section IX of the ASME Boiler & Pressure Vessel Code.

11. Marking

11.1 In addition to the marking requirements of Specification A 788, the specification marking shall be followed by the letter A for annealed, N for normalized and tempered or Q for liquid quenched and tempered as applicable.

12. Test Reports

12.1 The certification requirements of Specification A 788 shall apply.

13. Keywords

13.1 chromium alloy steel; chromium-molybdenum steel; pressure containing parts; pressure vessel service; steel forgings—alloy; temperature service applications—high

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, and order. Details of these supplementary requirements shall be agreed upon between the manufacturer and the purchaser.

S1. Rough Turning and Boring

S1.1 The position of the rough turning and boring in the sequence of manufacturing operations shall be specified

S2. Transverse Tension Test

S2.1 Instead of test specimens taken in accordance with 8.1.1, the longitudinal axis of the test specimens shall be transverse to the direction of major working of the forging. The results shall conform with requirements of Table 1, with the exception of the ductility limits which shall be as prescribed in Table S2.1.

S3. Alternative Test Specimen Requirements

S3.1 The test requirements for materials of the ASME Boiler and Pressure Code, Section III, Article NB-2223.3, shall be used in place of that specified in 8.1.1.1.

S4. Hydrostatic Test

S4.1 A hydrostatic pressure test shall be applied. The details of the test, including its position in the sequence of manufacturing operations, shall be specified.

S6. Liquid Penetrant Examination

S6.1 After forgings have been heat treated by quenching and tempering, all accessible surfaces shall be inspected for quench cracks by the liquid penetrant method in accordance with Test Method E 165 as an alternative to magnetic particle examination.

S7. Marking

S7.1 Forgings shall be marked at a location indicated by the purchaser in the purchase order or drawing.

S8. Forging Requirements

S8.1 Large drum forgings shall be made from solid cast ingots, punched, bored, or trepanned, or from hollow ingots cast in metal molds. The walls of the hollowed or hollow ingots shall be reduced in thickness at least one-half by forging on mandrels.

S8.2 Drum forgings with one solid closed end may be hollow forged in closed dies or on a draw bench provided the metal is worked thoroughly.

S8.3 Drum forgings, either with open ends or one solid closed end, may also be produced by hot extrusion provided the metal is worked thoroughly.

S8.4 Small drum forgings may be made as solid forgings, subsequently bored, provided the purchaser agrees to this method of forging. The cross-sectional area of the solid forgings shall have a reduction by forging from that of the ingot in the ratio of not less than 3:1.

S8.5 Small sections or component parts of pressure vessels, which are to be subsequently assembled to form drums, may be made by expanding on a mandrel under a press or hammer, by hot extrusion or by ring rolling methods, provided the wall thickness is reduced at least one-half in the process.

S8.6 Heads or covers shall be forged as disks, upset from blocks cut from ingots or billets. The length of block before upsetting shall be at least twice the thickness of the as-forged head or cover.

S9. Individual Forging

S9.1 Forgings, whether identical or not identical, shall be produced individually. They shall not be forged in multiple and separated prior to or after heat treatment.

S9.2 The shape and size of individual forgings shall be agreed between the manufacturer and the purchaser by means of a forging drawing or the purchase order.

TABLE S2.1 Ductility Limits

	Grade																	
	F1	F11, Class 2	F11, Class 3	F11, Class 2	F12	F5	F5A	F9	F6	F21, Class 3	F21, Class 1	F22, Class 3	F22, Class 1	F3V	F46	F22V	F91	F911
Elongation in 2 in. or 50 mm, min, %	20	18	18	19	18	19	19	18	18	18	19	18	20	17	40	17	19	16
Reduction of area, min, %	30	35	30	40	25	35	35	35	35	35	35	25	35	35	50	35	40	30

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 336/A 336M-99 that may impact the use of this standard.

(1) Added supplementary requirement reference to Ordering Information.

Standard Specification for Steel Bars, Alloys, for Nitriding[1]

This standard is issued under the fixed designation A 355; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers alloy steel bars, suitable for surface hardening by nitriding, designated as Classes A, B, C, and D. Class A and Class D bars are general-purpose bars; Class B bars are free-machining bars; Class C bars contain 3.50 % nickel and are characterized by higher core strength. All classes are normally furnished in the hot-rolled, quenched, and tempered condition. However, centerless-ground or turned bars, in any of the classes, may be specified by the purchaser. Also, as-rolled, annealed, or unannealed bars suitable for forging may be purchased to this specification. When as-rolled, annealed, or unannealed bars are furnished, Sections 6, 10, and 11 are not applicable.

1.2 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold Finished, General Requirements for[2]

3. Ordering Information

3.1 Orders under this specification should include the following as required to adequately describe the desired materials:

3.1.1 Quantity (weight or number of pieces),

3.1.2 Name of material (alloy steel bars, for nitriding),

3.1.3 Surface finish (Section 1),

3.1.4 Cross-sectional shape,

3.1.5 Size,

3.1.6 Length (Section 15),

3.1.7 Class (Section 10),

3.1.8 Thermal treatment (Section 1),

3.1.9 Hardness (Section 12),

3.1.10 Microstructure when desired (Section 8),

3.1.11 Report of ladle analysis if desired (Section 10),

3.1.12 Straightness (Section 11),

3.1.13 ASTM designation A 355, and

3.1.14 End use, exceptions to the specification, or special requirements.

4. Process

4.1 The steel shall be made by the electric-furnace process only.

5. Discard

5.1 Sufficient discard shall be made from each ingot to ensure freedom from injurious piping and undue segregation.

6. Quenching and Tempering

6.1 The bars shall be given a liquid quench followed by a tempering treatment at a temperature not lower than 600°C (1112°F) to produce a fine spheroidized structure.

7. Microstructure

7.1 When specified the microstructure resulting from the heat treatment specified in Section 7 shall not show free ferrite in amounts exceeding those prescribed in Table 1. Other percentages of free ferrite may be supplied by agreement between the manufacturer and the purchaser.

7.2 The amount of free ferrite shall be determined by metallographic examination under suitable magnification of a specimen from the bars in the quenched and tempered condition. The number and location of tests and details of the basis of establishing free ferrite shall be as agreed upon between the manufacturer and the purchaser.

8. Decarburization

8.1 The maximum depth of total and partial decarburization of hot-rolled bars and heat-treated bars shall not exceed the amounts prescribed in Table 2.

8.2 Centerless-ground or turned bars shall be free from total and partial decarburization.

9. Heat Analysis

9.1 The steel shall conform to the requirements as to cast or heat (formerly ladle) analysis prescribed in Table 3.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.15 on Bars.

Current edition approved Dec. 7, 1989. Published February 1990. Originally published as A 355–52T. Last previous edition A 355–81(1988).

[2] *Annual Book of ASTM Standards*, Vol 01.05.

TABLE 1 Permissible Free Ferrite

Diameter or Thickness, in. (mm)	Permissible Free Ferrite Area, max, %
1.00 (25.4) and under	2
Over 1.00 to 3.00 (25.4 to 76.2), incl	4
Over 3.00 (76.2)	6

TABLE 2 Permissible Depth of Decarburization

Diameter or Distance Between Parallel Faces, in. (mm)	Depth of Decarburization, max, in. (mm)
½ (12.7) and under	0.030 (0.76)
Over ½ to 1 (12.7 to 25.4), incl	0.035 (0.89)
Over 1 to 1½ (25.4 to 38.1), incl	0.040 (1.02)
Over 1½ to 2 (38.1 to 50.8), incl	0.050 (1.27)
Over 2 to 2½ (50.8 to 63.5), incl	0.060 (1.52)
Over 2½ to 3 (63.5 to 76.2), incl	0.070 (1.78)
Over 3 to 5 (76.2 to 127.0), incl	0.085 (2.16)
Over 5 to 8 (127.0 to 203.2), incl	0.125 (3.18)

TABLE 3 Chemical Requirements

	Class A	Class B	Class C	Class D
Carbon, %	0.38–0.43	0.35–0.40	0.22–0.27	0.33–0.38
Manganese, %	0.50–0.70	0.70–0.95	0.50–0.70	0.50–0.70
Phosphorus, max, %	0.035	0.035	0.035	0.035
Sulfur, max, %	0.040	0.060	0.040	0.040
Silicon, %	0.15–0.35	0.15–0.35	0.15–0.35	0.15–0.35
Chromium, %	1.40–1.80	1.20–1.50	1.00–1.35	1.00–1.30
Aluminum, %	0.95–1.30	0.95–1.30	0.95–1.30	0.95–1.30
Molybdenum, %	0.30–0.40	0.15–0.25	0.20–0.30	0.15–0.25
Selenium, %	. . .	0.15–0.25	. . .	. . .
Nickel, %	. . .		3.25–3.75	. . .

10. Straightness

10.1 Unless otherwise specified, all material shall be supplied to a maximum straightness tolerance of ⅛ in. (3.18 mm) in any 5 ft (1.5 m) but it may not exceed the following:

Maximum straightness deviation, in. = ⅛ × (length in feet)/5

11. Hardness Test

11.1 The hardness of the steel after quenching and tempering shall conform to one of the ranges as specified in Table 4.

12. Permissible Variations in Dimensions

12.1 The hot-rolled bars shall not vary from the specified dimensions by more than the amounts prescribed in Specification A 29/A 29M.

TABLE 4 Hardness Requirements

Hardness Scale	Hardness Range 1	Range 2
Brinell	223 to 269	248 to 302
Rockwell C	19 to 28	24 to 32
Rockwell B	98 to 104	101 to 107

12.2 The diameter of centerless ground bars shall not vary from that specified by more than the following:

Specified Diameter, in. (mm)	Permissible Variations, Over or Under, in. (mm)
Under ¼ (6.35)	0.0005 (0.013)
¼ to 11⁄12 (6.35 to 8.73), incl	0.001 (0.025)
Over 11⁄32 to 19⁄32 (8.73 to 15.08), incl	0.0015 (0.038)
Over 19⁄32 to 1 3⁄32 (15.08 to 27.78), incl	0.002 (0.051)
Over 1 3⁄32 (27.78)	0.0025 (0.064)

12.3 The diameter of turned bars shall not vary from that specified by more than the following:

Specified Diameter, in. (mm)	Permissible Variations, Over or Under, in. (mm)
2 (51) and under	0.005 (0.13)
Over 2 to 4 (51 to 102), incl	0.0075 (0.19)
Over 4 (102)	0.010 (0.25)

13. Length

13.1 Unless otherwise specified, the bars shall be furnished in lengths of 8 to 12 ft (2.4 to 3.7 m). However, 10 % of the bars will be accepted in shorter lengths, but in no case shall the lengths be less than 5 ft (1.5 m).

14. Workmanship, Finish, and Appearance

14.1 Hot-rolled bars shall be sound, and commercially free of excessive scale, cracks, seams, and other injurious imperfections.

14.2 Centerless-ground or turned bars shall have a clean smooth surface and shall be oiled to prevent rusting.

15. General Requirements

15.1 Material furnished under this specification shall conform to the requirements of the current edition of Specification A 29/A 29M unless otherwise provided for herein.

16. Keywords

16.1 alloy steel bars; nitriding steel; steel bars

Designation: A 372/A 372M – 03

Standard Specification for Carbon and Alloy Steel Forgings for Thin-Walled Pressure Vessels[1]

This standard is issued under the fixed designation A 372/A 372M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification[2] covers relatively thin-walled forgings (including gas bottles) for pressure vessel use. Three types of carbon steel and six types of alloy steel are included. Provision is made for integrally forging the ends of vessel bodies made from seamless pipe or tubing.

NOTE 1—When working to the chemical and tensile requirements of this specification, the influence of wall thickness and cooling rate will necessarily eliminate certain forging sizes in each class.

NOTE 2—Designations have been changed as follows:

Current	Formerly
Grade A	Type I
Grade B	Type II
Grade C	Type III
Grade D	Type IV
Grade E Class 55	Type V Grade 1 Class 55
Grade E Class 65	Type V Grade 1 Class 65
Grade E Class 70	Type V Grade 1 Class 70
Grade F Class 55	Type V Grade 2 Class 55
Grade F Class 65	Type V Grade 2 Class 65
Grade F Class 70	Type V Grade 2 Class 70
Grade G Class 55	Type V Grade 3 Class 55
Grade G Class 65	Type V Grade 3 Class 65
Grade G Class 70	Type V Grade 3 Class 70
Grade H Class 55	Type V Grade 4 Class 55
Grade H Class 65	Type V Grade 4 Class 65
Grade H Class 70	Type V Grade 4 Class 70
Grade J Class 55	Type V Grade 5 Class 55
Grade J Class 65	Type V Grade 5 Class 65
Grade J Class 70	Type V Grade 5 Class 70
Grade K	Type VI
Grade L	Type VII
Grade J Class 110	Type VIII
Grade M Class 85	Type IX Class A
Grade M Class 100	Type IX Class B

1.2 The values stated in either inch-pound or SI [metric] units are to be regarded separately as the standard. Within the text and the tables, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.3 Unless the order specifies the applicable "M" specification designation (SI units), the material shall be furnished to inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings[3]
A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[4]
A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings[3]
A 530/A 530M Specification for General Requirements for Specialized Carbon and Alloy Steel Pipe[5]
A 788 Specification for Steel Forgings, General Requirements[3]
E 112 Test Methods for Determining the Average Grain Size[6]
E 165 Practice for Liquid Penetrant Examination[7]
E 290 Test Method for Semi-Guided Bend Test for Ductility of Metallic Materials[6]
E 433 Reference Photographs for Liquid Penetrant Inspection[7]

3. Ordering Information and General Requirements

3.1 In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order a detailed drawing, sketch, or written description of the forging and the areas of significant loading in the forging when required (see 6.4.2.2).

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] For ASME Boiler and Pressure Vessel Code applications, see related Specification SA-372/SA-372M in Section II of that code.

[3] *Annual Book of ASTM Standards*, Vol 01.05.
[4] *Annual Book of ASTM Standards*, Vol 01.03.
[5] *Annual Book of ASTM Standards*, Vol 01.01.
[6] *Annual Book of ASTM Standards*, Vol 03.01.
[7] *Annual Book of ASTM Standards*, Vol 03.03.

***A Summary of Changes section appears at the end of this standard.**

3.2 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

3.3 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

4. Materials and Manufacture

4.1 *Melting Practice*:

4.1.1 The steel melting procedures of Specification A 788 shall apply except that for Grade M forgings, only steel that has been vacuum treated prior to or during the pouring of the ingot, in order to remove objectionable gases, particularly hydrogen, shall be used.

4.2 *Production Methods*:

4.2.1 Methods for the production of gas bottles and similar vessels shall include the cupping of slabs or plates, the piercing of billets or plates, and the subsequent drawing of cups so produced. Such semifinished forgings or seamless steel pipe or tubing shall be closed by spinning, swedging, or pressing. In all cases there shall be sufficient discard to ensure soundness in the completed forging.

4.3 *Heat Treatment*:

4.3.1 At the option of the manufacturer, Grades A, B, C, D and Classes 55, 65, 70 of Grades E, F, G, H, and J forgings shall be normalized, normalized and tempered, or liquid-quenched and tempered.

4.3.2 Grades K, L, M, and Class 110 of Grade J forgings shall be liquid-quenched and tempered.

4.3.3 When normalized forgings are to be tempered, or when forgings have been quenched, they shall be reheated to a subcritical temperature and held for at least ½ h/in. [25 mm] of maximum cross section.

4.3.3.1 Minimum tempering temperatures shall be as follows:

Grades E, F, G, H, J in Classes 55, 65, 70	1100°F [595°C]
Grade K	1100°F [595°C]
Grade L	1000°F [540°C]
Grade J Class 110	1000°F [540°C]
Grade M	1100°F [595°C]

4.3.3.2 If an attachment is welded onto a previously quenched and tempered pressure vessel, the post weld heat treatment temperature of a weldment shall not exceed the prior tempering temperature of the pressure vessel. Fabrication welding of pressure shell is not permitted. Attachment welding prior to heat treatment is not permitted.

4.3.4 All quenched and tempered forgings shall be subject to magnetic particle examination in accordance with Section 7.

4.3.5 Heat treatment is to be performed after all forming operations.

5. Chemical Composition

5.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 shall comply with Table 1.

TABLE 1 Chemical Requirements

Elements	Composition, %				
	Grade A	Grade B	Grade C	Grade D	
Carbon	0.30 max	0.35 max	0.48 max	0.40–0.50	
Manganese	1.00 max	1.35 max	1.65 max	1.40–1.80	
Phosphorus, max	0.025	0.025	0.025	0.025	
Sulfur, max	0.025	0.025	0.025	0.025	
Silicon	0.15–0.35	0.15–0.35	0.15–0.35	0.15–0.35	
Nickel	—	—	—	—	
Chromium	—	—	—	—	
Molybdenum	—	—	—	0.17–0.27	
	Grade E Classes 55, 65, 70	Grade F Classes 55, 65, 70	Grade G Classes 55, 65, 70	Grade H Classes 55, 65, 70	Grade J Classes 55, 65, 70, 110
Carbon	0.25–0.35	0.30–0.40	0.25–0.35	0.30–0.40	0.35–0.50
Manganese	0.40–0.90	0.70–1.00	0.70–1.00	0.75–1.05	0.75–1.05
Phosphorus, max	0.025	0.025	0.025	0.025	0.025
Sulfur, max	0.025	0.025	0.025	0.025	0.025
Silicon	0.15–0.35	0.15–0.35	0.15–0.35	0.15–0.35	0.15–0.35
Nickel	—	—	—	—	—
Chromium	0.80–1.15	0.80–1.15	0.40–0.65	0.40–0.65	0.80–1.15
Molybdenum	0.15–0.25	0.15–0.25	0.15–0.25	0.15–0.25	0.15–0.25
	Grade K	Grade L	Grade M Classes 85 and 100		
Carbon	0.18 max	0.38–0.43	0.23 max		
Manganese	0.10–0.40	0.60–0.80	0.20–0.40		
Phosphorus, max	0.025 max	0.025	0.020		
Sulfur, max	0.025 max	0.025	0.020		
Silicon	0.15–0.35	0.15–0.35	0.30 max		
Nickel	2.0–3.3	1.65–2.00	2.8–3.9		
Chromium	1.00–1.80	0.70–0.90	1.50–2.00		
Molybdenum	0.20–0.60	0.20–0.30	0.40–0.60		
Vanadium			0.08 max		

5.2 *Product Analysis*—The purchaser may use the product analysis provision of Specification A 788 to obtain a product analysis from a forging representing each heat or multiple heat.

5.3 Starting material produced to a specification that specifically requires the addition of any element beyond those listed in Table 1 for the applicable grade of material is not permitted. This does not preclude use of deoxidation or inclusion control additions. Supplementary Requirements S1 and S2 of Specification A 788 shall apply.

6. Mechanical Properties

6.1 Mechanical tests for acceptance shall be made after the final heat treatment of the forgings.

6.2 *Tension Test*—When tested in accordance with Test Methods and Definitions A 370, the material shall conform to the requirements of Table 2. The yield strength shall be determined by the 0.2 % offset method.

6.3 *Bending Properties*—Depending upon the outside diameter, *D*, and the wall thickness, *T*, of hollow or bored forgings, a bend test or flattening test will be required.

6.3.1 For bored or hollow forgings with outside diameters of 14 in. [355 mm] or less and with a *D/T* ratio of more than 10.0, a flattening test is required. This shall be carried out in accordance with Specification A 530/A 530M and Table 3. No breaks or cracks in the test ring are acceptable until the distance between the plates is less than that shown in Table 3.

TABLE 2 Mechanical Requirements

Type	Tensile Strength, ksi [MPa]	Yield Strength (0.2 % Offset), ksi [MPa], min	Elongation in 2 in. [50 mm], min, %	Hardness, HB, min[A]
Grade A	60–85 [415–585]	35 [240]	20	121
Grade B	75–100 [515–690]	45 [310]	18	156
Grade C	90–115 [620–795]	55 [380]	15	187
Grade D	105–130 [725–895]	65 [450]	15	217
Grades E, F, G, H, J (Class 55)	85–110 [545–760]	55 [380]	20	179
Grades E, F, G, H, J (Class 65)	105–130 [725–895]	65 [450]	19	217
Grades E, F, G, H, J (Class 70)	120–145 [825–1000]	70 [485]	18	248
Grade J (Class 110)	135–160 [930–1100]	110 [760]	15	277
Grade K	100–125 [690–860]	80 [550]	20	207
Grade L	155–180 [1070–1240]	135 [930]	12	311
Grade M (Class 85)	105–130 [725–895]	85 [585]	18	217
Grade M (Class 100)	120–145 [825–1000]	100 [690]	16	248

[A] When required by 6.6.

TABLE 3 Distance Between Plates for Flattening Tests[A]

Type	Distance Between Plates, min, in. [mm]
Grade A	0.50 *D*
Grade B	0.6 *D*
Grade C	0.65 *D*
Grade D	0.7 *D*
Grades E, F, G, H, J (Class 55)	0.7 *D*
Grades E, F, G, H, J (Class 65)	0.8 *D*
Grades E, F, G, H, J (Class 70)	0.8 *D*
Grade J (Class 110)	0.9 *D*
Grade K	0.8 *D*
Grade L	0.9 *D*
Grade M (Class 85)	0.7 *D*
Grade M (Class 100)	0.8 *D*

[A] *D* = outside diameter.

6.3.2 For bored or hollow forgings with outside diameters over 14 in. [355 mm], or where the *D/T* ratio is 10.0 or less at the manufacturer's option, the flattening test specified in 6.3.1, or a transverse bend test in accordance with Arrangement C of Test Method E 290 is required. The bend test pin diameter shall be as specified in Table 4. No cracks or ruptures in the test piece are allowable when the test piece is bent through the required angle.

6.4 *Orientation and Location of Test Specimens*:

TABLE 4 Maximum Pin Diameters and Minimum Angle for Bend Test

Type	Pin Diameter	Angle, deg
Grade A	2*t*	180
Grade B	2*t*	180
Grade C	3*t*	180
Grade D	4*t*	150
Grades E, F, G, H, J (Class 55)	4*t*	150
Grades E, F, G, H, J (Class 65)	4*t*	150
Grades E, F, G, H, J (Class 70)	4*t*	150
Grade J (Class 110)	6*t*	150
Grade K	4*t*	150
Grade L	6*t*	150
Grade M (Class 85)	4*t*	150
Grade M (Class 100)	4*t*	150

6.4.1 Test specimens representing vessel bodies or shells shall be taken from a prolongation of a forging, from test rings that have been heat treated with the forgings they represent, or from a representative forging after heat treatment in accordance with 4.3.

6.4.1.1 Test specimens representing vessel bodies or shells shall be located at a position corresponding to the mid-wall location of the parallel side wall of the heat-treated forging and shall be oriented parallel to the longitudinal axis of the vessel.

6.4.1.2 A test ring shall be in the shape of a right circular cylinder having the same diameter and wall thickness as the cylinders it represents. In addition, the test ring shall be from the same heat of steel and be subjected to the same heat treatment as the cylinders it represents. The method of quenching the test ring must duplicate that of the cylinders; if the cylinders are quenched from the outside only, then the test ring must have its ends closed. The length of test rings that will be liquid quenched must be at least 24 in. [610 mm]. The ends of such test rings may be vented to prevent pressure buildup during heat treating.

6.4.2 Test specimens representing vessel covers or similar components may be taken from a full section prolongation of the cover, from a representative forging, or from an integral prolongation when the part is contour-machined prior to heat treatment.

6.4.2.1 Test specimens taken from full size prolongations or representative forgings shall be located at a position midway between the center and the surface.

6.4.2.2 When forgings are contour-machined prior to heat treatment so that highly stressed surfaces are exposed, the test specimens may be taken at an equal distance (t) from the nearest quenched surface as the highly stressed area, but not less than ¾ in. [20 mm]. The location of the specimens from a second surface shall be at least the greater of 1½ in. [40 mm] or 2t.

6.5 *Number of Tests*:

6.5.1 Up to 200 like forgings, each with a heat-treated weight of less than 1000 lb [510 kg] when heat treated in a single batch furnace charge, shall have one tension test taken in accordance with 6.4.1 or 6.4.2 to represent each heat. In addition, for hollow or bored forgings, one bend or flattening test shall be taken in accordance with 6.3.

6.5.2 Like forgings, weighing less than 1000 lb [450 kg] each when heat treated in a continuous furnace, shall have one tensile test taken to represent each heat and not more than 200 forgings in any continuous period up to 4 h duration. In addition, bored or hollow forgings shall have one bend or flattening test taken per heat per 200 forgings in any continuous period up to 4 h duration in accordance with 6.3.

6.5.3 For heat-treated forgings weighing 1000 lb [450 kg] or more, one tension test shall be taken in accordance with 6.4.1 or 6.4.2 to represent each heat and not more than ten forgings in a heat-treat lot. In addition, hollow or bored forgings shall have one bend or flattening test, taken in accordance with 6.3, to represent each ten or fewer forgings from the same heat and heat-treatment lot.

6.6 *Hardness Testing*:

6.6.1 Forgings under 1000 lb [450 kgm] in weight, heat treated in a batch lot of up to 200 pieces (6.5.1) or in a continuous furnace run covering up to 200 pieces in up to four hours production (6.5.2) shall be subject to a uniformity check by Brinell hardness testing, or an equivalent method. For this purpose, 10 % of the furnace production shall be sampled and shall meet the minimum hardness specified in Table 2 for the type and shall also be within 20 Brinell points of the hardness of the forging from which the tensile test was taken.

6.6.2 In the event that the test sample does not meet these criteria, the remainder of that production group shall be hardness tested and all of those forgings that fall outside these limits shall be retempered or reheat-treated at the manufacturer's option and retested.

7. Magnetic Particle Examination

7.1 All quenched and tempered forgings shall be subject to magnetic particle examination after heat treatment. The methods used shall be in accordance with Test Method A 275/A 275M.

7.2 Only direct current or rectified alternating (full or half wave) current shall be used as the electric power source for any of the magnetizing methods.

7.3 The forgings shall be free from linear indications indicative of cracks. In case of doubt as to the type of condition giving rise to linear magnetic particle indications, they may be inspected for Type II indications referenced in Reference Photographs E 433 when inspected by the liquid penetrant method in accordance with Practice E 165. Alternatively, some other suitable method for classifying the indications may be used as agreed upon between the manufacturer and the purchaser.

8. Workmanship

8.1 If the thickness of a portion of the wall of a forging is less than that specified, the forgings may be accepted by the purchaser, provided that such irregularity will not require lowering the allowable working pressure below that for which the forging was designed.

9. Repair Welding

9.1 Repair welding shall be permitted when mutually agreed upon between the purchaser and the manufacturer and shall be performed in accordance with all the requirements of the applicable code or rules of construction.

10. Keywords

10.1 alloy steel forgings; carbon steel forgings; gas bottles; pressure vessels; thin wall

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser on the inquiry, contract, or order. Details of these supplementary requirements shall be agreed upon by the manufacturer and the purchaser.

S1.Grain Size

S1.1 When a grain size range is required, it shall be specified in the ordering information, and shall be determined by an agreed-upon method from Test Methods E 112.

S1.2 Samples for grain size estimation shall be taken from the tension test specimen location.

S2. Rough Machining

S2.1 Rough machining shall be performed in the sequence and manner as specified.

S3. Impact Testing

S3.1 Charpy V-notch test specimens shall be taken from the same location and in the same orientation as tension test specimens. The number of specimens, minimum energy values, and test temperature(s) shall be as specified.

S4. Fracture Toughness

S4.1 Specific fracture toughness requirements are levied by certain sections of the ASME Boiler and Pressure Vessel Code. Forgings in the permitted types shall comply with the applicable code sections.

S4.2 The necessary code references toughness criteria and test temperature data shall be included in the ordering information.

S5. Ultrasonic Examination

S5.1 Ultrasonic examination of forgings shall be carried out in accordance with Practice A 388/A 388M.

S5.2 Acceptance criteria shall be specified and shall be in accordance with the applicable Code or purchaser's specification and shall be included as part of the ordering information.

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 372/A 372M-02 that may impact the use of this standard.

(1) Revised Section 4.2 and added 4.3.3.2.

Designation: A 388/A 388M – 03

Used in USNRC-RDT standards

Standard Practice for Ultrasonic Examination of Heavy Steel Forgings[1]

This standard is issued under the fixed designation A 388/A 388M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This practice[2] covers the examination procedures for the contact, pulse-echo ultrasonic examination of heavy steel forgings by the straight and angle-beam techniques. The straight beam techniques include utilization of the DGS (Distance Gain-Size) method. See Appendix X3.

1.2 This practice is to be used whenever the inquiry, contract, order, or specification states that forgings are to be subject to ultrasonic examination in accordance with Practice A 388/A 388M.

1.3 The values stated in either inch-pound or SI units are to be regarded as the standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.4 This specification and the applicable material specifications are expressed in both inch-pound units and SI units. However, unless the order specifies the applicable "M" specification designation [SI units], the material shall be furnished to inch-pound units.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 469 Specification for Vacuum-Treated Steel Forgings for Generator Rotors[3]

A 745/A 745M Practice for Ultrasonic Examination of Austenitic Steel Forgings[3]

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Examination Instruments and Systems Without the Use of Electronic Measurement Instruments[4]

E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection[4]

2.2 *ANSI Standard:*

B 46.1 Surface Texture[5]

2.3 *Other Document:*

Recommended Practice for Nondestructive Personnel Qualification and Certification SNT-TC-1A, Supplement C—Ultrasonic Testing[6]

3. Ordering Information

3.1 When this practice is to be applied to an inquiry, contract, or order, the purchaser shall so state and shall also furnish the following information:

3.1.1 Method of establishing the sensitivity in accordance with 7.2.2 and 7.3.3 (Vee or rectangular notch),

3.1.1.1 The diameter and test metal distance of the flat-bottom hole and the material of the reference block in accordance with 7.2.2.2,

3.1.2 Quality level for the entire forging or portions thereof in accordance with 10.3, and

3.1.3 Any options in accordance with 6.1, 6.2, and 7.1.11.

4. Apparatus

4.1 An ultrasonic, pulsed, reflection type of instrument shall be used for this examination. The system shall have a minimum capability for examining at frequencies from 1 to 5 MHz. On examining austenitic stainless forgings the system shall have the capabilities for examining at frequencies down to 0.4 MHz.

4.1.1 The ultrasonic instrument shall provide linear presentation (within 5 %) for at least 75 % of the screen height (sweep line to top of screen). The 5 % linearity referred to is descriptive of the screen presentation of amplitude. Instrument linearity shall be verified in accordance with the intent of

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[1] This practice is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved April 10, 2003. Published June 2003. Originally published as A 388–55T. Last previous edition A 388/A 388M–01.

[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-388/SA-388M in Section II of that Code.

[3] *Annual Book of ASTM Standards*, Vol 01.05.

[4] *Annual Book of ASTM Standards*, Vol 03.03.

[5] Available from the American National Standards Institute, Inc., 25 W. 43rd Street, 4th floor, New York, NY 10036.

[6] Available from the American Society for Nondestructive Testing, 1711 Arlingate Ln., P.O. Box 28518, Columbus, OH 43228–0518.

***A Summary of Changes section appears at the end of this standard.**

Practice E 317. Any set of blocks processed in accordance with Practice E 317 or E 428 may be used to establish the specified ±5 % instrument linearity.

4.1.2 The electronic apparatus shall contain an attenuator (accurate over its useful range to ±10 % (+1 dB) of the amplitude ratio) which will allow measurement of indications beyond the linear range of the instrument.

4.2 *Search Units*, having a transducer with a maximum active area of 1 in.^{2} [650 mm^2] with ¾ in. [20 mm] minimum to 1⅛ in. [30 mm] maximum dimensions shall be used for straight-beam scanning (see 7.2); and search units equipped from ½ by 1 in. [13 by 25 mm] to 1 by 1 in. [25 by 25 mm] shall be used for angle-beam scanning (see 7.3).

4.2.1 *Transducers* shall be utilized at their rated frequencies.

4.2.2 Other search units may be used for evaluating and pinpointing indications.

4.3 *Couplants*, having good wetting characteristics such as SAE No. 20 or No. 30 motor oil, glycerin, pine oil, or water shall be used. Couplants may not be comparable to one another and the same couplant shall be used for calibration and examination.

4.4 *Reference Blocks*, containing flat-bottom holes may be used for calibration of equipment in accordance with 4.1.1 and may be used to establish recording levels for straight-beam examination when so specified by the order or contract.

4.5 *DGS Scales*, matched to the ultrasonic test unit and transducer to be utilized, may be used to establish recording levels for straight beam examination, when so specified by the order or contract. The DGS scale range must be selected to include the full thickness cross-section of the forging to be examined. An example of a DGS overlay is found in Appendix X3.

5. Personnel Requirements

5.1 Personnel performing the ultrasonic examinations to this practice shall be qualified and certified in accordance with a written procedure conforming to Recommended Practice No. SNT-TC-1A or another national standard that is acceptable to both the purchaser and the supplier.

6. Preparation of Forging for Ultrasonic Examination

6.1 Unless otherwise specified in the order or contract, the forging shall be machined to provide cylindrical surfaces for radial examination in the case of round forgings; the ends of the forgings shall be machined perpendicular to the axis of the forging for the axial examination. Faces of disk and rectangular forgings shall be machined flat and parallel to one another.

6.2 The surface roughness of exterior finishes shall not exceed 250 µin. [6 µm] unless otherwise shown on the forging drawing or stated in the order or the contract.

6.3 The surfaces of the forging to be examined shall be free of extraneous material such as loose scale, paint, dirt, and so forth.

7. Procedure

7.1 *General*:

7.1.1 As far as practicable, subject the entire volume of the forging to ultrasonic examination. Because of radii at change of sections and other local configurations, it may be impossible to examine some sections of a forging.

7.1.2 Perform the ultrasonic examination after heat treatment for mechanical properties (exclusive of stress-relief treatments) but prior to drilling holes, cutting keyways, tapers, grooves, or machining sections to contour. If the configuration of the forging required for the treatment for mechanical properties prohibits a subsequent complete examination of the forging, it shall be permissible to examine prior to treatment for mechanical properties. In such cases, reexamine the forging ultrasonically as completely as possible after heat treatment.

7.1.3 To ensure complete coverage of the forging volume, index the search unit with at least 15 % overlap with each pass.

7.1.4 For manual scanning, do not exceed a scanning rate of 6 in./s [150 mm/s].

7.1.5 For automated scanning, adjust scanning speed or instrument repetition rate, or both, to permit detection of the smallest discontinuities referenced in the specification and to allow the recording or signaling device to function. At no time shall the scanning speed exceed the speed at which an acceptable calibration was made.

7.1.6 If possible, scan all sections of forgings in two perpendicular directions.

7.1.7 Scan disk forgings using a straight beam technique from at least one flat face and radially from the circumference, whenever practicable.

7.1.8 Scan cylindrical sections and hollow forgings radially using a straight-beam technique. When practicable, also examine the forging in the axial direction.

7.1.9 In addition, examine hollow forgings by angle-beam technique from the outside diameter surface as required in 7.3.1.

7.1.10 In rechecking or reevaluation by manufacturer or purchaser use comparable equipment, search units, frequency, and couplant.

7.1.11 Forgings may be examined either stationary or while rotating in a lathe or on rollers. If not specified by the purchaser, either method may be used at the manufacturer's option.

7.2 *Straight-Beam Examination*:

7.2.1 For straight-beam examination use a nominal 2¼-MHz search unit whenever practicable; however, 1 MHz is the preferred frequency for coarse grained austenitic materials and long testing distances. In many instances on examining coarse grained austenitic materials it may be necessary to use a frequency of 0.4 MHz. Other frequencies may be used if desirable for better resolution, penetrability, or detectability of flaws.

7.2.2 Establish the instrument sensitivity by either the reflection, reference-block technique, or DGS method (see Appendix X3 for an explanation of the DGS method).

7.2.2.1 *Back-Reflection Technique (Back-Reflection Calibration Applicable to Forgings with Parallel Entry and Back Surfaces)*—With the attenuator set at an appropriate level, for example 5 to 1 or 14 dB, adjust the instrument controls to obtain a back reflection approximately 75 % of the full-screen height from the opposite side of the forging. Scan the forging at the maximum amplification setting of the attenuator (attenuator set at 1 to 1). Carry out the evaluation of discontinuities with the gain control set at the reference level. Recalibration is required for significant changes in section thickness or diameter.

NOTE 1—High sensitivity levels are not usually employed when inspecting austenitic steel forgings due to attendant high level of "noise" or "hash" caused by coarse grain structure.

7.2.2.2 *Reference-Block Calibration*—The test surface roughness on the calibration standard shall be comparable to but no better than the item to be examined. Adjust the instrument controls to obtain the required signal amplitude from the flat-bottom hole in the specified reference block. Utilize the attenuator in order to set up on amplitudes larger than the vertical linearity of the instrument. In those cases, remove the attenuation prior to scanning the forging.

NOTE 2—When flat-surfaced reference block calibration is specified, adjust the amplitude of indication from the reference block or blocks to compensate for examination surface curvature (an example is given in Appendix X1).

7.2.2.3 *DGS Calibration*—Prior to use, verify that the DGS overlay matches the transducer size and frequency. Accuracy of the overlay can be verified by reference blocks and procedures outlined in Practice E 317. Overlays are to be serialized to match the ultrasonic transducer and pulse echo testing system that they are to be utilized with.

7.2.2.4 Choose the appropriate DGS scale for the cross-sectional thickness of the forging to be examined. Insert the overlay over the CRT screen, ensuring the DGS scale base line coincides with the sweep line of the CRT screen. Place the probe on the forging, adjust the gain to make the first backwall echo appear clearly on CRT screen. Using the Delay and Sweep control, shift the screen pattern so that the leading edge of the initial pulse is on zero of the DGS scale and the backwall echo is on the DGS scale value corresponding to the thickness of the forging. Adjust the gain so the forging backwall echo matches the height of the DGS reference slope within ± 1 Db. Once adjusted, increase the gain by the Db shown on the DGS scale for the reference slope. Instrument is now calibrated and flaw sizes that can be reliably detected can be directly read from the CRT screen. These flaw sizes are the equivalent flat bottom reflector that can be used as a reference point.

NOTE 3—The above can be utilized on all solid forgings. Cylindrical hollow forgings, and drilled or bored forgings must be corrected to compensate for attenuation due to the central hole (see Appendix X4).

7.2.3 *Recalibration*—Any change in the search unit, couplant, instrument setting, or scanning speed from that used for calibration shall require recalibration. Perform a calibration check at least once every 8 h shift. When a loss of 15 % or greater in the gain level is indicated, reestablish the required calibration and reexamine all of the material examined in the preceding calibration period. When an increase of 15 % or greater in the gain level is indicated, reevaluate all recorded indications.

7.2.4 During the examination of the forging, monitor the back reflection for any significant reduction in amplitude. Reduction in back-reflection amplitude may indicate not only the presence of a discontinuity but also poor coupling of the search unit with the surface of the forging, nonparallel back-reflection surface, or local variations of attenuation in the forging. Recheck any areas causing loss of back reflection.

7.3 *Angle-Beam Examination—Rings and Hollow Forgings*:

7.3.1 Perform the examination from the circumference of rings and hollow forgings that have an axial length greater than 2 in. [50 mm] and an outside to inside diameter ratio of less than 2.0 to 1.

7.3.2 Use a 1 MHz, 45° angle-beam search unit unless thickness, OD/ID ratio, or other geometric configuration results in failure to achieve calibration. Other frequencies may be used if desirable for better resolution, penetrability, or detectability of flaws. For angle-beam inspection of hollow forgings up to 2.0 to 1 ratio, provide the transducer with a wedge or shoe that will result in the beam mode and angle required by the size and shape of the cross section under examination.

7.3.3 Calibrate the instrument for the angle-beam examination to obtain an indication amplitude of approximately 75 % full-screen height from a rectangular or a 60° V-notch on inside diameter (ID) in the axial direction and parallel to the axis of the forging. A separate calibration standard may be used; however, it shall have the same nominal composition, heat treatment, and thickness as the forging it represents. The test surface finish on the calibration standard shall be comparable but no better than the item to be examined. Where a group of identical forgings is made, one of these forgings may be used as the separate calibration standard. Cut the ID notch depth to 3 % maximum of the thickness or ¼ in. [6 mm], whichever is smaller, and its length approximately 1 in. [25 mm]. Thickness is defined as the thickness of the forging to be examined at the time of examination. At the same instrument setting, obtain a reflection from a similar OD notch. Draw a line through the peaks of the first reflections obtained from the ID and OD notches. This shall be the amplitude reference line. It is preferable to have the notches in excess metal or test metal when possible. When the OD notch cannot be detected when examining the OD surface, perform the examination when practicable (some ID's may be too small to permit examination), as indicated above from both the OD and ID surfaces. Utilize the ID notch when inspecting from the OD, and the OD notch when inspecting from the ID. Curve wedges or shoes may be used when necessary and practicable.

7.3.4 Perform the examination by scanning over the entire surface area circumferentially in both the clockwise and counter-clockwise directions from the OD surface. Examine forgings, which cannot be examined axially using a straight beam, in both axial directions with an angle-beam search unit. For axial scanning, use rectangular or 60° V-notches on the ID and OD for the calibration. These notches shall be perpendicular to the axis of the forging and the same dimensions as the axial notch.

8. Recording

8.1 *Straight-Beam Examination*—Record the following indications as information for the purchaser. These recordable indications do not constitute a rejectable condition unless negotiated as such in the purchase order.

8.1.1 In the back-reflection technique, individual indications equal to or exceeding 10 % of the back reflection from an adjacent area free from indications; in the reference-block or DGS technique, indications equal to or exceeding 100 % of the reference amplitude.

8.1.2 An indication that is continuous on the same plane regardless of amplitude, and found over an area larger than twice the diameter of the search unit. The extent of such an indication shall be accurately measured along with variations in amplitudes of reflections.

8.1.2.1 Planar indications shall be considered continuous over a plane if they have a major axis greater than 1 in. [25 mm]. In recording these indications corrections must be made for beam divergence at the estimated flaw depth.

8.1.3 In the back-reflection technique, discontinuity indications equal to or exceeding 5 % of the back reflection. In the reference-block technique, indications equal to or exceeding 50 % of the reference amplitude providing that they travel, are continuous, or appear as clusters.

8.1.3.1 Traveling indications are herein defined as indications whose leading edge moves a distance equivalent to 1 in. [25 mm] or more of metal depth with movement of the search unit over the surface of the forging.

8.1.3.2 A cluster of indications is defined as five or more indications located in a volume representing a 2-in. [50-mm] or smaller cube in the forging.

8.1.4 Reduction in back reflection exceeding 20 % of the original measured in increments of 10 %.

8.1.5 Amplitudes of recordable indications in increments of 10 %.

8.2 *Angle-Beam Examination*—Record discontinuity indications equal to or exceeding 50 % of the indication from the reference line. When an amplitude reference line cannot be generated, record discontinuity indications equal to or exceeding 50 % of the reference notch. These recordable indications do not constitute a rejectable condition unless negotiated as such in the purchase order.

9. Report

9.1 Report the following information:

9.1.1 All recordable indications (see Section 8).

9.1.2 For the purpose of reporting the locations of recordable indications, a sketch shall be prepared showing the physical outline of the forging including dimensions of all areas not inspected due to geometric configuration, the purchaser's drawing number, the purchaser's order number, and the manufacturer's serial number, and the axial, radial, and circumferential distribution of recordable ultrasonic indications.

9.1.3 The specification to which the examination was performed as well as the frequency used, method of setting sensitivity, type of instrument, surface finish, couplant, and search unit employed.

9.1.4 The inspector's signature and date examination performed.

10. Quality Levels

10.1 This practice is intended for application to forgings, with a wide variety of sizes, shapes, compositions, melting processes, and applications. It is, therefore, impracticable to specify an ultrasonic quality level which would be universally applicable to such a diversity of products. Ultrasonic acceptance or rejection criteria for individual forgings should be based on a realistic appraisal of service requirements and the quality that can normally be obtained in the production of the particular type forging.

10.2 Heavy austenitic stainless steel forgings are more difficult to penetrate ultrasonically than similar carbon or low-alloy steel forgings. The degree of attenuation normally increases with section size; and the noise level, generally or in isolated areas, may become too great to permit detection of discrete indications. In most instances, this attenuation results from inherent coarse grained microstructure of these austenitic alloys. For these reasons, the methods and standards employed for ultrasonically examining carbon and low-alloy steel forgings may not be applicable to heavy austenitic steel forgings. In general, only straight beam inspecting using a back-reflection reference standard is used. However, utilization of Practice A 745/A 745M for austenitic steel forgings can be considered if flat bottom hole reference standards or angle beam examination of these grades are required.

10.3 Acceptance quality levels shall be established between purchaser and manufacturer on the basis of one or more of the following criteria.

10.3.1 *Straight-Beam Examination*:

10.3.1.1 No indications larger than some percentage of the reference back reflection.

10.3.1.2 No indications equal to or larger than the indication received form the flat-bottom hole in a specific reference block or blocks.

10.3.1.3 No areas showing loss of back reflection larger than some percentage of the reference back reflection.

10.3.1.4 No indications per 10.3.1.1 or 10.3.1.2 coupled with some loss of resultant back reflection per 10.3.1.3.

10.3.1.5 No indications exceeding the reference level specified in the DGS method

10.3.2 *Angle-Beam Examination*—No indications exceeding a stated percentage of the reflection from a reference notch or of the amplitude reference line.

10.4 Intelligent application of ultrasonic quality levels involves an understanding of the effects of many parameters on examination results.

11. Keywords

11.1 angle beam examination; back-reflection; DGS; reference–block; straight beam examination; ultrasonic

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order. Details shall be agreed upon by the manufacturer and the purchaser.

S1. Reporting Criteria

S1.1 Reference block calibration shall be performed using at least three holes, spaced to approximate minimum, mean, and maximum thickness as tested, and shall be used to generate a distance amplitude correction (DAC) curve. The following hole sizes apply:

1. ¹⁄₁₆ in. [1.5 mm] flat bottom holes (FBH) for thicknesses less than 1.5 in. [40 mm]
2. ⅛ in. [3 mm] FBH for thicknesses of 1.5-6 in. [40-150 mm] inclusive
3. ¼ in. [6 mm] FBH for thicknesses over 6 in. [150 mm]

S1.2 Reporting criteria include:

1. All indications exceeding the DAC curve
2. Two or more indications separated by ½ in. [12 mm] or less

APPENDIXES

(Nonmandatory Information)

X1. TYPICAL TUNING LEVEL COMPENSATION FOR THE EFFECTS OF FORGING CURVATURE

X1.1 The curve (Fig. X1.1) was determined for the following test conditions:

Material	nickel-molybdenum-vanadium alloy steel (Specification A 469, Class 4)
Instrument	Type UR Reflectoscope
Search unit	1⅛-in. [30 mm] diameter quartz
Frequency	2¼ MHz
Reference block	ASTM No. 3-0600 (aluminum)
Reflection area of reference curve	0.010 in.^{2} [6.5 mm^2] in nickel-molybdenum-vanadium alloy steel
Surface finish	250 µin. [6 µm], max, roughness

X1.2 To utilize curve, adjust reflectoscope sensitivity to obtain indicated ultrasonic response on ASTM No. 3-0600 reference block for each diameter as shown. A response of 1 in. [25 mm] sweep-to-peak is used for flat surfaces. Use attenuator to obtain desired amplitude, but do testing at 1 to 1 setting.

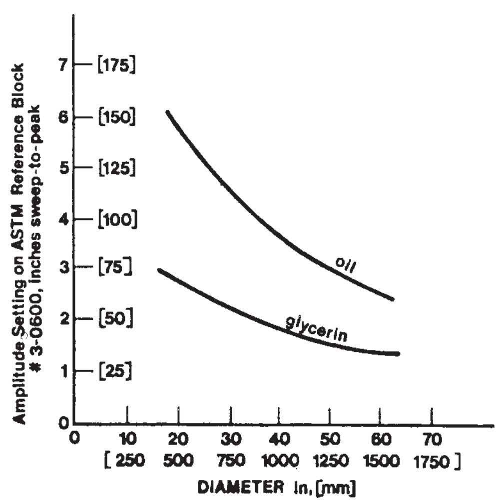


FIG. X1.1 Typical Compensation Curve for Effects of Forging Curvature

X2. INDICATION AMPLITUDE COMPENSATION FOR TEST DISTANCE VARIATIONS

X2.1 The curve (Fig. X2.1) has been determined for the following test conditions:

Material	nickel-molybdenum-vanadium alloy steel (Specification A 469, Class 4)
Instrument	Type UR Reflectoscope
Search unit	1⅛-in. [30 mm] diameter quartz
Frequency	2¼ MHz
Couplant	No. 20 oil
Reference block	ASTM No. 3-0600 (aluminum)
Reflection area of reference curve	0.010 in.^{2} [65 mm^2] in nickel-molybdenum-vanadium alloy steel
Surface finish	250 µin. max, roughness

X2.2 To utilize curve, establish amplitude from ASTM reference block to coincide with values from Appendix X1.

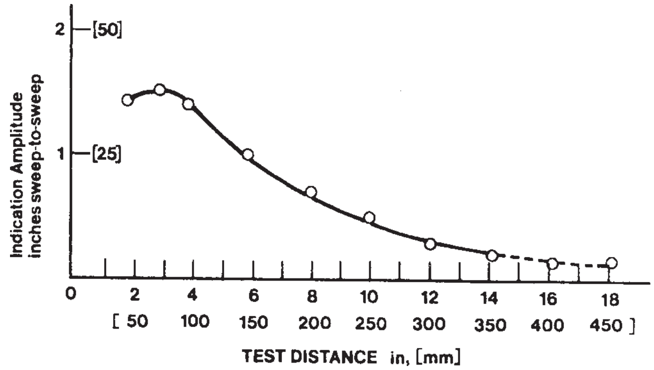


FIG. X2.1 Typical Distance-Amplitude Correction Curve

X3. BACKGROUND INFORMATION ON THE DGS METHODS

X3.1 The DGS method was developed to determine flaw sizes by comparison to a back wall echo produced on the part to be ultrasonic tested. The derivation of DGS curves is extensively covered and can be found in standard texts on ultrasonic testing, and will not be covered here. The distance or thickness of the forging (*A*) to be tested, as noted on the overlay, must be accurately defined on the CRT screen. The back reflection (*B*) of the part must be established and suitable gain added. Flaw echo indications that appear can be sized via the flaw size curves (*C*) on the overlay. Item (*D*) depicts the transducers that the overlay works in conjunction with and (*E*) depicts the series of curves that the overlay scales are matched to.

X4. COMPENSATION FOR CENTER HOLE ATTENUATION ON CYLINDRICAL BORED OR HOLLOW FORGINGS UTILIZING THE DGS METHOD

X4.1 The hole in a cylindrical bored forging causes sound scatter. In these cases, a correction is required which depends on the wall thickness and bore diameter.

X4.1.1 Determine the correction value in dB from the Nomogram (Fig. X4.1).

X4.1.2 Proceed as described in 7.2.2.3.

X4.1.3 With the GAIN-dB control, reduce the flaw detector gain by the correction value determined as per the Nomogram (Fig. X4.2). Thus, the flaw detector gain is accurately adjusted.

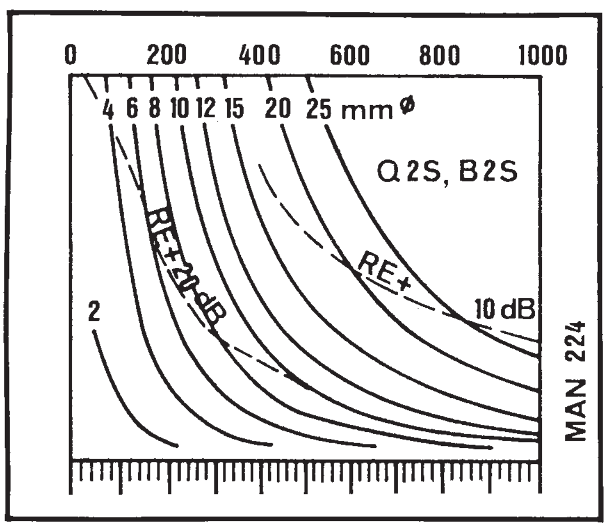
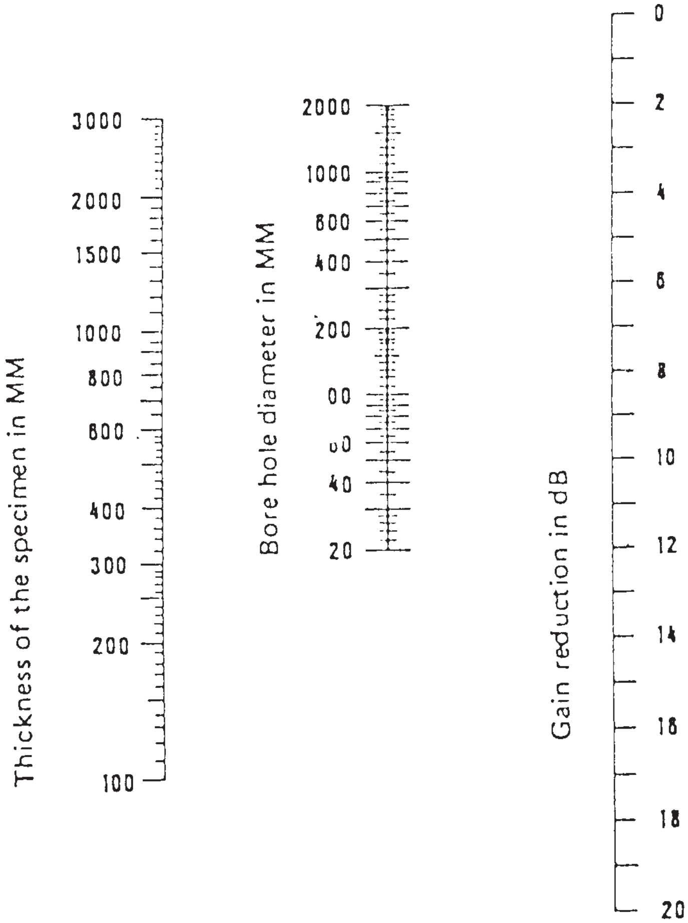


FIG. X4.1 Example of DGS Overlay



NOTE—Metric units are presented in this figure to be consistent with DGS scales presently available. Conversion to English units would also be acceptable.

FIG. X4.2 The Influence of a Central Bore on the Backwall Echo Amplitude of Cylindrical or Plane Parallel Forgings

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes since A 388/A 388M–01 that may impact the use of this standard.

(1) Revise Section 7.1.7.

Designation: A 391/A 391M – 01

Standard Specification for Grade 80 Alloy Steel Chain[1]

This standard is issued under the fixed designation A 391/A 391M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers Grade 80 heat-treated alloy steel chain for such applications as slings, lifting assemblies, and load binding.

NOTE 1—This specification does not cover alloy steel chain for pocket wheel applications.

1.2 The values stated in either SI units or in other units shall be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system must be used independently of the other, without combining values in any way.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

E 30 Test Methods for Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron[3]

E 44 Definitions of Terms Relating to Heat Treatment of Metals[4]

E 350 Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron[3]

E 415 Test Method for Optical Emission Vacuum Spectrometric Analysis of Carbon and Low-Alloy Steel[3]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *breaking force, minimum*—the minimum force in pounds or newtons at which the chain, during manufacture, has been found by testing to break when a constantly increasing force is applied in direct tension. This test is a manufacturer's attribute acceptance test and shall not be used as criteria for service.

3.1.2 *lot*—for the purpose of acceptance testing, a lot shall consist of 3000 ft [1000 m], or fraction thereof, of the same grade and size chain. If a continuous length of chain exceeds 3000 ft [1000 m], it shall also be considered a lot.

3.1.3 *proof test*—a quality control tensile test applied to chain for the purpose of verifying weld and material quality. It is the minimum force in pounds or newtons which the chain has withstood at the time it left the producer, under a test in which a constantly increasing force has been applied in direct tension to a straight length of chain. Proof test loads are a manufacturing integrity test and shall not be used as criteria for service or design purposes.

3.1.4 *working load limit (WLL)*—the maximum combined static and dynamic load in pounds or kilograms that shall be applied in direct tension to an undamaged straight length of chain.

4. Ordering Information

4.1 It shall be the responsibility of the purchaser to specify all requirements that are necessary for material ordered under this specification. Such requirements to be considered include, but are not limited to, the following:

4.1.1 Product to conform to Specification A 391 or A 391M and year of issue,

4.1.2 Nominal size of chain in in. [mm],

4.1.3 Quantity of chain in ft [m],

4.1.4 Length of each piece, if required,

4.1.5 Finish, if required,

4.1.6 Certification of test(s), if required, and

4.1.7 Acceptance of inspection by purchaser, if required.

5. Manufacturing

5.1 *Melting Process*—The alloy steel shall be made to a fully-killed fine austenitic grain process.

5.2 *Welding Process*—Alloy steel chain may be made by the electric welding or gas welding process.

5.3 *Heat Treatment*—After welding, alloy steel chain shall be heat treated before applying the proof test. Heat treatment shall include quenching and tempering as defined by Definitions E 44.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.27 on Steel Chain.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] Discontinued. See 1995 *Annual Book of ASTM Standards*, Vol 03.05.

[4] Discontinued. See 1993 *Annual Book of ASTM Standards*, Vol 01.02.

***A Summary of Changes section appears at the end of this standard.**

TABLE 1 Grade 80 Alloy Chain Mechanical and Dimensional Requirements

Nominal Chain Size		Material Diameter		Working Load Limit, max		Proof Test,[A] min		Minimum Breaking Force[A]		Inside Length, max		Inside Width, min to max	
in.	mm	in.	mm	lb	kg	lb	kN	lb	kN	in.	mm	in.	mm
7⁄32	5.5	0.217	5.5	2 100	970	4 200	19.0	8 400	38.0	0.69	17.6	0.281 to 0.325	7.14 to 8.25
9⁄32	7.0	0.276	7.0	3 500	1 570	7 000	30.8	14 000	61.6	0.90	22.9	0.375 to 0.430	9.53 to 10.92
5⁄16	8.0	0.315	8.0	4 500	2 000	9 000	40.3	18 000	80.6	1.04	26.4	0.410 to 0.472	10.41 to 12.00
3⁄8	10.0	0.394	10.0	7 100	3 200	14 200	63.0	28 400	126.0	1.26	32.0	0.512 to 0.591	13.00 to 15.00
1⁄2	13.0	0.512	13.0	12 000	5 400	24 000	107.0	48 000	214.0	1.64	41.6	0.688 to 0.768	17.43 to 19.50
5⁄8	16.0	0.630	16.0	18 100	8 200	36 200	161.0	72 400	322.0	2.02	51.2	0.812 to 0.945	20.63 to 24.00
3⁄4	20.0	0.787	20.0	28 300	12 800	56 600	252.0	113 200	504.0	2.52	64.0	0.984 to 1.180	25.00 to 30.00
7⁄8	22.0	0.866	22.0	34 200	15 500	68 400	305.0	136 800	608.0	2.77	70.4	1.080 to 1.300	27.50 to 33.00
1	26.0	1.024	26.0	47 700	21 600	95 400	425.0	190 800	850.0	3.28	83.2	1.280 to 1.540	32.50 to 39.00
1 1⁄4	32.0	1.260	32.0	72 300	32 800	144 600	644.0	289 200	1288.0	4.03	102.4	1.580 to 1.890	40.00 to 48.00

[A] The proof test and minimum breaking force loads *shall not* be used as criteria for service or design purposes. (See Section 3.)

6. Material Requirements

6.1 *Heat Analysis*—The selection and amounts of the alloying elements in the steel are left to the judgment of the individual chain manufacturer provided the steel meets the following criteria: Carbon: 0.35 % max.; Phosphorous: 0.025 % max.; Sulfur: 0.025 % max. Nickel must be present in an alloying amount (0.40 % min); and at least one of the following elements must be present in an alloying amount: Chromium (0.40 % min) or Molybdenum (0.15 % min).

6.2 *Product Analysis*—The steel used may be analyzed by the purchaser and shall conform to the requirements of 6.1 subject to the product analysis tolerances specified in Specification A 29/A 29M. Test samples may be taken from rods, bars, or finished chain. Samples for analysis shall be so taken as to represent the full cross section of the specimen.

6.3 Test Methods E 30, E 350, or E 415 shall be used for referee purposes.

7. Mechanical Requirements

7.1 *Proof Test*—All chain shall be tested to at least the proof load prescribed in Table 1 for the appropriate size chain. When so tested it shall withstand these loads without loss of chain integrity. Links or chain segments not withstanding the proof test load shall be removed from the chain.

7.2 *Breaking Force*—The breaking force test specimen shall consist of a length from the lot containing at least the number of links in Table 2. All chain shall be in the quenched and tempered condition before the breaking force is measured.

7.2.1 Fixtures for securing chain in a testing machine shall be properly designed to support securely the shoulder of the link (see Note 2). The opening in the fixture shall not be more than 125 % of the stock diameter being tested. Links engaged in the testing fixture shall not be considered part of the test specimen.

TABLE 2 Mechanical Test Sample Length Requirements

Size of Chain	Minimum Number of Links in Test Specimen
7⁄32 in. [5.5 mm]	9
Larger than 7⁄32 in. [5.5 mm] but less than 3⁄4 in. [20.0 mm]	7
3⁄4 in. [20.0 mm] and larger	3

NOTE 2—"U" bolts of the same or larger diameter and the same or greater strength may be used to secure the chain to the jaws of the testing machine.

7.2.2 Test specimens shall meet or exceed the minimum breaking force values given in Table 1 for the appropriate size chain.

7.3 *Elongation*:

7.3.1 All chain must be in the quenched and tempered condition before the elongation is measured.

7.3.2 The elongation test specimen shall consist of a length from the lot containing at least the number of links in Table 2.

7.3.3 A positive load not exceeding 10 % of the proof test shall be applied for determining the original gage length ($L\{0\}$).

7.3.4 The elongation shall be based on the total extension at fracture. This is expressed as a percentage of the change in length (ΔL) divided by the original gage length ($L\{0\}$). The elongation may be determined by the equation below or by autographic recorder or side scale.

$$\text{Elongation (\%)} = \left\{\Delta L \,/\, L\{0\}\right\} \times 100$$

where:

ΔL = test specimen final length at fracture – test specimen original gage length ($L\{0\}$), and

$L\{0\}$ = original gage length (sum or the inside lengths of the test chain links, not counting the fixture links, or as determined in 7.3.3).

7.3.5 The elongation shall be a minimum of 20 %.

7.4 One test for breaking strength and elongation shall be made from each lot. The elongation and breaking force tests may be performed at the same time on the same test specimen.

8. Dimensional Requirements

8.1 The chain shall conform to the dimensional requirements specified in Table 1 for the appropriate size chain.

8.2 *Diameter*—The diameter of the material from which the chain is manufactured shall not be smaller than the material diameter listed in Table 1 within the following tolerance: −3 %. Oversized material may be used for all applications.

9. Workmanship, Finish, and Appearance

9.1 The chain at the time of shipment shall be free of discontinuities that would prevent the chain from enduring the working load limit forces.

9.2 The manufacturer may apply a surface treatment or coating of their own choice for identification or corrosion resistance unless the customer specifies otherwise.

10. Retests

10.1 If the original test specimen fails to conform to the requirements in 7.2.2, two additional test specimens from the same lot may be tested, each of which shall conform to the requirements in 7.2.2. If both additional tests are satisfactory, the chain will be considered acceptable.

11. Rework and Retreatment

11.1 Materials that fail to conform to the requirements for dimensions and mechanical tests may be resubmitted after being reworked.

12. Inspection

12.1 When requested on the purchase order or contract, the chain shall be free of paint or other coatings which could mask surface discontinuities at the time of inspection.

12.2 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to verify that the chain produced is being furnished in accordance with this specification. Inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspection shall be made at the place of manufacture, unless otherwise agreed upon.

12.3 The purchaser may make the tests to govern acceptance or rejection of the chain at their own laboratory or elsewhere. Tests and acceptance criteria shall conform to the requirements contained in this specification unless otherwise stated in the purchase order. Tests at the purchaser's laboratory or elsewhere shall be made at the expense of the purchaser.

13. Rejection and Rehearing

13.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection shall be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of any test, the producer or supplier may make claim for a rehearing.

13.2 In the case of dissatisfaction with the results of the test in 12.3, the manufacturer may make claim for a rehearing.

14. Certification

14.1 A manufacturer's certification that the chain conforms to Specification A 391 or A 391M of the date of issue specified shall be furnished when requested on the purchase contract or order.

14.2 When requested on the purchase contract or order, the manufacturer shall furnish a certificate of proof test to the purchaser or his representative.

15. Product Marking

15.1 Body chain links shall not be marked with indented characters.

15.2 Body chain links shall be marked for identification purposes at intervals no greater than 3 ft [0.9 m].

15.3 The embossing shall consist of at least manufacturer's grade identification.

15.4 The marking for Grade 80 shall be at least 8, 80, or 800.

16. Keywords

16.1 alloy steel chain; chain; Grade 80; steel chain

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since A 391/A 391M–98 that may impact the use of this standard.

(1) Revised Paragraphs 3.1.1, 7.2, 7.3, and 7.4.
(2) Revised Table 1 inside length dimensions and breaking force for ⅞ in. size.
(3) Deleted Figs. 1 and 2.
(4) Deleted reference to Test Methods and Definitions A 370.

Standard Practice for Steel Bars, Selection Guide, Composition, and Mechanical Properties[1]

This standard is issued under the fixed designation A 400; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice is intended as a guide for the selection of steel bars according to section and to the mechanical properties desired in the part to be produced. This is not a specification for the procurement of steel. Applicable procurement specifications are listed in Section 5.

1.2 Several steel compositions intended for various sections and mechanical property requirements are presented in Tables 1-6. The criteria for placing a steel composition in one of the three general class designations, Classes P, Q, and R (described in Section 4) are as follows:

1.2.1 *Classes P and Q* should be capable of developing the mechanical properties shown in Tables 1-4 by liquid quenching from a suitable austenitizing temperature, and tempering at 800°F (427°C) or higher. A hardness indicated by tests made at a location shown in Fig. 1, A, B, or C, is taken as evidence that a composition is capable of meeting other equivalent mechanical properties shown in the tables. Normal good shop practices are assumed, with control of austenitizing and tempering temperatures, and mild agitation of the part in the quenching bath.

1.2.2 *Class R* should be capable of developing the mechanical properties shown in Tables 5 and 6 as hot rolled, by cold drawing, or by cold drawing with additional thermal treatment. The locations for obtaining tension tests are described in 6.2.

1.3 It is not implied that the compositions listed in the tables are the only ones satisfactory for a certain class and mechanical property requirement. Steels with lower alloy contents are often satisfactory through the use of special processing techniques.

2. Referenced Documents

2.1 *ASTM Standards:*

A 108 Specification for Steel Bars, Carbon, Cold-Finished, Standard Quality[2]

A 304 Specification for Steel Bars, Alloy, Subject to End-Quench Hardenability Requirements[2]

A 311/A 311M Specification for Steel Bars, Carbon, Stress-Relieved, Cold-Drawn, Subject to Mechanical Property Requirements[2]

A 322 Specification for Steel Bars, Alloy, Standard Grades[2]

A 633/A 633M Specification for Normalized High-Strength Low-Alloy Structural Steel Plates[3]

A 675/A 675M Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties[2]

3. Significance and Use

3.1 If the desired mechanical properties are as described in 4.1.1 for material identified as Classes P-1 through P-7, or in 4.1.2 for material identified as Classes Q-1 through Q-7, the strength level desired can be based on hardness or the equivalent tensile or yield strength as shown in Tables 1-4. If the desired mechanical properties are as set forth in 4.1.3 for material identified as Classes R-1 through R-6, the strength level is based on yield strength as shown in Tables 5 and 6.

3.2 The user, after determining the mechanical property requirements of the critical section (that carrying the greatest stress) of the part, should select the composition or compositions from Tables 1-6 that fulfills these requirements and is most suitable for processing.

4. Classification

4.1 Steel bar compositions under this practice are classified according to mechanical property requirements and the critical section size of the part to be produced, as follows:

4.1.1 *Classes P-1 through P-7* comprise bars for parts to operate under severe service conditions requiring high yield strength (90 000 psi (621 MPa) and over), good ductility, and relatively high notch toughness. The applicable section sizes,

[1] This practice is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.04.

TABLE 1 Steels for Moderately Quenched Parts—Classes P-1 Through P-7

(Applicable to oil-quenching or equivalent rate of heat-removal.)

NOTE 1—Steels listed as approved for a certain section or strength may be used for lighter sections and lower strengths.

NOTE 2—Steel composition numbers correspond to SAE, AISI, or ASTM designations. Those in italics are no longer considered standard grades due to decreased usage.

NOTE 3—An H-steel with the same grade designation as a standard SAE-AISI steel is capable of meeting the same section and strength requirements as the standard steel (see ASTM Specification A 304), and is the preferred method of specification.

NOTE 4—Steels having a maximum carbon content of 0.40 % or over, or a hardness of HB 293 or over after heat-treating, are not recommended for applications involving welding.

Desired Minimum Hardness		Equivalent Tensile Strength, psi[A]	Equivalent Yield Strength, psi[A]	Minimum[B] As-Quenched Hardness		Class							
						P-1		P-2	P-3	P-4	P-5	P-6	P-7
						Diameter of Round (or Distance Between Faces of Square or Hexagonal) Sections, in.[C]							
						To ½ , incl		Over ½ to 1, incl	Over 1 to 1½ , incl	Over 1½ to 2, incl	Over 2 to 2½ , incl	Over 2½ to 3, incl	Over 3 to 3½ , incl
						Thickness of Flat Sections, in.[C]							
HB	HRC			HB	HRC	To 0.3, incl		Over 0.3 to 0.6, incl	Over 0.6 to 1, incl	Over 1 to 1.3, incl	Over 1.3 to 1.6, incl	Over 1.6 to 2.0, incl	Over 2.0 to 2.3, incl
229 to 293, incl	20 to 33, incl	110 000 to 145 000, incl	90 000 to 125 000, incl	388	42	1330 4130 5132 8630	*50B30*						
Over 293 to 341, incl	Over 33 to 38, incl	Over 145 000 to 170 000, incl	Over 125 000 to 150 000, incl	409	44	1335 *3135* 4042 5135	94B30	*3140* *4135* *4640* 8640 8740	4137		4142	9840	4337
Over 341 to 388, incl	Over 38 to 42, incl	Over 170 000 to 190 000, incl	Over 150 000 to 170 000, incl	455	48	1340 *3140* 4047 *4135* 5140 8637 *TS14B50* *50B40*		4137 *6145* 8642 8645 *8742*	4140 *TS4140* 94B40		4145 9840	4147 *4337* *86B45*	4340
Over 388 to 429, incl	Over 42 to 45, incl	Over 190 000 to 205 000, incl	Over 170 000 to 185 000, incl	496	51	1345 *4063* *4068* 4140 *4640* 5145 5150 8640 8642	8645 8740 *8742* 9260 *9261* *TS4140* 50B46 50B44 50B50	5147 5155 5160 6150 *9262* *94B40*	4142 4145 *4337* *8650* 8655 50B60 51B60 81B45	*8660* *9840*	4147 4161 4340 *86B45*	4150 4161 *TS4150*	E4340 *9850*

[A] 1 psi = 0.006895 MPa.

[B] Minimum as-quenched hardness for obtaining desired hardness after tempering at 800°F (427°C) or higher.

[C] 1 in. = 25.4 mm.

identified as Classes P-1 through P-7, are shown in Table 7. The steel compositions suitable for Classes P-1 through P-7 and for various desired mechanical properties are listed in Tables 1 and 2.

4.1.2 *Classes Q-1 through Q-7* comprise bars for parts operating under moderate service conditions requiring moderate to high yield strength (75 000 to 185 000 psi (517 to 1276 MPa)), corresponding tensile-strength levels, and good ductility. The applicable section sizes, identified as Classes Q-1 through Q-7, are shown in Table 7. The steel compositions suitable for Classes Q-1 through Q-7 and various desired mechanical properties are listed in Tables 3 and 4.

4.1.3 *Classes R-1 through R-6* comprise bars for parts requiring a lower yield strength (30 000 to 120 000 psi (207 to 827 MPa)), with fair to good ductility. The applicable section sizes, identified as Classes R-1 through R-6, are shown in Table 7. The steel compositions capable of developing the various desired mechanical properties are listed in Tables 5 and 6.

5. Applicable Procurement Specifications

5.1 For procurement of steel, it is recommended that the following ASTM specifications of latest issue be used: Specification A 108, Specification A 304, Specification A 311/

TABLE 2 Steels for Drastically Quenched Parts—Classes P-1 Through P-7

(Applicable to water-quenching or equivalent rate of heat-removal — See Note 5)

NOTE 1—Steels listed as approved for heavier sections or higher strengths may be used in the same conditions for lighter sections and lower strengths.

NOTE 2—Steel composition numbers correspond to ASE, AISI, or ASTM designations. Those in italics are no longer considered standard grades due to decreased usage.

NOTE 3—An H-steel with the same grade designation as a standard SAE-AISI steel is capable of meeting the same section and strength requirements as the standard steel (see ASTM Specification A 304), and is the preferred method of specification.

NOTE 4—Steels having a maximum carbon content of 0.40 % or over, or a hardness of HB 293 or over after heat-treating, are not recommended for applications involving welding.

NOTE 5—Parts made of steel with a carbon content of 0.33 % or higher, where the section is under 1 1/2 in. (38.1 mm) should not be quenched in water without careful exploration for quench-cracking.

Desired Minimum Hardness		Equivalent Tensile Strength, psi[A]	Equivalent Yield Strength, psi[A]	Minimum[B] As-Quenched Hardness		Class						
						P-1	P-2	P-3	P-4	P-5	P-6	P-7
						Diameter of Round (or Distance Between Faces of Square or Hexagonal) Sections, in.[C]						
						To ½ , incl	Over ½ to 1, incl	Over 1 to 1½ , incl	Over 1½ to 2, incl	Over 2 to 2½ , incl	Over 2½ to 3, incl	Over 3 to 3½ , incl
						Thickness of Flat Sections, in.[C]						
HB	HRC			HB	HRC	To 0.3, incl	Over 0.3 to 0.6, incl	Over 0.6 to 1.0, incl	Over 1.0 to 1.3, incl	Over 1.3 to 1.6, incl	Over 1.6 to 2.0, incl	Over 2.0 to 2.3, incl
229 to 293, incl	20 to 33, incl	110 000 to 145 000, incl	90 000 to 125 000, incl	388	42	8625 8627	4130 5130 8630 *50B30*	94B30				
Over 293 to 341, incl	Over 33 to 38, incl	Over 145 000 to 170 000, incl	Over 125 000 to 150 000, incl	409	44	*4032* 4037 4130 5130 8630 *TS14B35* *508B30*	1330 5132 94B30	1335 5135 5140 *50B40*		1340[D] *3135*[D] *4640* 8637[D] 8640 8740	*3140* *4135*	4137 *4337* *9840*

[A] 1 psi = 0.006895 MPa.

[B] Minimum as-quenched hardness for obtaining desired hardness after tempering at 800°F (427°C) or higher.

[C] 1 in. = 25.4 mm.

[D] These steels have insufficient hardenability for Class P-4, because of difference in test locations, but are satisfactory for other smaller sizes.

A 311M, Specification A 322, Specification A 633/ A 633M, and Specification A 675/A 675M.

6. Location at Which Desired Properties Are Obtained

6.1 *Classes P-1 Through P-7 and Q-1 Through Q-7*—The mechanical properties shown in Tables 1-4 are based on obtaining hardness test specimens from the locations shown in Fig. 1, A, B, and C. For bars, the location should be at least twice the diameter or minimum distance between faces from an end; and for flat sections, at least twice the thickness from an edge.

6.2 *Classes R-1 Through R-6*—The mechanical properties shown in Tables 5 and 6 are based on obtaining tension test specimens from the following locations:

6.2.1 Center of bars or plates under 1½ in. (38.1 mm) in diameter or in distance between parallel surfaces, and

6.2.2 Mid-radius or a quarter of the distance between parallel faces from the surface for larger sections.

7. Hardness Criteria for Quenched and Tempered Parts

7.1 *Classes Q-1 Through Q-7*—To obtain the properties stated in 4.1.2 at the locations shown in Fig. 1, A, B, and C, a microstructure containing a minimum of 50 % martensite is necessary.

8. Keywords

8.1 steel bars

TABLE 3 Steels for Moderately Quenched Parts—Classes Q-1 Through Q-7
(Applicable to oil-quenching or equivalent rate of heat-removal.)

NOTE 1—Steels listed as approved for heavier sections or higher strengths may be used in the same conditions for lighter sections and lower strengths.

NOTE 2—Steel composition numbers correspond to ASE, AISI, or ASTM designations. Those in italics are no longer considered standard grades due to decreased usage.

NOTE 3—An H-steel with the same grade designation as a standard SAE-AISI steel is capable of meeting the same section and strength requirements as the standard steel (see ASTM Specification A 304), and is the preferred method of specification.

NOTE 4—Steels having a maximum carbon content of 0.40 % or over, or a hardness of HB 293 or over after heat-treating, are not recommended for applications involving welding.

Desired Minimum Hardness		Equivalent Tensile Strength, psi[A]	Equivalent Yield Strength, psi[A]	Minimum[B] As-Quenched Hardness		Class						
						Q-1	Q-2	Q-3	Q-4	Q-5	Q-6	Q-7
						Diameter of Round (or Distance Between Faces of Square or Hexagonal) Sections, in.[C]						
						To ½, incl	Over ½ to 1, incl	Over 1 to 1½, incl	Over 1½ to 2, incl	Over 2 to 2½, incl	Over 2½ to 3, incl	Over 3 to 3½, incl
						Thickness of Flat Sections, in.[C]						
HB	HRC			HB	HRC	To 0.3, incl	Over 0.3 to 0.6, incl	Over 0.6 to 1, incl	Over 1 to 1.3, incl	Over 1.3 to 1.6, incl	Over 1.6 to 2.0, incl	Over 2.0 to 2.3, incl
187 to 293, incl	91 (R_b) to 33, incl	95 000 to 145 000, incl	75 000 to 125 000, incl	388	42	1330 8630 4130 *50B30* 5132	8637	3140 8740	4140 *TS4140* 94B40		4142	
Over 293 to 341, incl	Over 33 to 38, incl	Over 145 000 to 170 000, incl	Over 125 000 to 150 000, incl	409	44	1335 *4042* *50B30* 5135 94B30	*3140* 8740 *4135* *4640* 8640	4137 *TS4140* 4140 8642 8645 *8742*	81B45	4142	4145	4147 *4337* *9840* *86B45*
Over 341 to 388, incl	Over 38 to 42, incl	Over 170 000 to 190 000, incl	Over 150 000 to 170 000, incl	455	48	1340 8637 *3135* *TS14B50* *3140* *50B40* 4047 *4135* 5140	1345 *8742* 4137 *TS4140* 4140 50B50 5150 8642 8645	4142 *94B40* 5147 5155 6150	51B60	4145 8655 *9840*	4147 *4337* *86B45*	4150 4340 *TS4150*
Over 388 to 429, incl	Over 42 to 45, incl	Over 190 000 to 205 000, incl	Over 170 000 to 185 000, incl	496	51	1345 8645 4047 8740 *4063* *8742* *4068* 9260 4140 *TS4140* *4640* 50B46 5145 50B44 5150 50B50 8640 8642	4142 5147 5155 6150 *9261* *94B40*	4145 *4337* 5160 *8650* 8655 *9262* 50B60 51B60 81B45	*9840*	4147 4340 *8660* *86B45*	4150 *TS4150*	E4340 *9850*

[A] 1 psi = 0.006895 MPa.
[B] Minimum as-quenched hardness for obtaining desired hardness after tempering at 800°F (427°C) or higher.
[C] 1 in. = 25.4 mm.

TABLE 4 Steels for Drastically Quenched Parts—Classes Q-1 Through Q-7

(Applicable to water-quenching or equivalent rate of heat-removal—See Note 5)

NOTE 1—Steels listed as approved for heavier sections or higher strengths may be used in the same conditions for lighter sections and lower strengths.

NOTE 2—Steel composition numbers correspond to SAE, AISI, or ASTM designations. Those in italics are no longer considered standard grades due to decreased usage.

NOTE 3—An H-steel with the same grade designation as a standard SAE-AISI steel is capable of meeting the same section and strength requirements as the standard steel (see ASTM Specification A 304), and is the preferred method of specification.

NOTE 4—Steels having a maximum carbon content of 0.40 % or over, or a hardness of HB 293 or over after heat-treating, are not recommended for applications involving welding.

NOTE 5—Parts made of steel with a carbon content of 0.33 % or higher, where the section is under 1½ in. (38.1 mm) should not be quenched in water without careful exploration for quench-cracking.

Desired Minimum Hardness		Equivalent Tensile Strength, psi[A]	Equivalent Yield Strength, psi[A]	Minimum[B] As-Quenched Hardness		Class						
						Q-1	Q-2	Q-3	Q-4	Q-5	Q-6	Q-7
						Diameter of Round (or Distance Between Faces of Square or Hexagonal) Sections, in.[C]						
						To ½, incl	Over ½ to 1, incl	Over 1 to 1½, incl	Over 1½ to 2, incl	Over 2 to 2½, incl	Over 2½ to 3, incl	Over 3 to 3½, incl
						Thickness of Flat Sections, in.[C]						
HB	HRC			HB	HRC	To 0.3, incl	Over 0.3 to 0.6, incl	Over 0.6 to 1.0, incl	Over 1.0 to 1.3, incl	Over 1.3 to 1.6, incl	Over 1.6 to 2.0, incl	Over 2.0 to 2.3, incl
187 to 293, incl	91 (HRB) to 33, incl	95 000 to 145 000, incl	75 000 to 125 000, incl	388	42	1000 series, from 1024 to 1040, incl[E] 8625 8627	4037 4130 5130 5132 8630 *50B30*	5135 94B30		5140[D] 8637 *50B40*[D]	*4640*	*3140* 8740
Over 293 to 341, incl	Over 33 to 38, incl	Over 145 000 to 170 000, incl	Over 125 000 to 150 000, incl	409	44	1036 to 1045,[E] incl *4032* 8630	1330 *5046* 5135 94B30	1335		1340[D] *3135*[D] *3140* 8637[D]	*4135* 8640 8740	4137 4140 8642 8645 *8742* *TS4140*
Over 341 to 388, incl	Over 38 to 42, incl	Over 170 000 to 190 000, incl	Over 150 000 to 170 000, incl	455	48	1335 4037 *TS14B35* 4130 *5046* *50B30* 5130 5132 5135 94B30 *8635*	*3135* *4042* 4047	1340 *3140* *4135* 5140 8637 *50B40*		1345 50B44[D] 4137 *4640*[D] 5145[D] 5150 8640[D] 8642 8740[D] 50B50	4140 8645 *8742* *TS4140*	4142 *4337* 5147 6150 *8650* *9840* 81B45 *94B40*

[A] 1 psi = 0.006895 MPa.

[B] Minimum as-quenched hardness for obtaining desired hardness after tempering at 800°F (427°C) or higher.

[C] 1 in. = 25.4 mm.

[D] These steels have insufficient hardenability for Class Q-4 parts because of different location of test specimens, but are satisfactory for smaller sections.

[E] For these steels, the yield to tensile-strength ratio will usually be lower than 80 %.

TABLE 5 Steels for Parts Manufactured From Hot Rolled[A] and Cold Drawn[B,C] Bars—Classes R-1 Through R-6

NOTE 1—Steels listed as approved for heavier section or higher strengths may be used in the same conditions for lighter sections and lower strengths.

NOTE 2—Steel composition numbers correspond to ASE, AISI, or ASTM designations. Those in italics are no longer considered standard grades due to decreased usage.

NOTE 3—Hot-rolled 1000 series steels with a maximum carbon content of 0.40 % only are approved for welding. Only cold-drawn 1000 series steels used in the strength level and section thickness for which hot-rolled steels of the same composition are approved may be welded, and in this case caution should be exercised to see that excessive grain growth does not occur in the heat-affected zone.

Desired Minimum Yield Strength, psi[D]	Class			
	R-1	R-2	R-3 and R-4	R-5 and R-6
	Diameters of Round or Approximately Round Sections, in.[E]			
	To ½ , incl	Over ½ to 1, incl	Over 1 to 2, incl	Over 2 to 3, incl
	Thickness of Flat Sections, in.[E]			
	To 0.3, incl	Over 0.3 to 0.6, incl	Over 0.6 to 1.3, incl	Over 1.3 to 2.0, incl
Over 30 000 to 35 000, incl	HR 1016 HR 1020 HR 1018 HR 1019	HR 1016 HR 1020 HR 1018 HR 1022 HR 1019	HR 1018 HR 1019 HR 1021	HR 1018 HR 1022 HR 1030
Over 35 000 to 40 000, incl	HR 1022 HR 1030	HR 1030 HR 1035	HR 1030 HR 1035	HR 1035
Over 40 000 to 45 000, incl	HR 1035	HR 1040	CD 1010 HR 1040	CD 1010 HR 1045 CD 1015 HR 1040
Over 45 000 to 50 000, incl	CD 1010 HR 1040 HR 1045	CD 1010 CD 1015 HR 1045	CD 1015 HR 1045 HR 1137	CD 1020 HR 1137 *CD 1115* HR 1050
Over 50 000 to 55 000, incl	CD 1015 HR 1050 HR 1137	CD 1020 HR 1137 *CD 1115* HR 1141 HR 1050	CD 1018 CD 1115 CD 1020 HR 1050 HR 1141 CD 1025 HR 1144	CD 1018 HR 1141 CD 1019 HR 1141 CD 1025
Over 55 000 to 60 000, incl	CD 1018 CD 1115 CD 1025 CD 1019 HR 1141 CD 1020 HR 1144	CD 1018 HR 1144 CD 1019 CD 1025	CD 1019 CD 1120 CD 1022 CD 1117	CD 1022 *CD 1120* CD 1117 CD 1118

[A] Hot-rolled bars are indicated in table by prefix "HR."

[B] Cold-drawn bars are indicated in table by prefix "CD." These bars are produced by normal practice in cold-drawing and with no stress relief. Bars cold-finished by turning, grinding, turning and polishing, etc., are not covered under cold-drawn bars, as such cold-finished bars have the properties of hot-rolled bars.

[C] Classification of cold-drawn steels by size and yield-strength level in this table is based on yield-strength determinations at 0.2 % offset, or as determined by 0.005 in./in. elongation under load for yield strengths up to 90 000 psi, incl, and by 0.006 in./in. elongation under load for yield strengths above 90 000 psi.

[D] 1 psi = 0.006895 MPa.

[E] 1 in. = 25.4 mm.

TABLE 6 Steels for Parts Produced From Cold-Drawn and Cold-Drawn Stress-Relieved Bars—Classes R-1 Through R-6[A,B]

NOTE 1—Steels listed as approved for heavier section or higher strengths may be used in the same conditions for lighter sections and lower strengths.

NOTE 2—Steel composition numbers correspond to ASE, AISI, or ASTM designations. Those in italics are no longer considered standard grades due to decreased usage.

NOTE 3—Steels in conditions listed in this table are not approved for applications involving welding.

Desired Minimum Yield Strength, psi[C]	Class R-1	Class R-2	Class R-3 and R-4	Class R-5 and R-6
	Diameter of Round or Approximately Round Sections, in.[D]			
	To ½, incl	Over ½ to 1, incl	Over 1 to 2, incl	Over 2 to 3, incl
	Thickness of Flat Sections, in.[D]			
	To 0.3, incl	Over 0.3 to 0.6, incl	Over 0.6 to 1.3, incl	Over 1.3 to 2.0, incl
Over 60 000 to 65 000, incl	CD 1022 CD 1117 *CD 1120*	CD 1022 CD 1117 CD 1118 *CD 1120*	CD 1030 CD 1118	CD 1030
Over 65 000 to 70 000, incl	CD 1030 CDT 1040 CD 1118	CD 1030 CD 1035 CDT 1045	CD 1035 CDT 1137 CDT 1040 CDT 1050	CD 1035 CD 1050 CDT 1141 CDT 1045
Over 70 000 to 75 000, incl	CD 1035 CDT 1045	CDT 1137 CDT 1040 CDT 1050	CD 1040 CDT 1141 CDT 1045	CD 1045 CDT 1040 CDT 1144 CDT 1137 CDT 1050
Over 75 000 to 80 000, incl	CDT 1137 CDT 1040 CDT 1050	CD 1040 CDT 1141 CDT 1045	CD 1045 CDT 1040 CDT 1144 CDT 1137 CDT 1050	CD 1137 CDT 1045 CDT 1040 CDT 1141 CD 1050
Over 80 000 to 85 000, incl	CD 1040 CDT 1141 CDT 1045	CD 1045 CDT 1040 CDT 1144 CDT 1137 CDT 1050	CD 1137 CDT 1045 CDT 1040 CDT 1141 CD 1050	CD 1141 CDT 1137 CDT 1045 CDT 1040 CDT 1144 CDT 1050
Over 85 000 to 90 000, incl	CD 1045 CDT 1040 CDT 1144 CDT 1137 CDT 1050	CD 1137 CDT 1045 CDT 1040 CDT 1141 CD 1050	CD 1141 CDT 1137 CDT 1145 CDT 1040 CDT 1144 CDT 1050	CD 1144 CDT 1141 CDT 1137 CDT 1045 CDT 1050
Over 90 000 to 95 000, incl	CD 1137 CDT 1045 CDT 1040 CDT 1141 CD 1050	CD 1141 CDT 1137 CDT 1045 CDT 1050 CDT 1144 CDT 1050	CD 1144 CDT 1141 CDT 1137 CDT 1045 CDT 1050	CDT 1144 CDT 1141 CDT 1137 CDT 1050
Over 95 000 to 100 000, incl	CD 1141 CDT 1137 CDT 1045 CDT 1040 CDT 1144 CDT 1050	CD 1144 CDT 1141 CDT 1137 CDT 1045 CDT 1050	CDT 1144 CDT 1141 CDT 1137 CDT 1050	CDT 1144 CDT 1141
Over 100 000 to 105 000, incl	CD 1144 CDT 1141 CDT 1137 CDT 1045 CDT 1050	CDT 1144 CDT 1141 CDT 1137 CDT 1050	CDT 1144 CDT 1141	CDT 1144
Over 105 000 to 110 000, incl	CDT 1144 CDT 1141 CDT 1137 CDT 1050	CDT 1144 CDT 1141	CDT 1144	
Over 110 000 to 115 000, incl	CDT 1144 CDT 1141	CDT 1144		
Over 115 000 to 120 000, incl	CDT 1144			

[A] Conditions and treatments of bars are indicated in this table by the symbols shown below. Bars cold-finished by turning, grinding, turning and polishing, etc., are not covered, as such bars have the properties of hot-rolled bars.

"CD" = Bars produced by normal practice in cold-drawing, and with no stress relief.

"CDT" = Cold-drawn bars with subsequent thermal treatment. Heavier than normal drafts may be required.

[B] Classification of cold-drawn steels by size and yield-strength level in this table is based on yield-strength determinations at 0.2 % offset or as determined by 0.005 in./in. elongation under load for yield strengths up to 90 000 psi, and by 0.006 in./in. elongation under load for yield strengths above 90 000 psi.

[C] 1 psi = 0.006895 MPa.

[D] 1 in. = 25.4 mm.

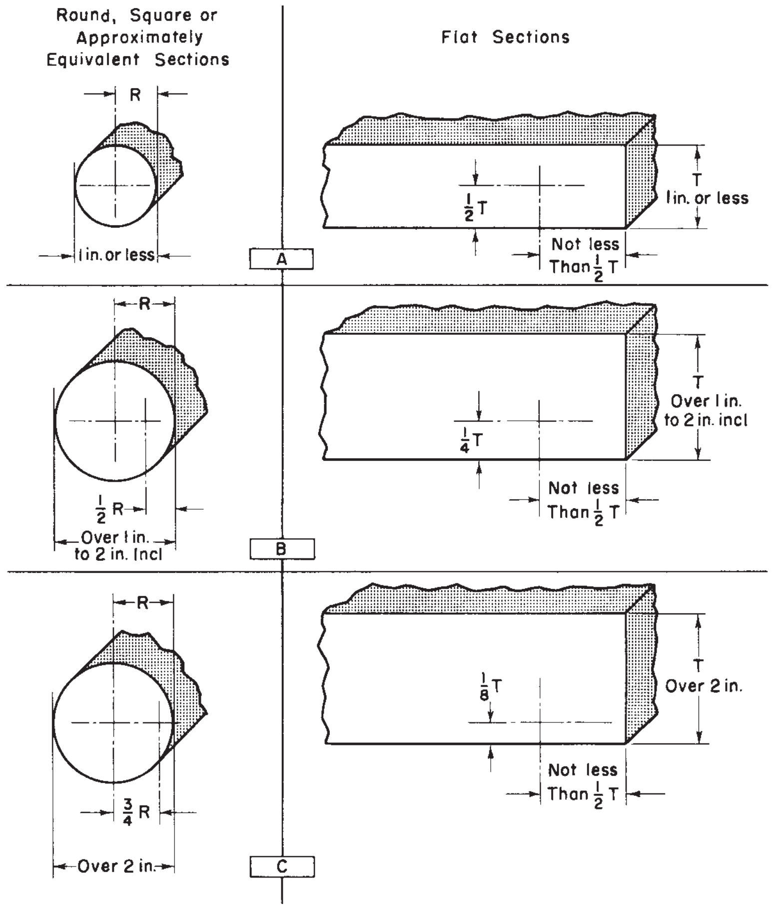

FIG. 1 Locations in Typical Cross Sections of Steel Bars at Which Desired Properties Are Obtained

TABLE 7 Applicable Classes for Critical Section Size

Round, Square, Hexagonal, etc., Sections, Diameter or Dimension Between Opposite Faces, in.[A]		Flat Sections, Thickness, in.[A]		Applicable Class
Over	To and Including	Over	To and Including	
. . .	½	. . .	0.3	P-1, Q-1, or R-1
½	1	0.3	0.6	P-2, Q-2, or R-2
1	1½	0.6	1.0	P-3, Q-3, or R-3
1½	2	1.0	1.3	P-4, Q-4, or R-4
2	2½	1.3	1.6	P-5, Q-5, or R-5
2½	3	1.6	2.0	P-6, Q-6, or R-6
3	3½	2.0	2.3	P-7 or Q-7

[A] 1 in. = 25.4 mm.

Designation: A 413/A 413M – 01

Standard Specification for Carbon Steel Chain[1]

This standard is issued under the fixed designation A 413/A 413M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers carbon steel chain for such applications as railroad cars, construction, industrial uses, load binding, and general purposes other than overhead lifting.

NOTE 1—This specification does not cover carbon steel chain for sprocket applications.

1.2 Three classes of carbon steel chain are covered:

1.2.1 *Grade 30*—Proof coil chain.

1.2.2 *Grade 43*—High test chain.

1.2.3 *Grade 70*—Transport chain.

1.3 The values stated in either acceptable metric units or in other units shall be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system must be used independently of the other, without combining values in any way.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

E 30 Test Methods for Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron and Wrought Iron[3]

E 44 Definitions of Terms Relating to Heat Treatment of Metals[4]

E 350 Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron and Wrought Iron[5]

E 415 Test Method for Optical Emission Vacuum Spectrometric Analysis of Carbon and Low-Alloy Steel[6]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *breaking force, minimum*—the minimum force in pounds or newtons at which the chain, during manufacture, has been found by testing to break when a constantly increasing force is applied in direct tension. This test is a manufacturer's attribute acceptance test and shall not be used as criteria for service.

3.1.2 *lot*—for the purpose of acceptance testing, a lot shall consist of 3000 ft [1000 m], or fraction thereof, of the same grade and size chain. If a continuous length of chain exceeds 3000 ft [1000 m], it shall also be considered a lot.

3.1.3 *proof test*—a quality control tensile test applied to chain for the purpose of verifying weld and material quality. It is the minimum force in pounds or newtons which the chain has withstood at the time it left the producer, under a test in which a constantly increasing force has been applied in direct tension to a straight length of chain. Proof test loads are a manufacturing integrity test and shall not be used as criteria for service or design purposes.

3.1.4 *working load limit (WLL)*—the maximum combined static and dynamic load in pounds or kilograms that shall be applied in direct tension to an undamaged straight length of chain.

4. Ordering Information

4.1 It shall be the responsibility of the purchaser to specify all requirements that are necessary for material ordered under this specification. Such requirements may include, but are not limited to, the following:

4.1.1 Product to conform to Specification A 413 or A 413M and date of issue,

4.1.2 Grade of chain,

4.1.3 Nominal size of chain (in. or mm),

4.1.4 Quantity of chain (ft or m),

4.1.5 Length of each piece, if required,

4.1.6 Finish, if required,

4.1.7 Certification of test(s), if required, and

4.1.8 Acceptance of inspection by purchaser, if required.

5. Material Requirements

5.1 *Heat Analysis*—The selection of the steel is left to the judgment of the individual chain manufacturer provided the steel meets the following criteria:

Carbon, max, %	0.370

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.27 on Steel Chain.

Current edition approved Sept. 10, 2001. Published November 2001. Originally published as A 413–57T. Last previous edition A 413/A 413M–00.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] Discontinued. See *1995 Annual Book of ASTM Standards*, Vol 03.05.

[4] Discontinued. See *1993 Annual Book of ASTM Standards*, Vol 01.02.

[5] *Annual Book of ASTM Standards*, Vol 03.05.

[6] *Annual Book of ASTM Standards*, Vol 03.06.

***A Summary of Changes section appears at the end of this standard.**

Phosphorus, max, %	0.048
Sulfur, max, %	0.058

5.2 *Product Analysis*—The steel used may be analyzed by the purchaser and shall conform to the requirements of 5.1 subject to the product analysis tolerances specified in Specification A 29/A 29M. Test samples may be taken from rods, bars, or finished chain. Samples for analysis shall be so taken as to represent the full cross section of the specimen.

5.3 Test Methods E 30, E 350, or E 415 shall be used for referee purposes.

6. Manufacture

6.1 *Welding Process*—Carbon steel chain may be made by the forge welding, electric welding, or gas welding process.

6.2 *Heat Treatment*—Grades 30 and 43 do not require heat treatment, but may be heat treated at the manufacturer's discretion. Grade 70, after welding, shall be heat treated. Heat treatment shall include quenching and tempering as described in Definitions E 44.

7. Dimensional Requirements

7.1 The chain shall conform to the dimensional requirements specified in Tables 1-3 for the appropriate grade and size chain.

7.2 *Diameter*—The diameter of the material from which the chain is manufactured shall not be smaller than the material diameter listed in Tables 1-3 within the following tolerance: −7 %. Oversized material may be used for all applications.

8. Workmanship, Finish, and Appearance

8.1 The chain at the time of shipment shall be free of discontinuities that would prevent the chain from enduring the working load limit forces.

8.2 The manufacturer may apply a surface treatment or coating of their own choice for identification or corrosion resistance unless the customer specifies otherwise.

9. Mechanical Requirements

9.1 *Proof Test*—All chain shall be tested to at least the proof load prescribed in Tables 1-3 for the appropriate grade and size chain. When so tested it shall withstand these loads without loss of chain integrity. Links or chain segments that do not withstand the proof test load shall be removed from the chain.

9.2 *Breaking Force*—The breaking force test specimen shall consist of a length from the lot containing at least the number of links in Table 4. All chain that is heat treated shall be in the quenched and tempered condition before the breaking force is measured.

9.2.1 Fixtures for securing chain in a testing machine shall be properly designed to support securely the shoulder of the link (see Note 2). The opening in the fixture shall not be more than 125 % of the stock diameter being tested. Links engaged in the testing fixture shall not be considered part of the test specimen.

NOTE 2—"U" bolts of the same or larger diameter and the same or greater strength may be used to secure the chain to the jaws of the testing machine.

9.2.2 Test specimens shall meet or exceed the minimum breaking force values given in Tables 1-3 for the appropriate grade and size chain.

9.3 *Elongation*:

9.3.1 All chain which is heat treated (see 6.2) must be in the quenched and tempered condition before the elongation is measured.

9.3.2 The elongation test specimen shall consist of a length from the lot containing at least the number of links in Table 4.

9.3.3 A positive load not exceeding 10 % of the proof test shall be applied for determining the original gage length ($L\{0\}$).

9.3.4 The elongation shall be based on the total extension at fracture. This is expressed as a percentage of the change in length (ΔL) divided by the original gage length ($L\{0\}$). The elongation may be determined by the equation below or by autographic recorder or side scale.

$$\text{Elongation (\%)} = \left\{\Delta L \,/\, L\{0\}\right\} \times 100$$

where:

ΔL = test specimen final length at fracture – test specimen original gage length ($L\{0\}$), and

$L\{0\}$ = original gage length (sum or the inside lengths of the test chain links, not counting the fixture links, or as determined in 9.3.3).

9.3.5 The elongation shall be a minimum of 15 %.

9.4 One test for breaking strength and elongation shall be made from each lot. The elongation and breaking force tests may be performed at the same time on the same test specimen.

TABLE 1 Grade 30 Proof Coil Chain

Nominal Chain Size		Material Diameter		Working Load Limit, max		Proof Test,[A] min		Minimum Breaking Force[A]		Inside Length, max		Inside Width, min	
in.	mm	in.	mm	lb	kg	lb	kN	lb	kN	in.	mm	in.	mm
1/8	4.0	0.156	4.0	400	180	800	3.6	1600	7.2	0.94	23.9	0.25	6.4
3/16	5.5	0.217	5.5	800	365	1600	7.2	3200	14.4	0.98	24.8	0.30	7.7
1/4	7.0	0.276	7.0	1300	580	2600	11.6	5200	23.2	1.24	31.5	0.38	9.8
5/16	8.0	0.331	8.4	1900	860	3800	16.9	7600	33.8	1.29	32.8	0.44	11.2
3/8	10.0	0.394	10.0	2650	1200	5300	23.6	10 600	47.2	1.38	35.0	0.55	14.0
7/16	11.9	0.488	11.9	3700	1680	7400	32.9	14 800	65.8	1.64	41.6	0.65	16.6
1/2	13.0	0.512	13.0	4500	2030	9000	40.0	18 000	80.0	1.79	45.5	0.72	18.2
5/8	16.0	0.630	16.0	6900	3130	13 800	61.3	27 600	122.6	2.20	56.0	0.79	20.0
3/4	20.0	0.787	20.0	10 600	4800	21 200	94.3	42 400	188.6	2.76	70.0	0.98	25.0
7/8	22.0	0.866	22.0	12 800	5810	25 600	114.1	51 200	228.2	3.03	77.0	1.08	27.5
1	26.0	1.02	26.0	17 900	8140	35 800	159.1	71 600	318.2	3.58	90.9	1.25	31.7

[A] The proof test and minimum breaking force loads *shall not* be used as criteria for service or design purposes (see Section 4).

TABLE 2 Grade 43 High Test Chain

Nominal Chain Size		Material Diameter		Working Load Limit, max		Proof Test,[A] min		Minimum Breaking Force[A]		Inside Length, max		Inside Width, min	
in.	mm	in.	mm	lb	kg	lb	kN	lb	kN	in.	mm	in.	mm
¼	7.0	0.276	7.0	2600	1180	3900	17.3	7800	34.6	1.24	31.5	0.38	9.8
5⁄16	8.7	0.343	8.7	3900	1770	5850	26.0	11 700	52.0	1.29	32.8	0.44	11.2
⅜	10.0	0.406	10.3	5400	2450	8100	36.0	16 200	72.0	1.38	35.0	0.55	14.0
7⁄16	11.9	0.468	11.9	7200	3270	10 800	48.0	21 600	96.0	1.64	41.6	0.65	16.6
½	13.0	0.531	13.5	9200	4170	13 800	61.3	27 600	122.6	1.79	45.5	0.72	18.2
⅝	16.0	0.630	16.0	13 000	5910	19 500	86.5	39 000	173.0	2.20	56.0	0.79	20.0
¾	20.0	0.787	20.0	20 200	9180	30 300	134.7	60 600	269.4	2.76	70.0	0.98	25.0
⅞	22.0	0.866	22.0	24 500	11 140	36 750	163.3	73 500	326.6	3.03	77.0	1.08	27.5

[A] The proof test and minimum breaking force loads *shall not* be used as criteria for service or design purposes (see Section 4).

TABLE 3 Grade 70 Transport Chain

Nominal Chain Size		Material Diameter		Working Load Limit, max		Proof Test,[A] min		Minimum Breaking Force[A]		Inside Length, max		Inside Width, min	
in.	mm	in.	mm	lb	kg	lb	kN	lb	kN	in.	mm	in.	mm
¼	7.0	0.281	7.0	3150	1430	6300	28.0	12 600	56.0	1.24	31.5	0.38	9.8
5⁄16	8.7	0.343	8.7	4700	2130	9400	41.8	18 800	83.6	1.29	32.8	0.44	11.2
⅜	10.0	0.406	10.3	6600	2990	13 200	58.7	26 400	117.4	1.38	35.0	0.55	14.0
7⁄16	11.9	0.468	11.9	8750	3970	17 500	77.7	35 000	155.4	1.64	41.6	0.65	16.6
½	13.0	0.531	13.5	11 300	5130	22 600	100.4	45 200	200.8	1.79	45.5	0.72	18.2
⅝	16.0	0.630	16.0	15 800	7170	31 600	140.4	63 200	280.8	2.20	56.0	0.79	20.0
¾	20.0	0.787	20.0	24 700	11 200	49 400	219.6	98 800	439.2	2.76	70.0	0.98	25.0

[A] The proof test and minimum breaking force loads *shall not* be used as criteria for service or design purposes (see Section 4).

TABLE 4 Mechanical Test Sample Length Requirements

Size of Chain	Minimum Number of Links in Test Specimen
7⁄32 in. [5.5 mm]	9
Larger than 7⁄32 in. [5.5 mm] but less than ¾ in. [20.0 mm]	7
¾ in. [20.0 mm] and larger	3

10. Retests

10.1 If the original test specimen fails to conform to the requirements in 9.2.2, two additional test specimens from the same lot may be tested, each of which shall conform to the requirements of 9.2.2. If both additional tests are satisfactory, the chain will be considered acceptable.

11. Rework and Retreatment

11.1 Materials that fail to comply to the requirements as to dimensions and mechanical tests may be resubmitted after being reworked.

12. Inspection

12.1 When requested on the purchase order or contract, the chain shall be free of paint or other coatings which could mask surface discontinuities at the time of inspection.

12.2 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to verify that the material is being furnished in accordance with this specification. Inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspection shall be made at the place of manufacture, unless otherwise agreed upon.

12.3 The purchaser may make the tests to govern acceptance or rejection of the material at their own laboratory or elsewhere. Tests and acceptance criteria shall conform to the requirements contained in this specification unless otherwise stated in the purchase order or contract. Tests at the purchaser's laboratory or elsewhere shall be made at the expense of the purchaser.

13. Rejection and Rehearing

13.1 Materials that fail to conform to the requirements of this specification may be rejected. Rejection shall be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of any test, the producer or supplier may make claim for a rehearing.

13.2 In the case of dissatisfaction with the results of any test in 12.3, the manufacture may make claim for a rehearing.

14. Certification and Reports

14.1 A manufacturer's certification that the chain conforms to Specification A 413 or A 413M of the date of issue specified shall be furnished when requested on the purchase order or contract.

14.2 When requested on the purchase order or contract, the manufacturer shall furnish a certificate of proof test to the purchaser or his representative.

15. Product Marking

15.1 Body chain links shall not be marked with indented characters.

15.2 The 5⁄16 in. [8.7 mm] and ⅜ in. [10 mm] Grade 43 and 70 chain shall be embossed at intervals no greater than 1 ft [0.3 m]. All other Grade 43 and 70 chains shall be embossed at intervals no greater than 3 ft [0.9 m].

15.3 Grade 30 chain, sized 5⁄16 in. (8.4 mm) and larger, shall be marked at least with 3, 30, or 300.

15.4 Grade 43 chain shall be marked at least with 4, 43, or 430.

15.5 Grade 70 chain shall be marked at least with 7, 70, or 700.

16. Keywords

16.1 chain; steel chain

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since A 413/A 413M–00 that may impact the use of this standard.

(1) Revised Paragraphs 3.1.1, 9.2, 9.3, and 9.4.

(2) Deleted Figs. 1 and 2.

Designation: A 418 – 99 (Reapproved 2003)

Standard Test Method for Ultrasonic Examination of Turbine and Generator Steel Rotor Forgings[1]

This standard is issued under the fixed designation A 418; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method for ultrasonic examination applies to turbine and generator steel rotor forgings covered by Specifications A 293, A 469, and A 470. This standard shall be used for contact testing only.

1.2 This test method describes a basic procedure of ultrasonically inspecting turbine and generator rotor forgings. It shall in no way restrict the use of other ultrasonic methods such as reference block calibrations when required by the applicable procurement documents nor is it intended to restrict the use of new and improved ultrasonic test equipment and methods as they are developed. The procedure utilizes different calibration techniques than had been used in previous issues. The frequency or amplitudes of recordable indications should not be interpreted necessarily as a change in quality of the product being examined.

1.3 This test method is intended to provide a means of inspecting cylindrical forgings so that the inspection sensitivity at the forging center line or bore surface is constant, independent of the forging or bore diameter. To this end, inspection sensitivity multiplication factors have been computed from theoretical analysis, with experimental verification. These are plotted in Fig. 1 (bored rotors) and Fig. 2 (solid rotors), for a true inspection frequency of 2.25 MHz, and an acoustic velocity of 2.30×10^5 in./s (5.85×10^5 cm/s). Means of converting to other sensitivity levels are provided in Fig. 3. (Sensitivity multiplication factors for other frequencies may be derived in accordance with X1.1 and X1.2 of Appendix X1.)

1.4 Considerable verification data for this method have been generated which indicate that even under controlled conditions very significant uncertainties may exist in estimating natural discontinuities in terms of minimum equivalent size flat-bottom holes. The possibility exists that the estimated minimum areas of natural discontinuities in terms of minimum areas of the comparison flat-bottom holes may differ by 20 dB (factor of 10) in terms of actual areas of natural discontinuities. This magnitude of inaccuracy does not apply to all results but should be recognized as a possibility. Rigid control of the actual frequency used, the coil bandpass width if tuned instruments are used, etc. tend to reduce the overall inaccuracy which is apt to develop.

1.5 This test method for inspection applies to solid cylindrical forgings having outer diameters of not less than 2.5 in. (63.5 mm) nor greater than 100 in. (2540 mm). It also applies to cylindrical forgings with concentric cylindrical bores having wall thicknesses of 2.5 (63.5 mm) in. or greater, within the same outer diameter limits as for solid cylinders. For solid sections less than 15 in. (381 mm) in diameter and for bored cylinders of less than 7.5 in. (190.5 mm) wall thickness the transducer used for the inspection will be different than the transducer used for larger sections.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 The reference is to the latest issue of these designations that appear in the *Annual Book of ASTM Standards* or are available as separate reprints. It shall also apply to product specifications, which may be issued when specifically referenced therein.

2.2 *ASTM Standards:* [2]

A 293 Specification for Steel Forgings, Carbon and Alloy, for Turbine Rotors and Shafts[3]

A 469 Specification for Vacuum-Treated Steel Forgings for Generator Rotors

A 470 Specification for Vacuum-Treated Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Examination Instruments and Systems Without the Use of Electronic Measurement Instruments

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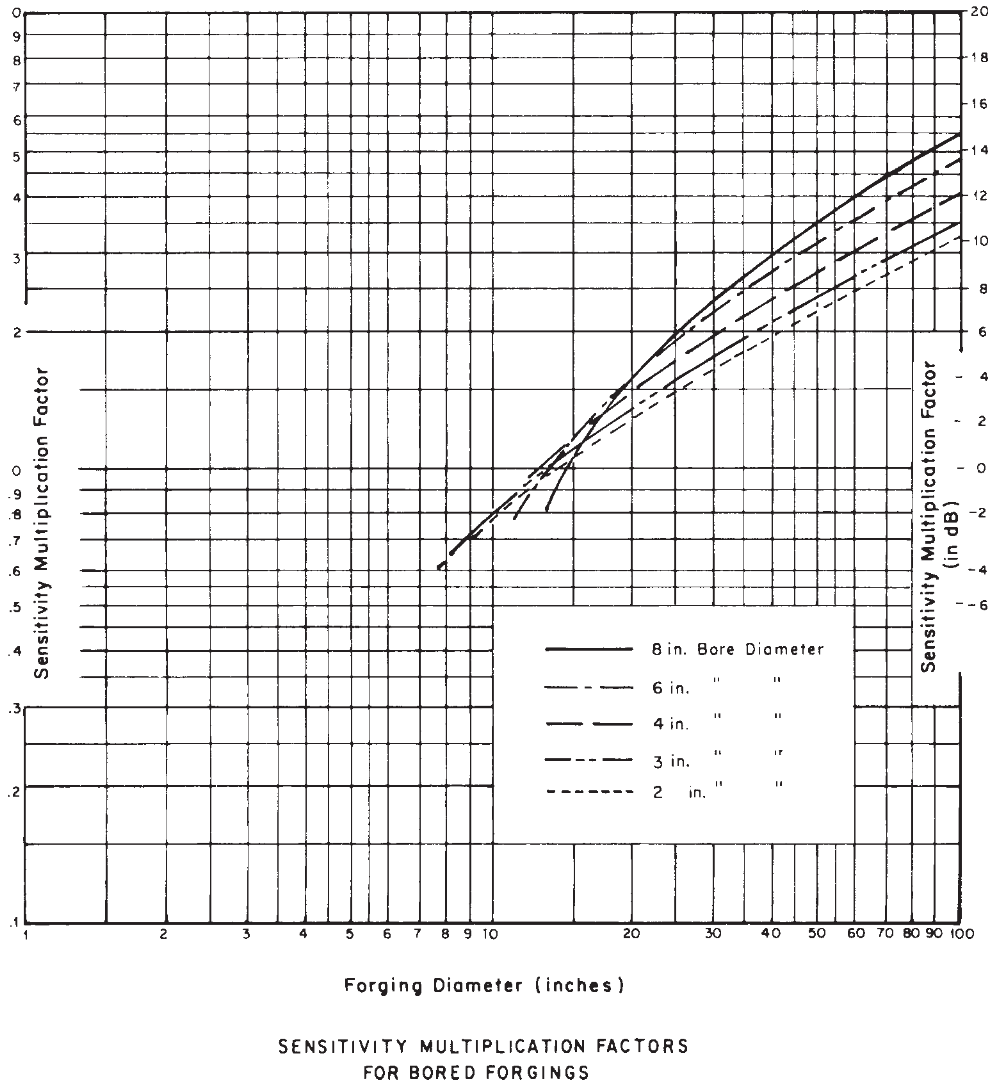
[1] This test method is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved Oct. 1, 2003. Published November 2003. Originally approved in 1957. Last previous edition approved in 1999 as A 418–99.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn.



NOTE—Sensitivity multiplication factor such that a 10 % indication at the forging bore surface will be equivalent to a ⅛ in. (3.175 mm) diameter flat bottom hole. Inspection frequency: 2.25 MHz. Material velocity: 2.30×10^5 in./s (5.85×10^5 cm/s).

FIG. 1 Bored Forgings

E 1065 Guide for Evaluating Characteristics of Ultrasonic Search Units

3. Application

3.1 This test method shall be used when ultrasonic inspection is required by the order or specification for inspection purposes where the acceptance of the forging is based on limitations of the number, amplitude or location of discontinuities or a combination thereof, which give rise to ultrasonic indications.

3.2 The acceptance criteria shall be clearly stated as order requirements.

4. General Requirements

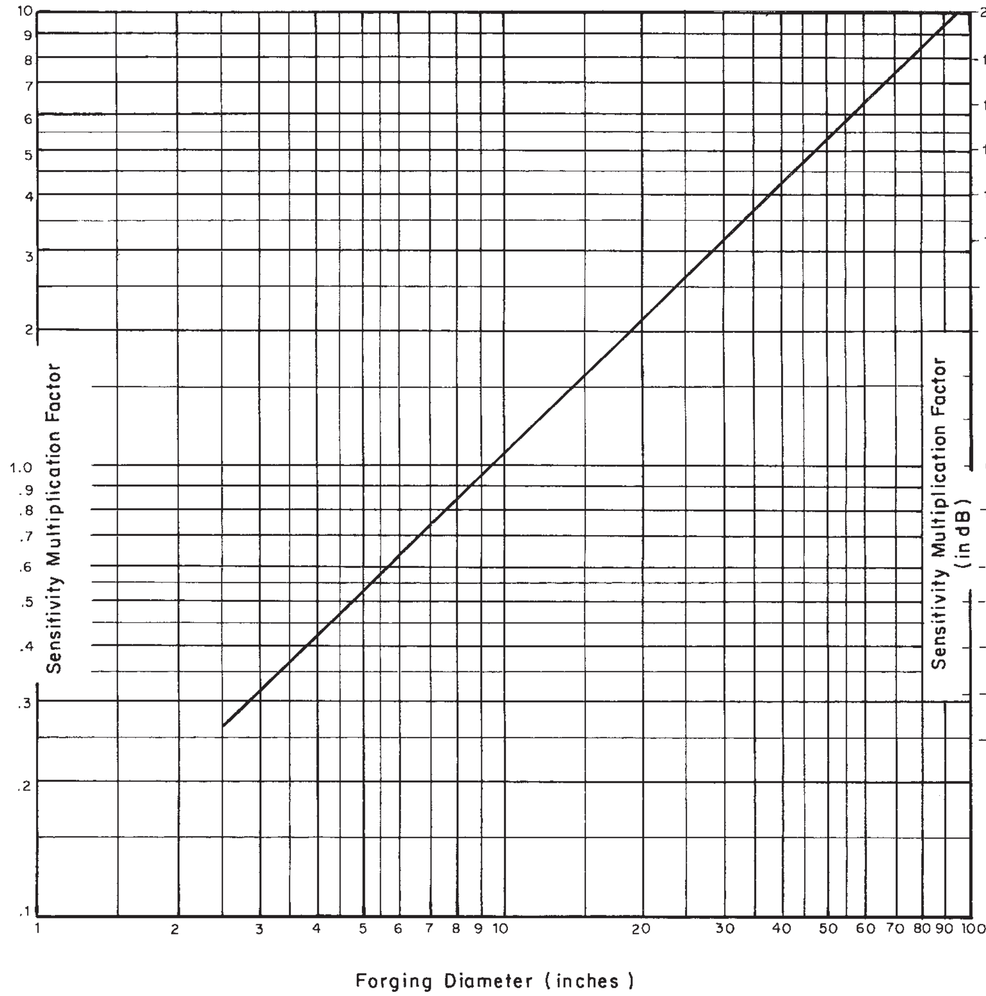
4.1 As far as possible, the entire volume of the forging shall be subjected to ultrasonic inspection. Because of fillets at stepdowns and other local configurations, it may be impossible to inspect some small portions of a forging.

4.2 The ultrasonic inspection shall be performed after final heat treatment of the forging. In those cases in which wheels, slots, or similar features are machined into the forging before heat treatment, the entire forging shall be inspected ultrasonically before such machining, and as completely as practicable after the final heat treatment.

4.3 For overall scanning, the ultrasonic beam shall be introduced radially. To conform with this requirement, external conical surfaces of the forging shall be replaced by stepped surfaces in order to maintain the ultrasonic beam perpendicular to the longitudinal axis. Such stepped surfaces shall be shown on the forging drawing.

4.4 Forgings may be tested either stationary or while rotated by means of a lathe or rollers. If not specified by the purchaser, either method may be used at the manufacturer's option. Scanning speed shall not exceed 6 in./s (15.24 cm/s).

4.5 To ensure complete coverage of the forging volume, the search unit shall be indexed approximately 75 % of the



SENSITIVITY MULTIPLICATION FACTORS
FOR SOLID FORGINGS

NOTE—Sensitivity multiplication factor such that a 10 % indication at the forging centerline surface will be equivalent to a ⅛ in. (3.175 mm) diameter flat bottom hole. Inspection frequency: 2.25 MHz. Material velocity: 2.30×10^5 in./s (5.85×10^5 cm/s).

FIG. 2 Solid Forgings

transducer width with each pass of the search unit. Mechanized inspection of the rotating forging wherein the search unit is mechanically controlled is an aid in meeting this requirement.

4.6 Frequencies of 1, 2.25, and 5 MHz may be used for accurately locating, determining orientation, and defining specific discontinuities detected during overall scanning as described in 4.4.

4.7 Axial scanning, if required, shall be performed at that frequency and transducer diameter which minimizes interfering ultrasonic reflections due to forging geometry and which gives optimum resolution. (Axial tests are normally used as a supplement to radial tests.)

5. Personnel Requirements

5.1 Personnel performing the ultrasonic examinations to this practice shall be qualified and certified in accordance with a written procedure conforming to Recommended Practice No. SNT-TC-1A or another national standard that is acceptable to both the purchaser and the supplier.

6. Pulsed Ultrasonic Reflection Equipment and Accessories

6.1 *Electronic Apparatus*—A pulse-echo instrument permitting inspection frequencies of 1 MHz, 2.25 MHz, and 5 MHz is required. The accuracy of discontinuity amplitude analysis using this test method involves a knowledge of the true operating frequency of the complete inspection system. One of the best ways to obtain the desired accuracy is by use of a tuned pulser and narrow band amplifier of known frequency response, with either a broad-band transducer, or a narrow-band tuned transducer of known and matching frequency.

6.1.1 *Apparatus Qualification and Calibration*—Basic qualification of the ultrasonic test instrument shall be performed at intervals not to exceed 12 months or whenever

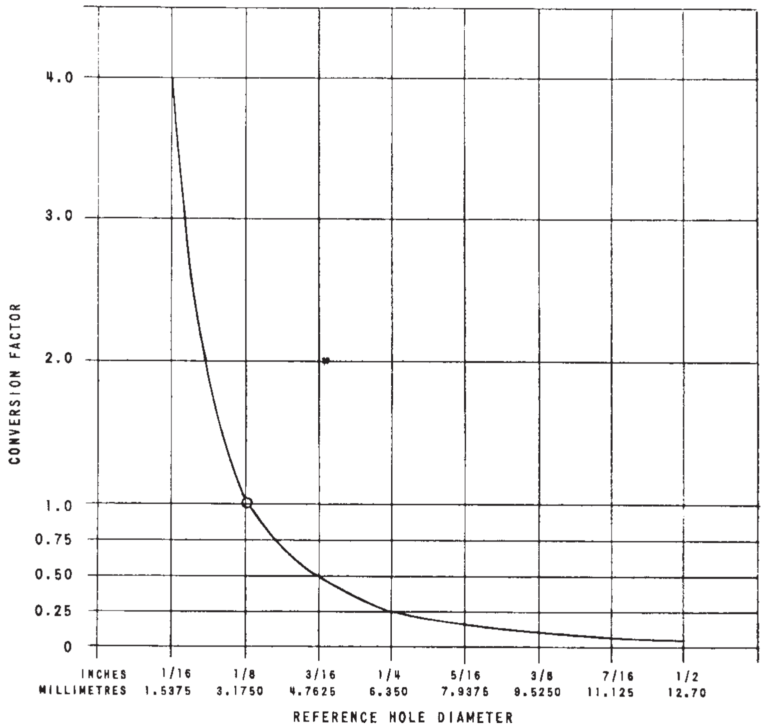


FIG. 3 Conversion Factors to Be Used in Conjunction with Fig. 1 and Fig. 2 if a Change in the Reference Reflector Diameter is Required

maintenance is performed that affects the equipment function. The date of the last calibration and the date of the next required calibration shall be displayed on the test equipment.

6.1.2 The horizontal linearity shall be checked on a distance calibration bar using the multiple order technique. See Practice E 317. The horizontal linearity shall be ±2 % of the metal path.

6.1.3 If the rotor has a coupling or similar thin axial section with parallel sides, the accuracy of the linearity shall be checked by ultrasonically verifying the thickness of the coupling or axial section. If necessary, minor adjustments for differences in the ultrasonic velocities between the calibration bar and the forging shall then be made.

6.2 *Amplifier*—The amplifier and the cathode ray tube shall provide linear response within ±2 %, up to 100% of full screen height.

6.2.1 *Amplifier Calibration*—An amplifier vertical linearity check shall be made prior to performing the test by observing a multiple order pattern from a calibration block using a 2.25 MHz transducer. See Practice E 317. The first back reflection shall be set at 100 % of full screen height. The higher order back reflections, 10 % and higher in amplitude, shall also be positioned on the screen and their amplitudes noted. The first back reflection shall be reduced to 50 % and then 25 % of full screen height. The amplitudes of the higher order back reflections shall be noted at each step. The vertical linearity will be considered acceptable if the signal heights of the higher order reflections decrease in proportion to the decrease set for the first back reflection. The maximum acceptable error for the decrease of the higher order reflections is the greater of ±5 % of the expected back reflection height or ±2 % of full screen height.

6.3 *Signal Attenuator*—The instrument shall contain a calibrated gain control or signal attenuator that meets the requirements of Practice E 317 (in each case, accurate within ±5 %) that will allow indications beyond the linear range of the instrument to be measured. It is recommended that these controls permit signal adjustments up to 25 to 1 (28 dB). See Fig. 1 and Fig. 2.

6.4 *Search Units*—Longitudinal wave search units of known effective frequency should be used for radial scanning. A ¼ by 1 in. (6.35 by 25.4 mm) 2.25 MHz transducer, used with the 1 in. dimension parallel to the forging axis, will give a desirable combination of resolution and beam width on large sections 15 in. (381 mm) in diameter or larger if solid or 7.5 in. (190.5 mm) or greater wall thickness if bored. A 1 in. (25.4 mm) diameter, 2.25 MHz transducer may be used. If a transducer with dimension circumferentially oriented to the forging, larger than ¼ in. (6.35 mm) is used, additional inspection at lower frequency is recommended to provide a wide beam for off-axis inspection. A 0.5 in. (12.7 mm) diameter 2.25 MHz transducer is suitable for solid sections under 15 in. (381 mm) in diameter and bored sections under 7.5 in. (190.5 mm) in wall thickness. The multiplication factors given are valid for the frequency and material velocity indicated provided they are used in the far field. (The near field is a characteristic that is dependent on the transducer frequency and size.) For other frequencies and material velocities, applicable sensitivity multiplication factors shall be computed.

6.4.1 *Search Unit Calibration*—The transducers used in performing the tests described in this test method shall be calibrated in accordance with Guide E 1065.

7. Preparation of Forging for Ultrasonic Inspection

7.1 Machine turn the forging to provide cylindrical surfaces for the radial test.

7.2 The end faces of the shaft extensions and of the body of the forging shall be sufficiently perpendicular to the axis of the forging to permit axial test.

7.3 The surface roughness of exterior finishes shall not exceed 250 µin. (6.35 µm) and the surface waviness shall not interfere with the ultrasonic test.

7.4 At the time of ultrasonic testing, the surfaces of the forging shall be free of tool tears, loose scale, machining or grinding particles, paint, or other foreign material.

8. Procedure

8.1 *Radial Scanning*:

8.1.1 Select the transducer to be used for the primary inspection according to the following criteria:

8.1.1.1 Use a 0.5 in. (12.7 mm) diameter, 2.25 MHz transducer to inspect solid cylindrical sections under 15 in. (381 mm) in diameter and bored sections having wall thicknesses of less than 7.5 in. (190.5 mm).

8.1.1.2 Use a ¼ by 1 in. (6.35 by 25.4 mm) (or 1 in. diameter), 2.25 MHz transducer to inspect solid sections 15 in. (381 mm) or greater in diameter and bored sections having wall thicknesses of 7.5 in. (190.5 mm) or greater.

8.1.2 The reference signal shall be the signal reflected from the diametrically opposed surface for solid (unbored) forgings and from the bore surface of bored forgings. The signal amplitude shall be set to 100 % full screen height while scanning in an indication-free area.

8.1.3 The required evaluation sensitivity shall be obtained by increasing the 100 % full screen height reference signal by the appropriate multiplication factor calculated as follows. Establish the inspection sensitivity in accordance with the curves in Fig. 1 (bored rotors) and Fig. 2 (solid rotors), which show the multiplication factors that shall be used to adjust a 100% full screen height, bore, or back reflection to the required inspection sensitivity. These sensitivities are sufficient to detect a ⅛ in. (3.175 mm) diameter reflector near the centerline of the forging. The inspection sensitivity must be adjusted if the outside diameter changes by more than 2 in. (51 mm) when using the larger transducer on heavy sections or by 1 in. (25.4 mm) when using the smaller transducer on smaller sections. Fig. 3 provides a means to convert this sensitivity level to the sensitivity level required to similarly display smaller or larger reference holes. The derivation of the sensitivity multiplication factors is summarized in the appendix.

8.1.4 Adjust the sweep length control to position the bore or back reflection approximately three fourths of the distance across the cathode ray tube.

8.1.5 Search each diameter of the forging and record indications 10 % or greater of the sweep-to-peak CRT segment at the prescribed high sensitivity. Mark the position of the search unit on the surface of the forging when indications are observed so that they may be investigated in accordance with 8.1.7 and 8.2.2.

8.1.6 When the forgings are tested while they are rotated, the maximum speed of rotation shall be calculated as follows:

$360/\pi d$	=	maximum revolutions per min.
d	=	diameter of forging in inches.
$915/\pi d$	=	maximum revolutions per min.
d	=	diameter of forging in centimetres.

The search unit may be held by a suitable fixture attached to the tool post of the lathe and traversed mechanically for scanning of the rotating forging or may be hand-held. If not specified by the purchaser, either method may be used at the manufacturer's option.

8.1.7 Measure the amplitude and extent of all indications and perform detailed investigation of specific indications with the forging stationary.

8.1.7.1 If the 0.5 in. (12.7 mm) diameter transducer can be satisfactorily calibrated for heavy sections, use this transducer to perform detailed investigations of indications located within 6 in. (152.4 mm) on the surface, regardless of the transducer used in the initial inspection. For indications lying beyond 6 in. (152.4 mm) from the test surface, perform the detailed investigation using the transducer with which the indication was detected during the primary scan.

8.1.7.2 Measure the extent of traveling and planar indications axially and circumferentially between the peak and ½-amplitude points.

8.1.8 For indications in heavy sections, if the 0.5 in. (12.7 mm) diameter transducer can be satisfactorily calibrated for the section, evaluate all indications located within the first 6 in. (152.4 mm) from the test surface using the 0.5 in. (12.7 mm) diameter transducer, regardless of the transducer used to locate the indication during the primary scan and regardless of the scan method employed during the primary scan (shaft rotating or hand scan).

8.2 *Supplementary Tests*:

8.2.1 *Special Radial Tests*—Test at additional frequencies may be used for accurately locating and determining the orientation of each recordable indication and for evaluating the minimum reflecting area of each large indication.

8.2.2 *Axial Tests*—When required, scan the flat surfaces normal to the forging axis. Establish the sensitivity level and recordable standards for the axial tests by agreement between purchaser and supplier (see 4.7).

9. Report

9.1 The manufacturer's report of final ultrasonic inspection shall contain the following data, and shall be furnished to the purchaser:

9.1.1 Each diameter shall be numbered on a sketch starting with rotor diameter No. 1 at the stenciled end. When an entire rotor is tested, a complete sketch showing the diameters shall be submitted with the test results. When a portion of the rotor is tested, a sketch of the portion of the rotor tested shall be submitted. When no recordable indications are found, a sketch is not required.

9.1.2 Recordable indications as described in 8.1.5 shall be located on the sketch (see 8.1.1) (*1*) radially with respect to the centerline or bore surface, (*2*) axially with respect to the stenciled end of the forging, and (*3*) circumferentially with the center point of the serial number which shall be used as 12 o'clock. The accuracy of the indication characterization shall be sufficient to permit the relocation and reproduction of the data.

9.1.3 Unless specified otherwise, the supplier shall report recordable indications as described in 8.1.5 as percentages of the 100% full screen height at the prescribed gain level, along with the distances to the discontinuity and to the bore or centerline (solid forgings) and shall be identified as normal, traveling, continuous, or indication level or a combination thereof. When flaw size estimates are required, these data shall be used for calculations as indicated in 8.1.5 and as limited by X1.4 of Appendix X1.

9.1.3.1 Normal indications are single indications that show a normal decrease in amplitude as the search unit is moved in any direction from the position of maximum amplitude and display none of the characteristics defined in 9.1.3.2 through 9.1.3.4. Normal indications shall be reported individually.

9.1.3.2 Traveling indications are indications whose leading edge moves a distance equivalent to 1 in. (25.4 mm) or more of metal depth with movement of the transducer over the surface of the forging. The variation in radial depth and planar area of traveling indications shall be determined and reported.

9.1.3.3 Planar indications shall be considered continuous over a plane if they have a major axis greater than 1 in. (25.4 mm). Their minor axes shall be reported when measurable in accordance with 8.1.7.2. In recording these flaw characteristics, corrections must be made for beam divergence at the estimated flaw depth.

9.1.3.4 Indication levels are group indications 10 % (5⁄32 in. (4.0 mm)) or larger of 100% full screen height at the prescribed high sensitivity showing continuously on the screen as the transducer is moved over the area tested.

9.1.4 When required, recordable indications shall be expressed as minimum reflecting areas as follows:

$$\textit{solid forgings}: A_F = A_R \times \left(\frac{a}{L}\right)^2 \times \frac{P}{10} \quad (1)$$

$$\textit{bored forgings}: A_F = A_R \times \left(\frac{a}{L}\right)^2 \times \frac{P}{10}\sqrt{\frac{b}{d}} \quad (2)$$

where:

A_F = minimum reflecting area of discontinuity,
A_R = reflecting area of reference (0.012 in.^{2} or 7.917 mm^2),
a = distance to discontinuity, in. (or mm),
L = distance to bore or centerline of solid forgings, in. (or mm), and
P = discontinuity reflection amplitude (percent of sweep-to-peak CRT segment at the prescribed high-sensitivity level).

9.1.5 Observable loss of bore or back reflection at the scanning sensitivity.

9.1.6 Couplant.

9.1.7 Type of instrument, manual or automated scanning, inspection frequency, and type transducers employed for the inspection.

9.1.8 Inspector's name or identity and date of test.

10. Keywords

10.1 generator material; nondestructive tests; rotors, turbine, or generator; steel forgings; steel forgings—alloy; testing methods; turbine materials; ultrasonic examination; ultrasonic examination method

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements apply when specified by the purchaser in the contract or order.

S1. Forging Rotation During Examination

S1.1 Forgings shall be rotated during testing by means of a lathe or rollers. Scanning speed shall not exceed 6 in./s (15.24 cm/s).

S2. Enhanced Inspection Coverage

S2.1 The search unit shall be indexed approximately 50% of the transducer width with each pass of the search unit. The search unit shall be held by a suitable fixture attached to the tool post of the lathe and traversed mechanically for scanning of the rotating forging. See 8.1.6 for recommended forging rotation speeds.

S2.2 Hand-held transducer testing is only permitted in those areas where the transducer holder interferes with the inspection coverage.

APPENDIX

(Nonmandatory Information)

X1. DERIVATION OF SENSITIVITY MULTIPLICATION FACTORS

X1.1 Theoretical formulas relating properties such as discontinuity area, distance, and echo amplitude, may be derived at various levels of complexity. Detailed descriptions of such methods of analysis may be found in standard texts on acoustics or ultrasonics, and will not be given here. The method used in deriving the curves of Fig. 1, Fig. 2, and Fig. 3 uses the spherical-wave approximation to describe the behavior of the sound field, with analytical techniques analogous to those of geometric optics. The resulting relations between theoretical echo amplitudes are as follows:

$$\frac{\text{echo from small disk reflector}}{\text{echo from large plane or solid cylinder}} = \frac{2dA}{a^2\lambda}$$

$$\frac{\text{echo from small disk reflector}}{\text{echo from cylindrical bore}} = \frac{(d-b)A}{a^2\lambda}\sqrt{\frac{d}{b}}$$

where:
a = distance to disk reflector (flat-bottom hole),
b = bore diameter,
d = forging cylinder diameter,
A = area of disk reflector, and
λ = wavelength of sound used for inspection.

X1.2 Using the procedure described in the main body of this standard, the echo from a forging back wall or bore is set at 100 % of (linear) screen height, and sensitivity is then adjusted by a multiplying factor M such that the theoretical echo amplitude from a disk reflector of given area A at the forging centerline or bore surface would be 10 % of screen height, that is, multiplying factor (M) times the echo from the small disk reflector (A) would equal 10 % of the echo from opposite surfaces of solid cylinders or from bore surfaces of bored cylinders. These multiplying factors would be:

$$\text{Solid cylinder: } M = \left(\frac{10}{100}\right)\left(\frac{a^2\lambda}{2dA}\right) = \frac{d\lambda}{80A}$$

$$\text{Bored cylinder: } M = \frac{(d-b)\lambda}{40A}\sqrt{\frac{b}{d}}$$

X1.3 The curves given in Fig. 1 and Fig. 2 have been calculated from these formulas, using a reference disk-reflector of 0.125-in. diameter, and values of sound velocity and frequency typical for steel forging inspection to define the wavelength. The validity of these theoretical curves has been checked experimentally. Fig. 3 shows an additional multiplication factor to be used if the reference reflector diameter is changed.

X1.4 Because of the approximations made in the derivation, these formulas and multiplication factors should not be used for any reflecting surface less than three near-field lengths from the transducer. The length N of the near-field may be calculated as follows:

$$N = \frac{D^2 - \lambda^2}{4\lambda}$$

where D is the effective transducer diameter. Other restrictions are as follows: (a) the reference hole diameter must be much smaller than the ultrasonic beam cross-section; (b) neither the reference hole diameter nor the apparent diameter of a discontinuity should be less than $\lambda/2$; (c) the bore diameter must be much larger than λ; and (d) attenuation in the material to be inspected should be negligibly small. Accuracy will also be impaired by test instrument nonlinearities, including built-in "reject" or "zero suppression." It is important that back reflection amplitudes be set from surfaces unobstructed by holes, fillets, or other changes in cross section within their area of intersection with the cross section of the ultrasonic beam.

X1.5 With sensitivity set in this manner, the theoretical minimum equivalent reflecting area of a discontinuity is given in terms of the area A R of the reference hole and the percentage of screen height, P, of the discontinuity indication, as:

$$A_F = \frac{2a^2A_RP}{5d^2} \text{ for a solid forging}$$

$$A_F = \frac{2a^2A_RP}{5(d-b)^2} \text{ for a bored forging}$$

Thus, a 10 % indication at the centerline ($a = d/2$) or the bore surface [$a = (d - b)/2$] has an area equivalent to that of the reference hole. These equations may be combined by setting L = (d/2) or ($d - b$)/2, to obtain the relation given in 9.1.4.

Designation: A 427 – 02

Standard Specification for Wrought Alloy Steel Rolls for Cold and Hot Reduction[1]

This standard is issued under the fixed designation A 427; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers homogeneous wrought hardened alloy steel rolls for use in cold or hot reduction of flat rolled ferrous and nonferrous products.

2. Referenced Documents

2.1 *ASTM Standards:*

A 788 Steel Forgings, General Requirements[2]

A 956 Leeb Hardness Testing of Steel Products[2]

E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials[3]

E 92 Test Method for Vickers Hardness of Metallic Materials[3]

E 140 Hardness Conversion Tables for Metals[3]

E 448 Practice for Scleroscope Hardness Testing of Metallic Materials[3]

3. Ordering Information

3.1 The purchaser shall specify in the inquiry, contract, or order the complete dimensions, hardness range, surface finish, and use. Any other requirements shall also be specified.

3.2 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

4. Process

4.1 The steel shall be made by the electric-furnace process. Additional refining by vacuum arc remelt or electroslag is permitted.

5. Manufacture

5.1 The forged rolls shall receive their hot mechanical work under a press or hammer of ample capacity to work the metal throughout its section. However, 6-in. (152-mm) diameter or less rolls may be produced from rolled bars.

6. Discard

6.1 Sufficient discard shall be made from each ingot to secure freedom from piping and undue segregation.

7. Chemical Requirements

7.1 Unless specified by the purchaser, the chemical requirements shall be at the discretion of the manufacturer.

8. Heat Treatment

8.1 The method of heat treatment and hardening shall be at the option of the manufacturer.

9. Hardness Requirements

9.1 The manufacturer shall supply rolls to the hardness ranges agreed upon by the purchaser and the manufacturer.

9.2 A hardness range of either 5 points Shore scleroscope or 100 numbers Vickers hardness is permissible.

10. Hardness Testing

10.1 Each roll shall be tested for hardness and shall be within limits specified on the order. The Shore forged roll scleroscope ($HFRS_C$ or $HFRS_D$), Rockwell hardness tester, Vickers hardness penetrator, or Leeb hardness tester (in accordance with Test Method A 956) may be used to determine compliance with the hardness range specified. The approximate relationship between Shore $HFRS_C$ scleroscope and diamond pyramid hardness is shown in Table 1.

10.2 The stage of processing at which hardness testing is conducted and the number and location of tests may be agreed upon by the purchaser and the manufacturer.

10.3 A sufficient number of hardness tests shall be made to ensure the required uniformity, both longitudinally and circumferentially.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved September 10, 2002. Published June 2003. Originally approved in 1958. Last previous edition approved in 2001 as A 427 – 74 (2001).

[2] *Annual Book of ASTM Standards,* Vol 01.05.

[3] *Annual Book of ASTM Standards,* Vol 03.01.

*A Summary of Changes section appears at the end of this standard.

TABLE 1 Approximate[A] Relationship Between Shore $HFRS_c$ Scleroscope and Diamond Pyramid Hardness for Wrought Hardened Alloy Steel Rolls

NOTE 1—This table is recommended for rolls over 6 in. (152 mm) in diameter. There is a tendency for rolls smaller than 6 in. in diameter with the same Vickers hardness to show lower scleroscope readings.

NOTE 2— For scleroscope hardness determinations, the calibration to standard reference blocks, and the verification of instrument are a constant necessity. See details recommended in Practice E 448.

NOTE 3—For Rockwell and Vickers hardness determinations, reference may be made to Test Method E 18 and E 92.

NOTE 4—For hardness conversion tables for metals, see Tables E 140.

Shore $HFRS_c$ Scleroscope Hardness	Vickers Hardness[B]	Shore HFRSc Scleroscope Hardness	Vickers Hardness[B]
65	420	86	685
66	432	87	698
67	445	88	710
68	457	89	723
69	470	90	735
70	482	91	748
71	495	92	761
72	508	93	774
73	520	94	787
74	533	95	800
75	545	96	812
76	558	97	825
77	571	98	837
78	584	99	850
79	597	100	862
80	610	101	875
81	622	102	888
82	635	103	900
83	647	104	913
84	660	105	926
85	672		

[A] The above hardness conversions cover an approximate relationship. The expected range of results on 95 % of hardness measurements is as follows:
Conversion from Vickers hardness to shore HFRSc scleroscope hardness, ± 3.7 Shore.
Conversion from Shore HFRSc scleroscope hardness to Vickers hardness, ± 43 HV.

[B] Vickers hardness measurements are based on a load of 30 kgf. The Vickers penetrator was calibrated with a dead-weight Vickers hardness tester.

11. Soundness

11.1 The material shall be free of injurious imperfections.

12. Workmanship

12.1 The roll shall conform to the dimensions and surface finish specified by the purchaser.

13. Marking

13.1 Each roll shall be permanently identified with marking by the manufacturer on the end face of the journals, unless otherwise specified.

14. Report

14.1 The manufacturer shall furnish a report of the hardness test. The type, model, and instrument used shall be reported. In the case of the Vickers hardness readings, the load shall be reported.

15. Inspection

15.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. All tests and inspections shall be made at the place of manufacture, unless otherwise specified, and shall not interfere unnecessarily with the manufacturer's operations.

16. Rejection

16.1 A roll that fails to comply with the requirements of this specification shall be subject to rejection, and the manufacturer shall be notified.

17. Keywords

17.1 cold and hot reduction; wrought alloy steel rolls

SUMMARY OF CHANGES

Committee A01 has identified the location of changes since A 427–74 (2001) that may impact the use of this standard.

(1) Revised Section 2 to include A 788 and A 952, added 3.2, revised 10.1 to include Leeb Testing.

(2) Added 3.2.

(3) Revised 10.1 to include Leeb Testing.

Designation: A 434 – 04

Standard Specification for Steel Bars, Alloy, Hot-Wrought or Cold-Finished, Quenched and Tempered[1]

This standard is issued under the fixed designation A 434; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers hot-wrought and cold-finished quenched and tempered alloy steel bars.

1.2 Hot-wrought bars are available in three strength level classes designated BB, BC, and BD, and cold-finished bars in two strength level classes designated BB and BC. The bars are available in the conditions specified in 4.4 subject to the size limitations shown.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought, General Requirements for

A 108 Specification for Steel Bar, Carbon and Alloy, Cold-Finished

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

E 112 Test Methods for Determining Average Grain Size

3. Ordering Information

3.1 Orders for material under this specification should include the following information:

3.1.1 Quantity (weight or number of pieces),

3.1.2 Name of material (heat-treated alloy steel bars),

3.1.3 Method of finish (condition) (4.4),

3.1.4 Dimensions, including length (if hot-wrought bars are for cold finishing, the cold-finished size should also be specified),

3.1.5 ASTM designation and date of issue,

3.1.6 Chemical composition grade (Section 5),

3.1.7 Strength class (Section 8 and Table 1),

3.1.8 Test report, if required (Section 11),

3.1.9 Supplementary Requirements or Special Requirements, if required, and

3.1.10 End use.

NOTE 1—A typical ordering description is as follows: 10 000 lb, Heat-Treated Alloy Steel Bars, Hot Rolled, 1.000 in. diameter × 10 ft, ASTM A 434 dated ____, Grade 4140, Class BB, Test Report Required, Motor Shafts.

4. Materials and Manufacture

4.1 *Melting Practice*—The steel shall be made by one or more of the following primary processes: open-hearth, basic-oxygen, or electric-furnace. The primary melting may incorporate separate degassing or refining and may be followed by secondary melting using electroslag remelting or vacuum arc remelting. Where secondary melting is employed, the heat shall be defined as all of the ingots remelted from a single primary heat.

4.2 *Discard*—Sufficient discard shall be made to secure freedom from injurious piping and undue segregation.

4.3 *Slow Cooling*—Hot-wrought alloy bars shall, immediately after rolling, be allowed to cool to a temperature below the critical range under suitable conditions to prevent injury by too rapid cooling.

4.4 *Condition*—Bars shall be furnished in one of the following conditions, as specified by the purchaser. Generally, size limits for various methods of processing round bars are:

Hot-wrought or hot-wrought descaled	9½ in. (241.3 mm), max
Cold-drawn	⅛ to 4 in. (3.2 to 102 mm), incl
Cold-drawn, ground, and polished	⅛ to 4 in. (3.2 to 102 mm), incl
Turned and polished	¾ to 9 in. (19.1 to 229 mm), incl
Turned, ground, and polished	¾ to 9 in. (19.1 to 229 mm), incl

4.5 *Heat Treatment*:

4.5.1 Heat treatment shall include quenching and tempering for all classes of material. The material shall be uniformly heated to the austenitizing temperature, soaked for a sufficient

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys, and is the direct responsibility of Subcommittee A01.15 on Bars.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

TABLE 1 Tensile Properties

NOTE—The mechanical properties of hot-wrought bars ordered for cold finishing, shall be governed by the cold-finished size.

Class	Diameter, in. (mm)	Yield Strength, min, ksi (MPa)[A]	Tensile Strength, min, ksi (MPa)	Elongation in 2 in. or 50 mm, min, %	Reduction of Area, min, %	SAE or AISI Representative Grade Types[B]
	1½ (38.1) and under	90 (620)	110 (760)	20	50	3100, 4100,
	Over 1½ to 2½ (38.1 to 63.5), incl	80 (550)	105 (720)	20	50	8600, 8700
BB[C]	Over 2½ to 4 (63.5 to 114), incl	75 (520)	100 (690)	20	50	
	Over 4 to 7 (114 to 178), incl	75 (520)	95 (660)	20	50	
	Over 7 to 9½ (178 to 241.3), incl	65 (450)	90 (620)	18	40	
	1½ (38.1) and under	110 (760)	130 (900)	16	50	3100, 4100, 6100,
	Over 1½ to 2½ (38.1 to 63.5), incl	105 (720)	125 (860)	16	50	8600, 8700
BC[C]	Over 2½ to 4 (63.5 to 114), incl	95 (660)	115 (790)	16	45	
	Over 4 to 7 (114 to 178), incl	85 (590)	110 (760)	16	45	3100, 4100
	Over 7 to 9½ (178 to 241.3), incl	80 (550)	105 (720)	15	40	4300, 9800
	1½ (38.1) and under	130 (900)	155 (1070)	14	35	4100, 4300,
	Over 1½ to 2½ (38.1 to 63.5), incl	120 (830)	150 (1030)	14	35	9800
BD[C]	Over 2½ to 4 (63.5 to 114), incl	110 (760)	140 (960)	14	35	
	Over 4 to 7 (114 to 178), incl	105 (720)	135 (930)	14	35	
	Over 7 to 9½ (178 to 241.3), incl	100 (690)	130 (900)	14	35	

[A] The carbon content of all steels listed in this column may vary up to 0.55% max, as agreed upon by the manufacturer and the purchaser.
[B] Determined by the 0.2% offset method.
[C] Class BB, BC, BD hot-wrought; Class BB, BC cold-finished.

length of time to produce the desired structure (a lot thus heated being known as a "quenching charge"), and quenched in a suitable medium under substantially uniform conditions for each quenching charge. The material shall then be uniformly reheated to the proper temperature for tempering (a lot thus reheated being known as a "tempering charge"), and allowed to cool uniformly. The temperature selected for tempering shall be not less than 800°F (427°C).

4.5.2 Material cold drawn after heat treatment shall be stress relieved, when this is necessary, in order to meet the specified mechanical properties.

4.5.3 Cold-finished bars may be stress relieved after straightening.

4.5.4 For heat-treated hot-wrought bars, where it is desirable to minimize internal stresses introduced by machine straightening, the purchaser may specify a stress relief as a final operation.

4.5.5 If warpage occurs in the stress-relieving operation, the bars may be restraightened without further stress-relieving, provided they meet the required mechanical properties.

5. Chemical Composition

5.1 The grade of steel furnished shall be specified by the purchaser and shall be selected from the standard alloy grades in Table 2 of Specification A 29/A 29M, or to such other compositions as may be specified using the ranges and limits in Table 4 of Specification A 29/A 29M.

5.2 In all cases, the grade specified shall be capable of developing the required mechanical properties. If, in the opinion of the manufacturer, the grade specified is not capable of developing the mechanical properties, the manufacturer shall notify the purchaser and whenever possible suggest an alternative grade.

5.3 Representative grade types listed for the respective classes and bar sizes in Table 1 are for information only.

6. Grain Size

6.1 *Requirement*—The bars shall have an austenitic grain size of 5 to 8. The grain structure shall be considered satisfactory if 70 % is within the specified size limits.

6.2 *Specimens*—Grain size specimens shall be taken in accordance with Test Methods E 112.

6.3 *Number of Tests*—Not less than one grain size test shall be made per heat.

6.4 *Test Method*—Grain size shall be determined in accordance with the Comparison Method of Test Methods E 112.

7. Mechanical Properties

7.1 *Requirements*—The material, as represented by test specimens, shall conform to the tensile properties in Table 1 for the class specified.

7.2 *Specimens*:

7.2.1 Test specimens shall be taken longitudinally after final processing.

7.2.2 Test specimens shall be selected from the locations and prepared for testing as specified in Test Methods and Definitions A 370.

7.3 *Number of Tests*—One tension test shall be made from each tempering or stress-relieving charge. If more than one quenching charge is represented, one tension test shall be made from each quenching charge. If more than one heat is represented in a quenching charge, one tension test shall be made from each heat and size. For continuous-type treatment, one tension test shall be made for each 25 tons (22.7 Mg) of each heat or size.

7.4 *Test Method*—Tension tests shall be made in accordance with Test Methods and Definitions A 370 using the 0.2 % offset method when determining yield strength.

8. Permissible Variation of Dimensions

8.1 *Special Straightness*—Unless otherwise specified, all material shall be supplied to a straightness tolerance of ⅛ in. (3.18 mm) in any 5 ft (1.5 m), but may not exceed the following:

$$\text{Maximum straightness deviation, in.} = 1/8 \times (\text{length in feet}/5)$$

9. Workmanship, Finish, and Appearance

9.1 *Workmanship*—The bars shall be free of pipe, cracks, and flakes. Within the limits of good manufacturing and inspection practices, the bars shall be free of injurious seams, laps, segregation, or other imperfections which, due to their nature, degree, or extent, will interfere with the use of the material in machining or fabrication of suitable parts.

9.2 *Oiling*—Unless otherwise specified, hot-wrought descaled bars and cold-finished bars shall be given a surface coating of oil or other rust inhibitor to protect against rust during shipment.

10. General Requirements

10.1 Material furnished under this specification shall conform to the applicable requirements for the current edition of Specification A 29/A 29M or Specification A 108.

11. Certification and Report of Testing

11.1 When specified by the purchaser, a manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the heat analysis, grain size, and tensile requirement test results shall be furnished. The report shall include the name of the manufacturer, ASTM designation number and yeardate and revision letter, if any, grade, class, heat number, and size.

11.2 When Supplementary Requirement S1 is specified, the report shall include a statement of compliance with the requirement or the results of tests when the requirement involves measured test values.

12. Keywords

12.1 alloy steel bars; cold-finished steel bars; hot-wrought steel bars; quenched and tempered steel bars; steel bars

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirement shall be applied only when specified by the purchaser in the inquiry, contract, or order. Details of this supplementary requirement shall be agreed upon in writing by the manufacturer and purchaser. Supplementary requirements shall in no way negate any requirements of the specification itself.

S1. Hardness Test

S1.1 Maximum surface Brinell hardness, if specified by the purchaser, shall be as agreed upon between the manufacturer and the purchaser.

Standard Specification for Magnetic Particle Examination of Large Crankshaft Forgings[1]

This standard is issued under the fixed designation A 456/A 456M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This is an acceptance specification for the magnetic particle inspection of forged steel crankshafts having main bearing journals or crankpins 4 in. [200 mm] or larger in diameter.

1.2 There are three classes, with acceptance standards of increasing severity:

1.2.1 Class 1.

1.2.2 Class 2 (originally the sole acceptance standard of Specification A 456).

1.2.3 Class 3 (formerly covered in Supplementary Requirement S1 of Specification A 456–64 (1970)).

1.3 This specification is not intended to cover continuous grain flow crankshafts, however, Test Method A 983/A 983M may be used for this purpose.

NOTE 1—Specification A 668/A 688M is a product specification which may be used for crankshaft forgings.

1.4 The values stated in either inches or SI (metric) units are to be regarded separately as the standard. Within the text and figures, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.5 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch units.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings

A 668/A 668M Specification for Steel Forgings, Carbon and Alloy, for General Industrial Use

A 966/A 966M Test Method for Magnetic Particle Examination of Steel Forgings Using Alternating Current

A 983/A 983M Specification for Continuous Grain Flow Forged Carbon and Alloy Steel Crankshafts for Medium Speed Diesel Engines

E 1417 Practice for Liquid Penetrant Examination

3. Classification of Indications

3.1 Magnetic particle indications on the surface of the crankshaft shall be classified as follows:

3.1.1 Open cracks, flake, or pipe.

3.1.2 Nonmetallic inclusions or stringers occurring in a longitudinal direction.

3.1.3 Twist cracks or nonmetallic inclusions usually occurring at 45 to 70° from the axis of the journal.

3.2 They shall also be classified as follows:

3.2.1 Open indications are visible after removal of the magnetic particles or can be detected by the use of contrast dye penetrant, as described in Type II of Practice E 1417.

3.2.1.1 Pinpoint indications are open indications 1⁄16 in. [1.5 mm] in maximum dimension, as detected by application of Type II of Practice E 1417.

3.2.2 Non-open indications are indications which are not visually detectable as described in 3.2.1.

4. Ordering Information

4.1 The inquiry and purchase agreement shall contain a statement that the crankshaft(s) is (are) to be subject to acceptance according to this specification. If reference to class is omitted, Class 2 shall apply.

4.2 The use of Supplementary Requirements S1 and S2 should be specified if required.

5. Procedure

5.1 Magnetic particle inspection shall be conducted according to Test Method A 966/A 966M, except when Supplementary Requirement S1 is to be used. The use of prod type contacts is not permitted on finished crankshafts. Magnetic

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys , and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

leeches may only be used on noncritical parts of the crankshaft when Supplementary Requirement S2 is utilized.

6. Areas of Inspection

6.1 *Major Critical Areas*:

6.1.1 The critical area of any crankpin shall be that area plus or minus 60° from the 6 o'clock position of the pin extending ⅜ in. [10 mm] above the thrust collar around the fillet, and ⅝ in. [16 mm] into the pin along its axis measured from approximately the blend of the pin surface and fillet, as shown in Fig. 1 and Fig. 2.

6.1.2 The critical areas of any main bearing journal shall be that area plus or minus 60° from the 12 o'clock position on top of the journal extending ⅜ in. [9.5 mm] above the thrust collar around the fillet and ⅝ in. [15.9 mm] into the journal along its axis measured from approximately the blend of the journal surface and the fillet, as shown in Fig. 1 and Fig. 2.

6.1.3 The critical area of any crankpin or main journal also includes that surface area closer than ¼ in. [6 mm] to the junction of the radius blend and the journal surface of any oil hole.

6.2 *Minor Critical Areas*—Minor critical areas include all machined fillets, thrust bearing, and bearing surfaces not specified as major critical areas.

7. Acceptance Standards

7.1 *Class 1*:

7.1.1 *Major Critical Areas*:

7.1.1.1 Open indications over ¼ in. [6 mm] in length shall be removed by dimpling to a depth no greater than 3⁄16 in. [5 mm]. Open indications over 1⁄16 to ¼ in. [1.5 to 6 mm] in length shall be depressed as in 7.2.2.3.

7.1.1.2 Pinpoint indications are permissible, except in clusters of more than 5 in any ¼ by ¼-in. [6 by 6-mm] area, in which case they must be dimpled to a depth of no more than 3⁄16 in. [5 mm]. If they do not open or increase in number they are acceptable and need not be removed.

7.1.1.3 Non-open indications are acceptable up to and including ½ in. [13 mm] in length. If non-open indications are over ½ in., depress, and if they are not open or are worsening, accept them. Otherwise remove by dimpling to a maximum depth of 3⁄16 in. [5 mm].

7.1.1.4 The total area of dimples shall be limited as in 7.2.1.3.

7.1.2 *Minor Critical Areas*:

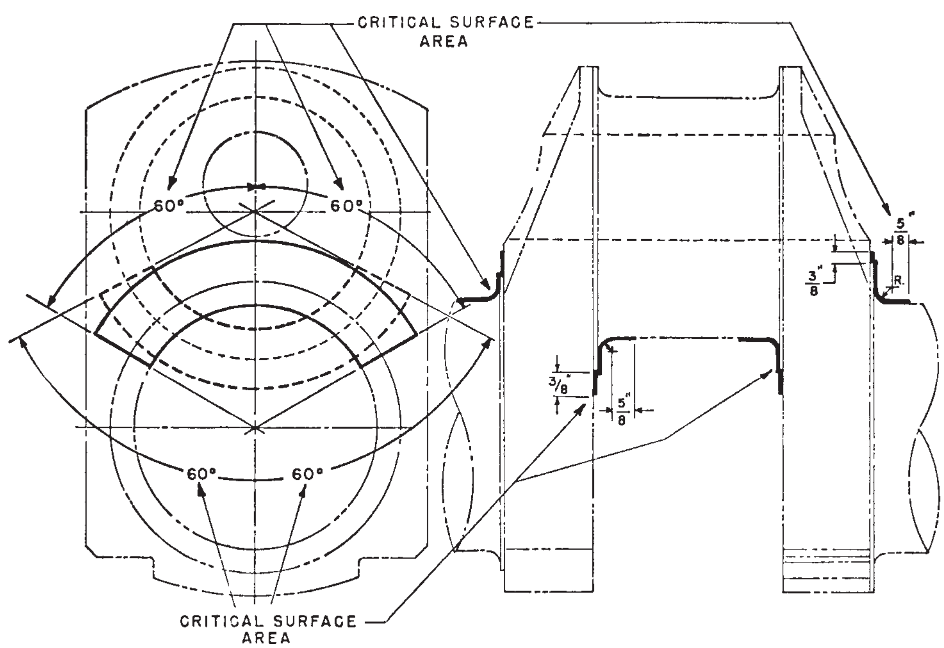
7.1.2.1 Open indications oriented at an angle in excess of 30° to the longitudinal axis must be removed to a depth not exceeding 3⁄16 in. [5 mm], by dimpling.

7.1.2.2 Open indications longer than 1½ in. [35 mm] individually or more than 3 in. [75 mm] of total length per bearing journal, that are parallel to the longitudinal axis within 30°, must be removed by dimpling to a depth no greater than 3⁄16 in. [5 mm]. Intermittent open indications in a line, spaced less than ¼ in. [6 mm] apart, shall be considered continuous or as one indication.

7.1.2.3 Open indications ⅛ in. [3 mm] to 1½ in. [35 mm] long, with the exception of those referred to in 7.1.2.1, shall be depressed 0.003 to 0.010 in. [0.05 to 0.25 mm] below the surface but need not be removed.

7.1.2.4 Open indications less than ⅛ in. [3 mm] long need not be depressed, dimpled, or removed.

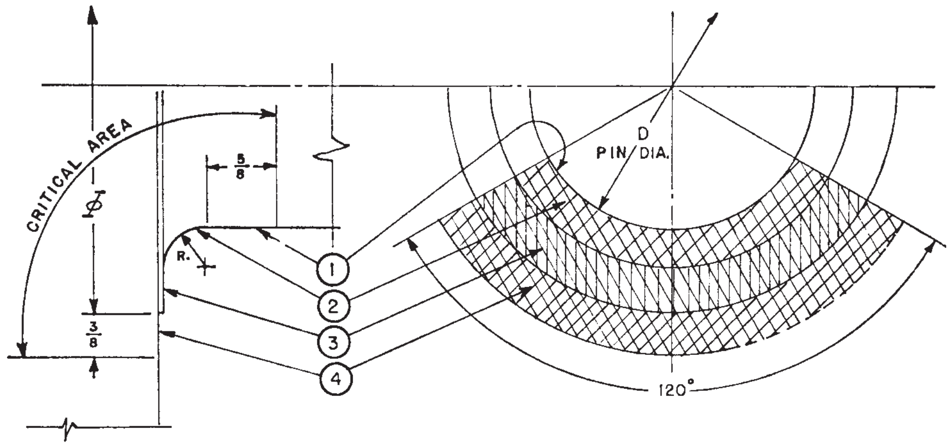
7.1.2.5 A cluster of open indications, with the exception of those referred to in 7.1.2.1, having a total length not exceeding 2½ in. [65 mm] in any 1 by 1-in. [25 by 25-mm] square area



Metric Equivalents

⅜ in. = [10 mm] ⅝ in. = [16 mm]

FIG. 1 Critical Surface Areas of Crankpin and Main Bearing Journal



(*1*)—5⁄8 in. [16 mm] on pin or journal,
(*2*)—Fillet radius, *R*,
(*3*)—Thrust collar, and
(*4*)—3⁄8 –in. [10-mm] ring beyond thrust collar.

NOTE 1—The critical area is 120 degrees on the pin or journal.

FIG. 2 Reference Dimensions for Calculations

of bearing surface shall be depressed 0.003 to 0.010 in. [0.05 to 0.25 mm] below the surface but need not be removed. When the total length exceeds 2½ in. [65 mm], the indications are to be removed by dimpling to a depth no greater than 3⁄16 in. [5 mm].

7.1.2.6 Non-open indications are acceptable.

7.1.2.7 The total area of dimples in any journal or crankpin shall not exceed 1 % of the total minor critical area of the crankpin or main journal concerned.

7.1.3 *Number of Dimples*—The number of dimples per crankshaft, excluding dimples in the areas defined in 6.1.3, shall not exceed the sum of the number of the crankpins and main journals, nor five per crankpin or main journal.

7.2 *Class 2*:

7.2.1 *Major Critical Areas*:

7.2.1.1 Open indications other than pinpoints are not permitted and must be removed by dimpling to a depth no greater than 3⁄16 in. [5 mm]. Pinpoint indications are permissible, if there are no more than three in any ¼ by ¼-in. [6 by 6-mm] square area. Pinpoints in excess of three must be dimpled to a depth of 3⁄16 in. [5 mm] and reduced to no more than three pinpoints unless they are removed at a lesser depth. If no more than three pinpoints remain at the 3⁄16-in. [5-mm] depth, they are acceptable and need not be removed.

7.2.1.2 Magnetic particle buildup exceeding ¼ in. [6 mm] in length and which has been found to be non-open by the procedure described in 3.2.1 shall be jointly investigated by the manufacturer and purchaser, or their representatives. Each indication, or, with the concurrence of the purchaser, selected representative indications, shall be explored to a depth of at least 0.003 in. [0.05 mm], but not exceeding 0.010 in. [0.25 mm]. If open indications are found (3.2.1), then the requirements of 7.2.1.1 shall apply. If open indications are not found, then the indications are acceptable and any explored area shall be suitable radiused and classed as a depressed area rather than a dimple. If the presence of subsurface discontinuities is to be investigated, then Test Method A 275/A 275M shall be included in such an investigation. However, caution should be exercised in demagnetizing the crankshaft on completion of this examination.

7.2.1.3 The total area of dimples shall be less than 10 % of the total major critical area of the crankpin or journal concerned. The areas referred to in 6.1.3 shall be excluded from the total area allowable.

7.2.2 *Minor Critical Areas*:

7.2.2.1 Open indications oriented at an angle in excess of 30° to the longitudinal axis must be removed at a depth not exceeding 3⁄16 in. [5 mm], by dimpling.

7.2.2.2 Open indications longer than 1 in. [25 mm] individually or more than 2 in. [50 mm] of total length per bearing journal, that are parallel to the longitudinal axis within 30°, must be removed by dimpling to a depth no greater than 3⁄16 in. [5 mm]. Intermittent open indications in a line, spaced less than ¼ in. [6 mm] apart, shall be considered continuous or as one indication.

7.2.2.3 Open indications ⅛ to 1 in. [3 to 25 mm] long, with the exception of those referred to in 7.2.2.1, shall be depressed 0.003 to 0.010 in. [0.05 to 0.25 mm] below the surface but need not be removed.

7.2.2.4 Open indications less than ⅛ in. [3 mm] long need not be depressed, dimpled, or removed.

7.2.2.5 A cluster of open indications, with the exception of those referred to in 7.2.2.1, having a total length not exceeding 1½ in. [35 mm] in any 1 by 1-in. [25 by 25-mm] square area of bearing surface, shall be depressed 0.003 to 0.010 in. [0.05 to 0.25 mm] below the surface but need not be removed. When the total length exceeds 1½ in. [35 mm], the indications are to be removed by dimpling to a depth no greater than 3⁄16 in. [5 mm].

7.2.2.6 Non-open indications are acceptable.

7.2.2.7 The total area of dimples in any journal or crankpin shall not exceed 1 % of the total minor critical area of the crankpin or main journal concerned.

7.2.3 *Number of Dimples*—The number of dimples per crankshaft, excluding dimples in the areas defined in 6.1.3, shall not exceed the sum of the number of the crankpins and main journals, nor five per crankpin or main journal.

7.3 *Class 3*:

7.3.1 *Major Critical Areas*—See 7.2.1.

7.3.2 *Minor Critical Areas*:

7.3.2.1 Open indications oriented at an angle in excess of 30° to the longitudinal axis must be removed at a depth not exceeding 3⁄16 in. [5 mm], by dimpling.

7.3.2.2 Open indications longer than 1⁄8 in. [3 mm] that are parallel to the longitudinal axis within 30° must be removed by dimpling to a depth no greater than 3⁄16 in. [5 mm]. Intermittent open indications in a line, spaced less than 1⁄4 in. [6 mm] apart, shall be considered continuous or as one indication.

7.3.2.3 Open indications (except pinpoint indications) 1⁄8 in. [3 mm] or less in length, with the exception of those referred to in 7.3.2.1, shall be depressed 0.003 to 0.010 in. [0.05 to 0.25 mm], below the surface, but need not be removed.

7.3.2.4 Non-open indications are acceptable.

7.3.2.5 The total areas of dimples in any journal or crankpin shall not exceed 1 % of the total minor critical area of the crankpin of main journal concerned.

8. Dimpling and Depressing

8.1 To dimple means to stone or grind to remove stock in an area that contains an open indication. All dimples shall have a bottom radius of approximately three times the dimple depth and should be smoothly blended to the surface area with a finish equal to the adjacent bearing surface.

8.2 To depress is to flatten or relieve the edges of an indication with a fine pointed abrasive stone with the restriction that the depth beneath the original surface shall be 0.003 in. [0.05 mm] minimum to 0.010 in. [0.25 mm] maximum and that the depressions be blended into the bearing surface. A depressed area is not considered a dimple and is made only to prevent galling of the bearings.

9. Inspection

9.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. All tests and inspections shall be made at the place of manufacture, unless otherwise agreed to, and shall not interfere unnecessarily with the manufacturer's operations.

9.2 Upon agreement with the purchaser or if expressed in the order or if shown on the drawing, the manufacturer of the crankshaft shall certify that the crankshaft was tested and is in accordance with this specification.

10. Product Marking

10.1 The purchaser of the crankshaft shall provide the manufacturer with any marking or stamping identification required.

11. Keywords

11.1 acceptance criteria; crankshaft forgings; magnetic particle examination; nondestructive examination

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the contract or order.

S1. Use of Direct Current Magnetization

S1.1 The magnetic particle examination of the crankshaft shall be done in accordance with Test Method A 275/A 275M.

S2. Use of Magnetic Leeches

S2.1 Magnetic leeches shall be applied only to noncritical surfaces of the crankshaft, as designated in the crankshaft drawing, or as permitted by the purchaser.

Designation: A 466/A 466M – ~~98~~01

~~An American National Standard~~

Standard Specification for Weldless Chain[1]

This standard is issued under the fixed designation A 466/A 466M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers weldless chain suitable for applications where a light and flexible chain is required. The material may be steel, brass, or bronze.

1.2 Seven classes of chain are covered:

1.2.1 *Class SL*—Single-loop chain.

1.2.2 *Class DL*—Double-loop chain.

1.2.3 *Class SH*—Sash chain.

1.2.4 *Class SF*—Plumbers' (safety) chain.

1.2.5 *Class SJ*—Single-jack chain.

1.2.6 *Class DJ*—Double-jack chain.

1.2.7 *Class RG*—Register chain.

1.3 The values stated in either SI units or in other units shall be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system must be used independently of the other, without combining values in any way.

2. Referenced Documents

2.1 *ASTM Standards:*

[1] This specification is under the jurisdiction of ASTM Committee ~~A-1~~ A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.27 on Steel Chain.

Current edition approved ~~Nov.~~ Sept. 10, ~~1998.~~ 2001. Published ~~January 1999.~~ November 2001. Originally published as A 466–62T. Last previous edition A 466/A 466M–~~93~~8.

***A Summary of Changes section appears at the end of this standard.**

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]
A 366/A 366M Specification for Commercial Steel (CS) Sheet, Carbon,~~ Cold-Rolled, Commercial Quality~~ (0.15 Maximum Percent) Cold-Rolled[3]
A 569/A 569M Specification for Steel, Carbon (0.15 Maximum, Percent), Hot-Rolled Sheet and Strip Commercial~~ Quality~~[3]
B 248 Specification for General Requirements for Wrought Copper and Copper-Alloy Plate, Sheet, Strip, and Rolled Bar[4]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *breaking force, minimum*—the minimum force in pounds or newtons at which the chain~~, in the condition it leaves the producer's plant,~~ during manufacture, has been found by representative testing to break when a constantly increasing force is applied in direct tension. This t~~o~~est is a~~ straight length of chain on a standard testing machine. Breaking force values are a statistical~~ manufacturer's attribute acceptance test and~~ are not a guarantee that all chain segments per lot will endure these loads. Breaking force loads~~ shall not be used as criteria for~~ service or design purposes.~~ service.

3.1.2 *lot*—for the purpose of acceptance testing, a lot shall consist of 3000 ft [1000 m] or fraction, thereof, of the same grade and size chain. If a continuous length of chain exceeds 3000 ft, it shall also be considered a lot.

3.1.3 *working load limit (WLL)*—the maximum combined static and dynamic load in pounds or kilograms that shall be applied in direct tension to an undamaged straight length of chain.

4. Ordering Information

4.1 It shall be the responsibility of the purchaser to specify all requirements that are necessary for material ordered under this specification. Such requirements to be considered include, but are not limited to, the following:

4.1.1 Product to conform to Specification A 466 or A 466M and year of issue,
4.1.2 Class of chain,
4.1.3 Material size or trade size of chain,
4.1.4 Material of chain (steel, brass, or bronze),
4.1.5 Quantity of chain in feet [metres],
4.1.6 Length of each piece, if required,
4.1.7 Finish, if required,
4.1.8 Certification of test(s), if required, and
4.1.9 Acceptance of inspection by purchaser, if required.

5. Materials and Manufacture

5.1 The selection of the base material is left to the judgment of the individual chain manufacturer provided that the chain complies with the requirements contained within this specification.

5.2 The methods utilized to produce the chain are left to the judgment of the individual chain manufacturer provided the chain complies with the requirements contained within this specification.

6. Dimensional Requirements

6.1 The chain shall conform to the dimensional requirements as specified in Tables 1-7. The tolerance is ±7 % from the specified nominal dimensions for all chain classes except Class SF. Class SF has a maximum length criterion. The inside length dimension can be measured either by individual link or by measuring the span of 100 links and dividing by 100.

6.2 *Material Diameter/Thickness*—The diameter or thickness of the material from which the chain is manufactured shall be at least the dimension shown in Tables 1-7, subject to the normal commercial tolerances listed in Specifications A 29/A 29M, A 366/A 366M, A 569/A 569M, and B 248. Oversized material may be used for all applications.

7. Workmanship, Finish and Appearance

7.1 The chain shall be free of injurious imperfections and shall have a workmanlike finish.

7.2 The manufacturers may apply a surface treatment or coating of their own choice for identification or corrosion resistance unless otherwise specified by the customer in the purchase order.

8. Mechanical Requirements

8.1 *Breaking Force Test*:

8.1.1 The breaking force test specimen shall consist of a length not less than 1 ft [0.3 m] from the lot of chain.

8.1.2 Fixtures for securing chain in a testing machine shall be properly designed to securely support the shoulder of the link. The opening in the fixture shall be not more than 25 % larger than the material diameter of the chain being tested. Links in the

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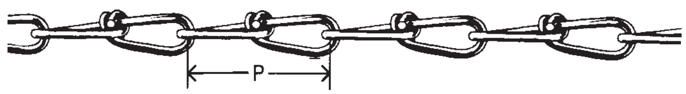
[2] *Annual Book of ASTM Standards*, Vol 01.05.
[3] *Annual Book of ASTM Standards*, Vol 01.03.
[4] *Annual Book of ASTM Standards*, Vol 02.01.

TABLE 1 Single Loop Chain (Class SL)

Trade Size	Material Size, in. [mm]	Nominal Inside Length (P) in. [mm]	Approximate Weight per 100 ft [30.5 m], lb [kg]	Working Load Limit, lb [kg]		Minimum Breaking Force, lb [kN][A]	
				Steel	Brass	Steel	Brass
2	0.091 [2.3]	1.08 [27.4]	10.0 [5]	155 [70]	110 [50]	620 [2.8]	440 [2.0]
1/0	0.120 [3.0]	1.29 [32.8]	17.0 [8]	265 [120]	185 [84]	1060 [4.7]	740 [3.3]
2/0	0.135 [3.4]	1.48 [37.6]	22.0 [10]	340 [154]	240 [109]	1360 [6.0]	960 [4.3]
3/0	0.148 [3.8]	1.63 [41.4]	26.0 [12]	405 [184]	285 [129]	1620 [7.2]	1140 [5.1]
4/0	0.162 [4.1]	1.80 [45.7]	31.0 [14]	485 [220]	340 [154]	1940 [8.6]	1360 [6.0]
5/0	0.177 [4.5]	2.15 [54.6]	35.0 [16]	580 [263]	405 [184]	2320 [10.3]	1620 [7.2]

[A] The minimum breaking force values shall not be used as criteria for service or design purposes. (See Section 3.)

TABLE 2 Double Loop Chain (Class DL)



Trade Size	Material Size, in. [mm]	Nominal Inside Length(P) in. [mm]	Approximate Weight per 100 ft [30.5 m], lb [kg]	Working Load Limit, lb [kg]		Minimum Breaking Force, lb [kN][A]	
				Steel	Brass	Steel	Brass
5	0.062 [1.6]	0.92 [23.4]	3.6 [2]	55 [25]	40 [18]	220 [1.0]	160 [0.7]
4	0.072 [1.8]	1.00 [25.4]	4.7 [2]	70 [32]	50 [23]	280 [1.2]	200 [0.9]
3	0.080 [2.0]	1.10 [27.9]	5.9 [3]	90 [41]	65 [29]	360 [1.6]	260 [1.2]
2	0.091 [2.3]	1.33 [33.8]	7.7 [4]	115 [52]	80 [36]	460 [2.0]	320 [1.4]
1	0.105 [2.7]	1.54 [39.1]	10.0 [5]	155 [70]	110 [50]	620 [2.8]	440 [2.0]
1*L*[B]	0.105 [2.7]	2.03 [51.6]	9.0 [4]	155 [70]	110 [50]	620 [2.8]	440 [2.0]
1/0	0.120 [3.0]	1.78 [45.2]	13.0 [6]	200 [91]	140 [63]	800 [3.6]	560 [2.5]
1/0*L*[B]	0.120 [3.0]	2.24 [56.9]	12.0 [5]	200 [91]	140 [63]	800 [3.6]	560 [2.5]
2/0	0.135 [3.4]	1.82 [46.2]	17.0 [8]	255 [116]	180 [82]	1020 [4.5]	720 [3.2]
2/0*L*[B]	0.135 [3.4]	2.24 [56.9]	16.0 [7]	255 [116]	180 [82]	1020 [4.5]	720 [3.2]
3/0	0.148 [3.8]	2.17 [55.1]	20.0 [9]	305 [138]	215 [98]	1220 [5.4]	860 [3.8]
4/0	0.162 [4.1]	2.19 [55.6]	25.0 [11]	365 [166]	255 [116]	1460 [6.5]	1020 [4.5]
6/0	0.192 [4.9]	2.96 [73.8]	34.0 [15]	510 [232]	355 [161]	2040 [9.1]	1420 [6.3]
8/0	0.225 [5.7]	2.90 [73.7]	51.0 [23]	705 [320]	500 [227]	2820 [12.5]	2000 [8.9]

[A] The minimum breaking force valves shall not be used as criteria for service or design purposes. (See Section 3.)
[B] *L* signifies *long link* construction.

testing fixture shall not be considered part of the test specimen.

8.1.3 Test specimens shall conform to the minimum breaking requirements as prescribed in Tables 1-7 for their respective sizes and classes.

8.1.4 *Number of Tests*—The manufacturer shall perform at least one test per lot of chain.

9. Retests

9.1 If the original test specimen fails to conform to the minimum breaking force requirements of 6.1.4, two additional test specimens from the same lot may be tested. If both additional specimens conform to the minimum breaking force requirements, the chain will be considered acceptable.

10. Rework and Retreatment

10.1 Materials that fail to comply to the requirements for dimensions and mechanical tests may be resubmitted after being reworked.

11. Inspection

11.1 Prior to testing and inspection at the manufacturer's plant, the chain shall be free of paint or other coatings which would tend to conceal defects.

11.2 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Mill inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspections shall be made at the place of manufacture, unless otherwise agreed.

TABLE 3 Single Jack Chain (Class SJ)

Trade Size	Material Size, in. [mm]	Nominal Inside Length (P) in. [mm]	Approximate Weight per 100 ft [30.5 m], lb [kg]	Working Load Limit, lb [kg]		Minimum Breaking Force, lb [kN][A]	
				Steel	Brass	Steel	Brass
20	0.034 [0.9]	0.30 [7.6]	1.0 [1]	3 [1]	2 [1]	12 [0.1]	8 [0.1]
18	0.047 [1.2]	0.39 [9.9]	1.7 [1]	5 [2]	4 [2]	20 [0.1]	15 [0.1]
16	0.062 [1.6]	0.50 [12.7]	2.9 [1]	10 [5]	8 [4]	40 [0.2]	30 [0.1]
14	0.080 [2.0]	0.63 [16.0]	4.8 [2]	16 [7]	11 [5]	65 [0.3]	45 [0.2]
12	0.105 [2.7]	0.75 [19.1]	8.5 [4]	29 [13]	20 [9]	115 [0.5]	80 [0.4]
10	0.135 [3.4]	0.93 [23.6]	14.0 [6]	43 [20]	34 [15]	170 [0.8]	135 [0.6]
8	0.162 [4.1]	1.09 [27.7]	21.0 [10]	60 [27]	43 [20]	240 [1.1]	170 [0.8]
6	0.192 [4.9]	1.24 [31.5]	30.0 [14]	88 [40]	66 [30]	350 [1.6]	265 [1.2]

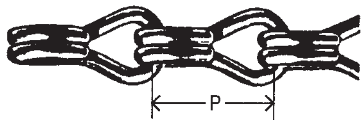
[A] The minimum breaking force values shall not be used as criteria for service or design purposes. (See Section 3.)

TABLE 4 Double Jack Chain (Class DJ)

Trade Size	Material Size, in. [mm]	Nominal Inside Length (P) in. [mm]	Approximate Weight per 100 ft [30.5 m], lb [kg]	Working Load Limit, lb [kg]		Minimum Breaking Force, lb [kN][A]	
				Steel	Brass	Steel	Brass
16	0.062 [1.6]	0.34 [8.6]	4.0 [2]	11 [5]	8 [4]	45 [0.2]	30 [0.1]

[A] The minimum breaking force values shall not be used as criteria for service or design purposes. (See Section 3.)

TABLE 5 Register Chain (Class RG)



Trade Size	Material Size, in. [mm]	Nominal Inside Length (P) in. [mm]	Approximate Weight per 100 ft [30.5 m], lb [kg]	Working Load Limit, lb [kg]		Minimum Breaking Force, lb [kN][A]	
				Steel	Brass	Steel	Brass
18	0.047 [1.2]	0.39 [9.9]	2.7 [1]	9 [4]	5 [2]	35 [0.2]	20 [0.1]
12	0.105 [2.7]	0.80 [20.3]	15.0 [7]	50 [23]	35 [16]	200 [0.9]	140 [0.6]
10	0.135 [3.4]	1.02 [25.9]	19.0 [9]	83 [38]	58 [26]	330 [1.5]	230 [1.0]

[A] The minimum breaking force values shall not be used as criteria for service or design purposes. (See Section 3.)

11.3 The purchaser may make tests to govern the acceptance or rejection of the material at his own laboratory or elsewhere. The tests shall be made at the expense of the purchaser.

12. Rejection and Rehearing

12.1 Unless otherwise specified, any rejection based on tests made in accordance with 11.3 shall be reported to the manufacturer within five working days from the date of testing by the purchaser.

12.2 Chains tested in accordance with 11.3 that represent rejected material shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

13. Certification and Reports

13.1 A manufacturer's certification that the chain conforms to Specification A 466 or A 466M of the date of issue specified shall be furnished when requested on the purchase order or contract.

14. Keywords

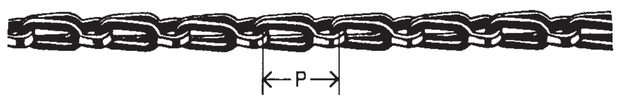
14.1 steel chain; weldless steel chain

TABLE 6 Sash Chain (Class SH)[A]

Trade Size	Material Size, in. [mm]	Nominal Inside Length (P) in. [mm]	Approximate Weight per 100 ft [30.5 m], lb [kg]	Working Load Limit, lb [kg]		Minimum Breaking Force, lb [kN][B]	
				Steel	Brass	Steel	Brass
8	0.035 [0.9]	0.56 [14.1]	3.9 [2]	75 [34]	68 [31]	300 [1.3]	270 [1.2]
25	0.042 [1.1]	0.56 [14.1]	4.9 [2]	94 [43]	80 [36]	375 [1.7]	320 [1.4]
30	0.028 [0.7]	0.57 [14.4]	4.9 [2]	81 [37]	75 [34]	325 [1.4]	300 [1.3]
35	0.035 [0.9]	0.57 [14.4]	5.7 [3]	106 [48]	100 [45]	425 [1.9]	400 [1.8]
40	0.042 [1.1]	0.57 [14.4]	7.0 [3]	131 [59]	125 [57]	525 [2.3]	500 [2.2]
45	0.050 [1.3]	0.57 [14.4]	8.7 [4]	175 [79]	163 [74]	700 [3.1]	650 [2.9]
50	0.060 [1.5]	0.65 [16.5]	12.0 [5]	225 [102]	210 [95]	900 [4.0]	840 [3.7]
60	0.062 [1.6]	0.76 [19.3]	15.0 [7]	231 [105]	225 [102]	925 [4.1]	900 [4.0]
65	0.072 [1.8]	0.88 [22.2]	19.0 [9]	319 [145]	300 [136]	1275 [5.7]	1200 [5.3]

[A] For bronze sash chain, all values in Table 6 are the same as those shown for brass sash chain.
[B] The minimum breaking force values shall not be used as criteria for service or design purposes. (See Section 3.)

TABLE 7 Plumbers' (Safety) Chain (Class SF)



Trade Size	Material Size, in. [mm]	Nominal Inside Length (P) in. [mm][A]	Approximate Weight per 100 ft [30.5 m], lb [kg]	Working Load Limit, lb [kg]		Minimum Breaking Force, lb [kN][B]	
				Steel	Brass	Steel	Brass
2/0	0.018 [0.5]	0.60 [15.3]	1.4 [1]	31 [14]	23 [10]	125 [0.5]	90 [0.4]
1/0	0.023 [0.6]	0.60 [15.3]	2.0 [1]	40 [18]	35 [16]	160 [0.7]	140 [0.6]
1	0.028 [0.7]	0.70 [17.8]	3.3 [2]	58 [26]	45 [20]	230 [1.0]	180 [0.8]

[A] Lengths specified for plumbers' chain are maximums.
[B] The minimum breaking force values shall not be used as criteria for service or design purposes. (See Section 3.)

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since A 466/A 466M–98 that may impact the use of this standard.

(1) Revised Paragraph 3.1.1.

Designation: A 467/A 467M – 01

Standard Specification for Machine and Coil Chain[1]

This standard is issued under the fixed designation A 467/A 467M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers welded carbon steel machine chain and coil chain. Although these chains are not intended for pocket wheel use, they can be used for pocket and sprocket wheel use. This chain shall never be used for overhead lifting applications.

1.2 There are two classes each of machine and coil chain:

1.2.1 *Class MS*—Machine, straight-link steel chain,

1.2.2 *Class MT*—Machine, twist-link steel chain,

1.2.3 *Class CS*—Coil, straight-link chain, and

1.2.4 *Class CT*—Coil, twist-link steel chain.

1.3 The values stated in either inch-pound units or SI units shall be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system must be used independently of the other, without combining values in any way.

2. Referenced Documents

2.1 *ASTM Standards:*

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products[2]

E 30 Test Methods for Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron[3]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *breaking force, minimum*—the minimum force in pounds or newtons at which the chain, during manufacture, has been found by representative testing to break when a constantly increasing force is applied in direct tension. This test is a manufacturer's attribute acceptance test and shall not be used as criteria for service.

3.1.2 *lot*—for the purpose of acceptance testing, a lot shall consist of 3000 ft [1000 m], or fraction thereof, of the same grade and size chain. If a continuous length of chain exceeds 3000 ft [1000 m], it shall also be considered a lot.

3.1.3 *overhead lifting*—that process of lifting that would elevate a freely suspended load such that dropping the load would present a possibility of bodily injury or property damage.

3.1.4 *proof test*—a quality control tensile test applied to chain for the purpose of verifying weld and material quality. It is the minimum force in pounds or newtons which the chain has withstood at the time it left the producer, under a test in which a constantly increasing force has been applied in direct tension to a straight length of chain. Proof test loads are a manufacturing integrity test and shall not be used as criteria for service or design purposes.

3.1.5 *working load limit (WLL)*—the maximum combined static and dynamic load in pounds or kilograms that shall be applied in direct tension to an undamaged, straight length of chain.

4. Ordering Information

4.1 It shall be the responsibility of the purchaser to specify all requirements that are necessary for material ordered under this specification. Such requirements to be considered include, but are not limited to, the following:

4.1.1 ASTM Specification A 467 or A 467M and year of issue,

4.1.2 Trade size of chain,

4.1.3 Class of chain,

4.1.4 Quantity of chain in feet or metres,

4.1.5 Length of each piece, if required,

4.1.6 Finish, if required,

4.1.7 Certification of test(s), if required, and

4.1.8 Acceptance of inspection by purchaser, if required.

5. Manufacture

5.1 *Melting Process*—The steel shall be made by the open-hearth, electric-furnace, or basic-oxygen process.

5.2 *Welding Process*—Classes MS, MT, CS, and CT shall be electric welded.

6. Chemical Requirements

6.1 *Product Analysis*—The material used shall conform to the following chemical requirements:

Elements, max, %	Classes MS, MT, CS, and CT
Carbon	0.37
Phosphorus	0.048

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.27 on Steel Chain.

Current edition approved Sept. 10, 2001. Published November 2001. Originally published as A 467–64. Last previous edition A 467/A 467M–98.

[2] *Annual Book of ASTM Standards*, Vol 01.03.

[3] Discontinued. See 1994 *Annual Book of ASTM Standards*, Vol 03.05.

***A Summary of Changes section appears at the end of this standard.**

Sulfur	0.058

6.2 The analysis may be made by the purchaser from the bars or finished chain. Samples for analysis shall represent the full cross section of the specimen.

6.3 For referee purposes, Test Methods E 30 shall be used.

7. Mechanical Properties Requirements

7.1 *Proof Test*—All chain in Classes MS and CS shall be proof tested to at least the proof load prescribed in Table 1 and Table 2 for the appropriate size and class chain. When so tested, it shall withstand these loads without loss of chain integrity. Links or chain segments not withstanding the proof test load shall be removed from the chain.

NOTE 1—Chain Classes MT and CT do not require proof testing since the twist operation is an adequate verification of link integrity.

7.2 *Breaking Force Test*:

7.2.1 The tension test specimen shall consist of a length from the lot containing at least the number of links specified in 7.3.1.

7.2.2 Fixtures for securing chain in a testing machine shall be properly designed to securely support the shoulder of the link (Note 2). The opening in the fixture shall not be more than 125 % of the stock diameter being tested. Links engaged in the testing fixture shall not be considered part of the test specimen.

NOTE 2—U-bolts of the same or larger diameter and the same or greater strength than the chain may be used to secure the chain to the jaws of the testing machine.

7.2.3 Test specimens from the finished chain shall conform to the minimum breaking force requirements as prescribed in Tables 1-4 for their respective sizes and classes.

7.3 *Elongation*:

7.3.1 The elongation test specimen shall consist of a length from the lot containing at least the number of links in Table 5.

7.3.2 A positive load not exceeding 10 % of the proof test shall be applied for determining the original gage length ($L\{0\}$).

7.3.3 The elongation shall be based on the total extension at fracture. This is expressed as a percentage of the change in length (ΔL) divided by the original gage length ($L\{0\}$). The elongation may be determined by the equation below or by autographic recorder or side scale.

$$\text{Elongation (\%)} = \left\{\Delta L \,/\, L\{0\}\right\} \times 100$$

where:

ΔL = test specimen final length at fracture – test specimen original gage length $L\{0\}$, and

$L\{0\}$ = original gage length (sum or the inside lengths of the test chain links, not counting the fixture links, or as determined in 7.3.2).

7.3.4 The elongation shall be a minimum of 10 %.

7.4 One test for breaking strength and elongation shall be made from each lot. The elongation and breaking force tests may be performed at the same time on the same test specimen.

8. Dimensional Requirements

8.1 The chain shall conform to the dimensional requirements specified in Tables 1-4 for the appropriate class and size chain. Inside widths and lengths are not to exceed ±5 % from the nominal dimensions.

8.2 *Diameter*—The diameter of the material from which the chain is manufactured shall not be smaller than the material diameter listed in Table 1 and Table 2 within a tolerance of −3 %. Oversized wire may be used for all applications.

9. Workmanship, Finish, and Appearance

9.1 The chain at the time of shipment shall be free of discontinuities that would prevent the chain from enduring the working load limit forces.

9.2 The manufacturer may apply a surface treatment or coating of his own choice for identification or corrosion resistance unless the customer specifies otherwise.

10. Retests

10.1 If the original test specimen fails to conform to the requirements of 7.2.3, two additional test specimens from the same lot may be tested. If both additional tests are satisfactory, the chain will be considered acceptable.

11. Rework and Retreatment

11.1 Chain that fails to comply to the requirements of this specification my be reworked and resubmitted.

12. Inspection

12.1 When requested on the purchase order or contract, the chain shall be free of paint or other coatings which could mask surface discontinuities at the time of inspection.

TABLE 1 Machine Chain—Straight Link
(Not to be used in overhead lifting applications)

Trade Size		Material Diameter		Working Load Limit, max		Proof Test,[A] min		Breaking Force,[A] min		Nominal Inside Length[B]		Nominal Inside Width[B]	
mm		in.	mm	lb	kg	lb	kN	lb	kN	in.	mm	in.	mm
3.0	4	0.120	3.0	215	98	430	1.91	860	3.82	0.55	14.0	0.21	5.3
3.4	3	0.135	3.4	270	122	540	2.40	1080	4.80	0.59	15.0	0.24	6.1
3.8	2	0.148	3.8	325	147	650	2.89	1300	5.78	0.61	15.5	0.26	6.6
4.1	1	0.162	4.1	390	177	780	3.47	1560	6.93	0.63	16.0	0.28	7.1
4.5	1/0	0.177	4.5	465	211	930	4.14	1860	8.27	0.74	18.8	0.31	7.9
4.9	2/0	0.192	4.9	545	247	1090	4.85	2180	9.69	0.78	19.8	0.34	8.6
5.3	3/0	0.207	5.3	635	288	1270	5.65	2540	11.29	0.85	21.6	0.36	9.1
5.5	4/0	0.218	5.5	700	318	1400	6.23	2800	12.44	0.99	25.1	0.38	9.6
6.4	5/0	0.250	6.4	925	420	1850	8.23	3700	16.44	1.07	27.2	0.44	11.2

[A] The Proof Test and Minimum Breaking Force *shall not* be used as criteria for service or design purposes. See Section 3.
[B] Actual inside lengths and widths should not vary more than ± 5 % from nominal dimensions.

TABLE 2 Coil Chain—Straight Link
(Not to be used in overhead lifting applications)

Trade Size		Material Diameter		Working Load Limit, max		Proof Test,^{A} min		Breaking Force,^{A} min		Nominal Inside Length^B		Nominal Inside Width^B	
mm		in.	mm	lb	kg	lb	kN	lb	kN	in.	mm	in.	mm
3.0	4	0.120	3.0	205	93	410	1.82	820	3.64	1.11	28.1	0.21	5.32
3.4	3	0.135	3.4	255	116	510	2.27	1020	4.53	1.17	29.6	0.24	6.09
3.8	2	0.148	3.8	310	141	620	2.76	1240	5.51	1.18	29.9	0.26	6.59
4.1	1	0.162	4.1	370	168	740	3.29	1480	6.58	1.25	31.7	0.28	7.10
4.5	1/0	0.177	4.5	440	200	880	3.91	1760	7.82	1.25	31.7	0.31	7.86
4.9	2/0	0.192	4.9	520	236	1040	4.63	2080	9.24	1.26	31.9	0.34	8.62
5.3	3/0	0.207	5.3	605	274	1210	5.38	2420	10.76	1.30	32.9	0.36	9.13
5.5	4/0	0.218	5.5	670	304	1340	5.96	2680	11.91	1.39	35.2	0.38	9.64
6.4	5/0	0.250	6.4	880	399	1760	7.83	3520	15.64	1.52	38.5	0.44	11.20

^{A} The Proof Test and Minimum Breaking Force *shall not* be used as criteria for service or design purposes. See Section 3.
^{B} Actual inside lengths and widths should not vary more than ± 5 % from nominal dimensions.

TABLE 3 Machine Chain—Twist Link
(Not to be used in overhead lifting applications)

Trade Size		Material Diameter		Working Load Limit, max		Breaking Force,^{A} min		Nominal Inside Length^B		Nominal Inside Width^B	
mm		in.	mm	lb	kg	lb	kN	in.	mm	in.	mm
3.0	4	0.120	3.0	205	93	820	3.64	0.52	13.1	0.17	4.3
3.4	3	0.135	3.4	255	116	1020	4.53	0.56	14.2	0.20	5.1
3.8	2	0.148	3.8	310	141	1240	5.51	0.58	14.7	0.21	5.3
4.1	1	0.162	4.1	370	168	1480	6.58	0.59	15.0	0.24	6.1
4.5	1/0	0.177	4.5	440	200	1760	7.82	0.68	17.2	0.26	6.6
4.9	2/0	0.192	4.9	520	236	2080	9.24	0.73	18.5	0.28	7.1
5.3	3/0	0.207	5.3	605	274	2420	10.76	0.80	20.3	0.31	7.9
5.5	4/0	0.218	5.5	670	304	2680	11.91	0.89	22.5	0.32	8.1
6.4	5/0	0.250	6.4	880	400	3520	15.64	1.00	25.3	0.37	9.4

^{A} The Minimum Breaking Force values *shall not* be used as criteria for service or design purposes. See Section 3.
^{B} Actual inside lengths and widths should not vary more than ± 5 % from nominal dimensions.

TABLE 4 Coil Chain—Twist Link
(Not to be used in overhead lifting applications)

Trade Size		Material Diameter		Working Load Limit, max		Breaking Force,^{A} min		Nominal Inside Length^B		Nominal Inside Width^B	
mm		in.	mm	lb	kg	lb	kN	in.	mm	in.	mm
3.0	4	0.120	3.0	195	88	780	3.47	1.09	27.6	0.18	4.56
3.4	3	0.135	3.4	240	109	970	4.31	1.14	28.9	0.21	5.32
3.8	2	0.148	3.8	295	134	1180	5.25	1.15	29.1	0.22	5.58
4.1	1	0.162	4.1	350	159	1405	6.24	1.22	30.9	0.25	6.34
4.5	1/0	0.177	4.5	415	188	1670	7.43	1.22	30.9	0.27	6.85
4.9	2/0	0.192	4.9	495	225	1975	8.78	1.24	31.4	0.29	7.36
5.3	3/0	0.207	5.3	575	261	2300	10.23	1.26	31.9	0.32	8.12
5.5	4/0	0.218	5.5	635	288	2545	11.32	1.34	34.0	0.33	8.32
6.4	5/0	0.250	6.4	835	379	3345	14.86	1.47	37.3	0.38	9.65

^{A} The Minimum Breaking Force values *shall not* be used as criteria for service or design purposes. See Section 3.
^{B} Actual inside lengths and widths should not vary more than ± 5 % from nominal dimensions.

TABLE 5 Mechanical Test Sample Length Requirements

Size of Chain	Minimum Number of Links in Test Specimen
2/0 and smaller	9
3/0 and larger	7

12.2 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to verify that the material is being furnished in accordance with this specification. Inspection by the purchaser shall not unnecessarily interfere with the manufacturer's operations. All tests and inspection shall be made at the place of manufacture, unless otherwise agreed upon between the manufacturer and the purchaser.

12.3 The purchaser may make the tests to govern acceptance or rejection of the material at their own laboratory or elsewhere. Tests and acceptance criteria shall conform to the requirements contained in this specification unless otherwise stated in the purchase order or contract. Tests at the purchaser's laboratory or elsewhere shall be made at the expense of the purchaser.

13. Rejection and Rehearing

13.1 Materials that fail to conform to the requirements of this specification may be rejected. Rejection shall be promptly reported, in writing, to the producer or supplier. In case of dissatisfaction with the results of the test, the producer or supplier may make claim for a rehearing.

13.2 In the case of dissatisfaction with the results of any test in 12.3, the manufacturer may make claim for a rehearing.

14. Certification

14.1 A manufacturer's certification that the chain conforms to ASTM Specification A 467 or A 467M of the year of issue specified shall be furnished when requested on the purchase order or contract.

14.2 When requested on the purchase order or contract, the manufacturer shall furnish a certificate of proof test to the producer or his representative.

15. Product Marking

15.1 The chain may be marked at the discretion of the manufacturer.

15.2 Chain shall not be marked with indented characters.

16. Keywords

16.1 steel chain

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since A 467/A 467M–98 that may impact the use of this standard.

(1) Revised Paragraphs 3.1.1, 7.2, 7.3, and 7.4.
(2) Deleted Figs. 1 and 2.

Designation: A 469 – 94a (Reapproved 1999)

Standard Specification for Vacuum-Treated Steel Forgings for Generator Rotors[1]

This standard is issued under the fixed designation A 469; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers vacuum-treated basic electric steel forgings for generator rotors.

1.2 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings[2]

A 341 Test Method for Direct-Current Magnetic Properties of Materials Using D-C Permeameters and the Ballistic Test Methods[3]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[4]

A 418 Test Method for Ultrasonic Examination of Turbine and Generator Steel Rotor Forgings[2]

A 773 Test Method for D-C Magnetic Properties of Materials Using Ring and Permeameter Procedures with D-C Electronic Hysteresigraphs[3]

A 788 Specification for Steel Forgings, General Requirements[2]

3. Ordering Information and General Requirements

3.1 In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order, a dimensioned drawing showing the mechanical test specimen locations, and details of magnetic permeability tests, if required.

3.2 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, production analysis variations, and additional supplementary requirements.

3.3 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

4. Materials and Manufacture

4.1 The vacuum degassing requirements of Specification A 788 are mandatory. In addition to these requirements, hydrogen testing per Supplementary Requirement S4 is mandatory.

4.1.1 When the ladle degassing process is used, the evacuation system shall be capable of reducing the system vacuum pressure to a low level (usually less then 1000 µm). The molten metal shall be adequately stirred for a sufficient length of time to maximize exposure to the evacuated atmosphere. When this process is used, hydrogen testing per Supplementary Requirement S4 is mandatory.

4.1.2 Other methods of degassing may be used if the supplier can demonstrate their adequacy to the satisfaction of the purchaser. When other processes are used, hydrogen testing per Supplementary Requirement S4 is mandatory.

4.2 *Heat Treatment*:

4.2.1 If possible, forgings should be heat treated in the vertical position. Supplementary Requirement S3 makes this mandatory, if activated in the ordering information.

4.2.2 The heat treatment for mechanical properties shall consist of quenching and tempering, but normalizing and tempering is permissible with prior purchaser approval. Also, with prior purchaser approval, the post rough machining stress relief in 4.2.3 may be omitted when double tempering is used, instead of a single temper, to complete this heat treatment cycle.

4.2.3 After heat treatment and the subsequent rough machining, the forging shall be stress relieved at a minimum temperature of 1050°F (566°C), unless otherwise specified by the purchaser.

4.3 *Machining*:

4.3.1 *Boring*—The manufacturer may bore the forging at any time prior to stress-relief anneal. (See Supplementary Requirement S1).

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys, and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 03.04.

[4] *Annual Book of ASTM Standards*, Vol 01.03.

5. Chemical Composition

5.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 shall comply with Table 1.

5.2 *Product Analysis*—The manufacturer shall use the product analysis provision of Specification A 788 to obtain a product analysis from a forging representing each heat or multiple heat.

6. Magnetic Properties

6.1 When specified in the ordering information, a permeability test shall be performed in accordance with the latest issue of Test Method A 341 or Test Method A 773.

7. Mechanical Properties

7.1 *Tension Test*:

7.1.1 The steel shall conform to the requirements of Table 2.

7.1.2 The number of locations of tension test specimens shall be as specified on the forging drawings furnished by the purchaser.

7.1.3 Tests for acceptance shall be made after heat treatment of the forging for mechanical properties. The purchaser may require check tests after completion of all heating cycles including stress relieving in accordance with 4.2.3.

7.1.4 Testing shall be performed in accordance with the latest issue of Test Methods and Definitions A 370. Tension specimens shall be the standard 0.5 in. (13.7 mm) round by 2-in. (50.8-mm) gage length, as shown in Test Methods and Definitions A 370.

7.1.5 The yield strength prescribed in Table 2 shall be determined by the offset method in Test Methods and Definitions A 370.

7.2 *Impact Test*:

7.2.1 The material shall conform to the requirements for notch toughness (both transition temperature and room temperature impact value) prescribed in Table 2.

7.2.2 Charpy V-notch specimens from surface radial test locations shall be oriented with the root of the notch perpendicular to a radial line of the forging and parallel to the axis of the forging. The notch shall be located as far below the heat treated surface of the forging as possible without exceeding the dimensions specified for the test material. The notch-toughness specimens shall conform to the Charpy V-notch specimen configuration, as shown in the latest issue of Test Methods and Definitions A 370.

8. Nondestructive Test Requirements

8.1 *General Requirements*:

8.1.1 The forgings shall be free of cracks, seams, laps, shrinkage, and other injurious imperfections.

8.1.2 The purchaser may request such tests and inspection methods including ultrasonic, magnetic particle, or etch tests, as are necessary to ensure compliance with this requirement.

8.2 *Ultrasonic Inspection*:

8.2.1 An ultrasonic inspection shall be made at the forging manufacturer's plant on the machined forgings. In making the ultrasonic inspection, reference shall be made to the latest issue of Test Method A 418.

8.2.2 Forgings having recordable ultrasonic indications shall be referred to the purchaser and evaluated on the basis of nature, frequency, and locations of indications both traveling and stationary. If the ultrasonic indications are considered objectionable, it shall be determined by conventional or mutually acceptable inspection procedures whether the forging will be rejected.

8.2.3 Forgings shall be ultrasonically tested prior to removal of the mid-body radial tension coupons.

8.3 *Internal Inspection*—Boring, when specified for periscopic inspection, shall be as shown on the drawings furnished by the purchaser. The drawings shall specify the nominal dimensions of the hole. Magnetic particle examination of the bore surface shall be performed in accordance with the latest issue of Test Method A 275/A 275M. In cases where objectionable conditions are revealed, the manufacturer shall advise the purchaser and any further action shall be taken only after mutual agreement.

9. Retreatment

9.1 If the results of the mechanical tests of any forging do not conform to the requirements specified, the manufacturer may retreat the forging one or more times, but not more than three additional times without approval of the purchaser, and retests shall be made in accordance with 7.1.2.

TABLE 1 Chemical Requirements

Element	Composition, %					
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6, 7, 8
Carbon, max	0.45	0.25	0.27	0.27	0.31	0.28
Manganese, max	0.90	0.60	0.60	0.70	0.70	0.60
Phosphorus, max	0.015	0.015	0.015	0.015	0.015	0.015
Sulfur, max	0.015	0.015	0.015	0.015	0.015	0.015
Silicon[A]	0.15 to 0.35	0.15 to 0.30	0.15 to 0.30	0.15 to 0.30	0.15 to 0.30	0.15 to 0.30
Nickel	. . .	2.50 min	2.50 min	3.00 min	3.00 min	3.25 to 4.00
Chromium	. . .	0.50 max	0.50 max	0.50 max	0.50 max	1.25 to 2.00
Molybdenum	. . .	0.20 to 0.50	0.20 to 0.50	0.20 to 0.60	0.20 to 0.70	0.30 to 0.60
Vanadium	0.03 to 0.12[B]	0.03 min	0.03 min	0.03 min	0.05 to 0.15	0.05 to 0.15
Antimony[C]	. . .	. . .	. . .	. . .	. . .	. . .

[A] Optional: Classes 2 to 8 steel may be vacuum deoxidized, silicon 0.10 max.
[B] Vanadium addition optional for Class 1.
[C] Information on Classes 6, 7, and 8.

TABLE 2 Tensile and Notch Toughness Requirements

		Class							
		1	2	3	4	5	6	7	8
Tensile strength, min, ksi		75	80	90	100	110	100	110	120
	MPa	515	550	620	690	760	690	760	825
Yield strength,[A] min, ksi		35	55	70	80	90	80	90	100
	MPa	240	380	485	550	620	550	620	690
Elongation in 2 in. or 50 mm, min, %		20	20	20	17	15	18	17	16
Reduction of area, min, %		30	50	50	45	40	55	50	45
$FATT_{50}$, max, F		175	100	100	120	175	0	20	40
$FATT_{50}$, max, C		80	38	38	49	80	−18	−7	4
Room temperature impact strength, min, ft·lbf(J)		10 (13)	30 (41)	30 (41)	25 (34)	15 (20)	60 (81)	50 (68)	40 (54)

[A] Yield strength at 0.02 % offset. Yield strength may also be specified at 0.2 % offset in which case 5000 psi (35 MPa) shall be added to these values.

9.2 If boring is specified under Supplementary Requirements S1, the remaining portions of the bore core shall be replaced in the bore during retreatment.

10. Certification and Reports

10.1 In addition to the requirements of Specification A 788, the product analysis results shall be reported.

11. Packaging and Package Marking

11.1 In addition to the marking requirements of Specification A 788, axial bores, if any, shall be protected and suitably plugged for shipment or storage.

12. Keywords

12.1 generator rotor materials; steel forgings; vacuum-treated steel

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser on the order.

S1. Bore Core Tests

S1.1 The purchaser may require physical tests from the bar cored from the longitudinal bore of the forging. These core tests will be for information only.

S1.2 Specimens for bore core tests shall be cored from the forging after heat treatment for mechanical properties.

S2. Method of Forging

S2.1 The purchaser may specify that hot working be performed on a press.

S3. Vertical Heat Treatment

S3.1 Heat treatment for mechanical properties shall be performed with the forging in the vertical position.

S4. Hydrogen Determination

S4.1 A hydrogen determination shall be made. The acceptable hydrogen limit as well as the stage in processing when sampling, the sample preparation procedure and the method of analysis shall be as agreed upon by manufacturer and purchaser.

S5. Magnetic Particle Examination

S5.1 A magnetic particle examination of the complete exterior and bore surfaces of the machined forging shall be made at the forging manufacturer's plant. The examination shall be performed in accordance with the latest issue of Test Method A 275/A 275M.

S5.2 Forgings with either cracks or linear indications of any length are subject to rejection unless they can be removed to the purchaser's satisfaction.

Designation: A 470 – 03

Standard Specification for Vacuum-Treated Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts[1]

This standard is issued under the fixed designation A 470; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers vacuum-treated carbon and alloy steel forgings for turbine rotors and shafts.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings[2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

A 418 Test Method for Ultrasonic Examination of Turbine and Generator Steel Rotor Forgings[2]

A 472 Test Method for Heat Stability of Steam Turbine Shafts and Rotor Forgings[2]

A 751 Test Methods, Practices and Terminology for Chemical Analysis of Steel Products[3]

A 788 Specification for Steel Forgings, General Requirements[2]

E 139 Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials[4]

3. Ordering Information and General Requirements

3.1 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing methods and procedures, marking, certification, production analysis variations, and additional supplementary requirements.

3.2 In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order, the grade and class of steel, alternative maximum for silicon content (see Table 1), the choice of yield strength offset (0.2 or 0.02 %) and any tests, supplementary requirements, and purchase options desired.

3.3 *Forging Drawing*—Each forging shall be manufactured in accordance with a drawing furnished by the purchaser showing the dimensions of the forging and bore hole, if any, and the location of mechanical test specimens.

3.4 *Supplementary Requirements*—Supplementary requirements are provided. These requirements shall apply only when specified in the purchase order.

3.5 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

4. Manufacture

4.1 *Melting Process*:

4.1.1 The steel shall be made by the basic electric-furnace process.

4.1.2 Provisions for subsequent secondary melting of the steel by the consumable electrode-electroslag or vacuum-arc remelting processes are included in Supplementary Requirement S7.

4.2 *Vacuum Treatment*—The vacuum degassing requirements of Specification A 788 are mandatory.

4.3 *Discard*—Sufficient discard shall be taken from each ingot to secure freedom from pipe and harmful segregation in the finished forging.

4.4 *Forging Process*—The forging shall receive its hot mechanical work under a press of ample power to adequately work the metal throughout the maximum section of the forging. It is important to maintain the axial center of the forging in common with the axial center of the ingot.

4.5 *Heat Treatment*:

4.5.1 After forging and before reheating for heat treatment for mechanical properties, the forging shall be allowed to cool in a manner designed to prevent injury and accomplish transformation.

4.5.2 The heat treatment for mechanical properties shall consist of double-normalizing and tempering for Grades A, B, D, and E and normalizing, quenching, and tempering for Grade C. In normalizing treatments, the forging may be cooled in still

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] *Annual Book of ASTM Standards,* Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards,* Vol 03.01.

***A Summary of Changes section appears at the end of this standard.**

TABLE 1 Chemical Requirements[A]

	Grade A	Grade B	Grade C	Grade D	Grade E
	Ni-Mo-V	Ni-Mo-V	Ni-Cr-Mo-V	Cr-Mo-V	Ni-Mo-V
Carbon	0.22–0.30	0.22–0.30	0.28	0.25–0.35	0.30
Manganese	0.20–0.60	0.20–0.60	0.20–0.60	1.00	0.70
Phosphorus	0.012	0.012	0.012	0.012	0.025
Sulfur	0.012	0.012	0.015	0.015	0.025
Silicon	[B]	[B]	[B,C]	[B]	[B]
Nickel	3.20–3.70	3.20–3.70	3.25–4.00	0.75	2.00 min.
Chromium	0.75	0.75	1.25–2.00	1.05–1.50	0.75
Molybdenum[D]	0.40–0.60	0.40–0.60	0.25–0.60	1.00–1.50	0.25 min
Vanadium	0.04–0.12	0.04–0.12	0.05–0.15	0.20–0.30	0.03–0.12
Antimony	[E]	[E]	[E]	[E]	[E]
Aluminum[F]	0.015	0.015	0.015	0.015	0.015
Equivalent Specification A 293 Grade Designation (replaced by Specification A 470)	...	...	...	Classes 2 and 3[G]	...

[A] Maximum or range, unless otherwise indicated.
[B] 0.10 % max, unless an alternative value, not in excess of 0.30 %, is specified in the purchase order.
[C] 0.15 to 0.30 % silicon is permitted for material that is subsequently VAR Processed.
[D] Supplementary Requirement, see S1.
[E] To be reported for information only on all Grades.
[F] Total of soluble and insoluble.
[G] Phosphorus of 0.035 max and sulfur of 0.035 max were specified for Specification A 293.

air or in an air blast at the manufacturer's option. Faster cooling rates for Grades A, B, D, and E may be used if authorized by the purchaser. These rates are obtained by liquid quenching, or by the addition of water sprays of fog to the air blast.

4.5.2.1 The first normalizing treatment shall be from well above the transformation temperature range. At the manufacturer's option, this operation may be performed as a part of the preliminary treatment of the forging before preliminary machining (see 4.6.1).

4.5.2.2 The second normalizing or quenching treatment shall be from above the transformation range but below the first normalizing temperature described in 4.5.2.1. This treatment shall be performed after preliminary machining (see 4.6.1).

4.5.2.3 The final tempering temperature for Grades A, B, C, and E shall be not less than 1075°F (580°C) and for Grade D not less than 1200°F (650°C). With prior purchaser approval, a second tempering operation shall be performed prior to the operations described in 4.6.2 and 4.6.3 to complete the heat treatment cycle. This second temper will be in place of the stress relief specified in 4.5.2.4 and 4.5.2.5 and the temperatures applied to the second temper will meet the temperature limits in 4.5.2.4. However, with the prior approval of the purchaser, the second tempering temperature may approach, equal or slightly exceed the first tempering temperature as a means of adjusting final strength or toughness. The required tests for mechanical properties shall be made after the second tempering operation. Mechanical property tests after the first temper are optional with the manufacturer.

4.5.2.4 After heat treatment and subsequent rough machining and axial boring (see 4.6.2 and 4.6.3), the forging shall be stress-relieved at a temperature not more than 100°F (55°C) below the final tempering temperature, but not less than 1025°F (550°C).

4.5.2.5 With the prior approval of the purchaser, the stress-relief temperature may approach, equal, or slightly exceed the final tempering temperature as a means of adjusting final strength or toughness. If the stress-relief temperature is within 25°F (14°C) of the final tempering temperature, or higher, additional tension tests must be obtained (6.1.3).

4.6 *Machining*:

4.6.1 *Preliminary Rough Machining*—All exterior surfaces of the forging shall be machined prior to heat treatment for mechanical properties.

4.6.2 *Second Rough Machining*—After heat treatment for mechanical properties, all surfaces of the forging shall be rough machined prior to stress relief and the stability test.

4.6.3 *Axial Bore*:

4.6.3.1 Forgings shall be bored to permissible bore size and tolerance when required by the purchaser's drawing.

4.6.3.2 Forgings may be bored to limits agreed to by the purchaser or indicated on the purchaser's drawing, to remove objectionable center conditions revealed by ultrasonic examination.

4.6.3.3 Unless otherwise specified by the purchaser, the manufacturer may bore the forging at any time prior to stress relief (see Supplementary Requirement S2).

4.6.4 *Machining to Purchaser's Requirements for Shipment*—The forging as shipped shall conform to the finish and dimension requirements specified on the purchaser's drawing or order.

5. Chemical Composition

5.1 The steel shall conform to the requirements for chemical composition prescribed in Table 1.

5.2 *Chemical Analysis*:

5.2.1 *Heat Analysis*—An analysis of each heat of steel shall be made by the manufacturer to determine the percentages of the elements specified in Table 1. This analysis shall be made from a test specimen preferably taken during the pouring of the heat. For forgings made from more than one heat, both individual heat analyses (when appropriate for the process) and a weighted average analysis shall be reported. In this case, the weighted average analysis of the component heats shall conform to Table 1.

5.2.1.1 If the test specimen taken for the heat analysis is lost or declared inadequate for chemical determinations, the manufacturer may take alternative specimens from appropriate locations near the surface of the ingot or forging as necessary to establish the analysis of the heat in question. Location and depth of the alternative specimens shall be reported to the purchaser along with the chemical analysis.

5.2.2 *Product Analysis*—The manufacturer shall make a product analysis from each forging. The sample location and product analysis tolerances shall conform to Specification A 788.

5.3 *Referee Analysis*—Test Methods, Practices and Terminology A 751 shall be used for referee purposes.

6. Mechanical Properties

6.1 *Tension Test*:

6.1.1 The steel shall conform to the tensile requirements of Table 2.

6.1.2 The number and location of tension test specimens shall be as specified on the drawing furnished by the purchaser.

6.1.3 Final acceptance tests shall be made after heat treatment of the forging for mechanical properties prior to stress relief, unless the stress relief temperature is within 25°F (14°C) of the tempering temperature, or higher, in which case check tests shall be made after the stress relief treatment and reported to the purchaser. The purchaser may require check tests after completion of all heating cycles, including stress relief and the heat stability tests.

6.1.4 Testing shall be performed in accordance with the latest revision of Test Methods and Definitions A 370. Tension specimens shall be the standard 0.5-in. diameter by 2-in. gage length (or 12.5 by 50.0-mm type) as shown in Test Methods and Definitions A 370.

6.1.5 The yield strength prescribed in Table 2 shall be determined by the offset method of Test Methods and Definitions A 370.

6.2 *Impact Test*:

6.2.1 The steel shall conform to the requirements for notch toughness (both transition temperature and room temperature impact values) prescribed in Table 2.

6.2.2 The impact specimens shall be machined from radial bars taken from the main body of the forging, as shown in the purchaser's drawing. The specimens shall be Charpy V-notch, as shown in Test Methods and Definitions A 370. The notch direction of the Charpy specimens shall be tangential.

6.2.3 The impact tests shall be performed in accordance with the section on Charpy impact testing of Test Methods and Definitions A 370.

6.3 The properties at the axial bore region may not necessarily be the same as those determined at the surface radial or axial prolongation regions. Slight variations in chemical homogeneity, different cooling rates, presence of non-metallics, and orientation of the test samples are some of the factors that can contribute to the difference. If axial bore properties are required, they can be obtained through Supplementary Requirement S2.

7. Dimensions, Tolerances, and Finish

7.1 The steel shall conform to the tensile requirements of Table 2.

7.2 The finish on each forging shall conform to the finish specified on the purchaser's drawing or order.

8. Nondestructive Tests

8.1 *General Requirements*:

8.1.1 The forgings shall be free of cracks, seams, laps, shrinkage, and similar imperfections.

8.1.2 The purchaser may request ultrasonic, magnetic particle, dye penetrant, etch, or other accepted nondestructive

TABLE 2 Tensile and Notch Toughness Requirements

	Grade A	Grade B		Grade C			Grade D	Grade E
	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9
Tensile strength, min, ksi (MPa)	80 (550)	90 (620)	105 (725)	90 to 110 (620–760)	105 to 125 (725–860)	120 to 135 (825–930)	105 to 125 (725–860)	95 (655)
Yield strength, min, ksi (MPa)	55 (380)	70 (483)	85 (585)	70 (483)	85 (585)	95 (655)	85 (585)	70 (485)
0.2 % offset	60 (415)	75 (520)	90 (620)	75 (520)	90 (620)	100 (690)	90 (620)	75 (520)
0.02 % offset	55 (380)	70 (485)	85 (585)	70 (485)	85 (585)	95 (655)	85 (585)	70 (485)
Elongation in 2 in. or 50 mm, min, %:								
Longitudinal prolongation	22	20	17	20	18	18	17	20
Radial body	20	17	16	18	17	17	14	15
Reduction of area, min, %:								
Longitudinal prolongation	50	48	45	52	52	52	43	40
Radial body	50	45	40	50	50	50	38	35
Transition temperature $FATT_{50}$max, °F(°C)	100 (38)	110 (43)	140 (60)	10 (−12)	20 (−7)	30 (−1)	250 (121)	175 (80)
Room temperature impact, min, ft·lbf (J)	28 (38.0)	25 (34.0)	20 (27.2)	50 (68.0)	45 (61.2)	40 (54.4)	6 (8.2)	12 (16)

examination necessary to evaluate imperfections and ensure compliance with this requirement.

8.2 *Ultrasonic Examination*:

8.2.1 An ultrasonic examination shall be made on the machined forging at the manufacturer's plant. This examination shall be made in accordance with Test Method A 418 to demonstrate freedom from rejectable internal indications.

8.2.2 The ultrasonic examination shall be made from all available surfaces prior to removal of test specimens that would interfere with complete testing of the forging.

8.2.3 Forgings with recordable ultrasonic indications shall be referred to the purchaser for evaluation based on the nature, frequency, and location of indications, both stationary and traveling. If the ultrasonic indications are considered objectionable, it shall be determined by conventional or mutually acceptable examination procedures whether the forging will be rejected.

8.3 *Internal Examination*:

8.3.1 Axial bore, when specified for internal visual examination, shall be in accordance with the drawing furnished by the purchaser. The drawing shall specify the nominal dimensions of the bore.

8.3.2 If objectionable conditions are encountered during the internal examination of the bore, the manufacturer shall notify the purchaser of the location and nature of the condition. Further action shall be taken only after mutual agreement between the manufacturer and purchaser.

9. Stability Test

9.1 Each Grade D and E forging shall be subjected to a heat stability test at the manufacturer's plant in accordance with the latest issue of Test Method A 472 to determine the stability or freedom from tendency to distort during high-temperature operating conditions.

9.2 The stability test shall be conducted after the forging has been stress relieved in accordance with 4.5.2.4.

NOTE 1—If agreed upon between the manufacturer and the purchaser, the stress relief may be performed as part of the stability test.

9.3 *Stability Test Requirements*:

9.3.1 The purchaser's drawing shall indicate the minimum portion of the forging to be included within the heating chamber during the stability test.

9.3.2 The purchaser's drawing or order shall indicate the minimum stability test temperature.

10. Retests

10.1 If the results of mechanical tests do not conform to the requirements specified, retests are permitted as outlined in Test Methods and Definitions A 370 or as permitted in the following paragraphs:

10.1.1 If any test specimen fails to meet the requirements specified for mechanical reasons such as test equipment malfunction or improper specimen preparation, it may be discarded and a specimen from an adjacent location in the forging may be substituted.

10.1.2 If any test specimen fails to meet the requirements specified, two adjacent specimens may be selected for retest without reheat treatment, provided the failure was not caused by rupture, flakes, or cracks in the steel. Both of these specimens must meet the requirements of the specification.

11. Retreatment

11.1 If the results of the mechanical tests of any forging do not conform to the requirements specified, the manufacturer may retreat the forging one or more times, but not more than three additional times, without the approval of the purchaser.

11.2 If bore core properties are specified under Supplementary Requirement S2 and retemper is necessary after boring, the remaining portions of the bore core shall be replaced in the bore during retemper.

11.3 If complete retreatment, including normalizing or quenching, is necessary after boring, the feasibility of retreating portions of the bore core in the bore of the forging shall be discussed between manufacturer and purchaser and a procedure agreed upon before retreatment.

12. Inspection

12.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities to satisfy him that the material is being produced and furnished in accordance with this specification. Mill examination by the purchaser shall not interfere unnecessarily with the manufacturer's operation. All tests and examination shall be made at the place of manufacture prior to shipment, unless otherwise specified or agreed upon.

13. Rejection and Rehearing

13.1 Any forging showing nonconforming conditions prior to, or subsequent to, acceptance at the manufacturer's plant shall be subject to rejection.

13.2 Any rejection based on tests in accordance with 5.2.2 shall be reported to the manufacturer within 60 days.

13.3 Samples tested in accordance with 5.2.2 that represent rejected material shall be preserved for 60 days from the date of the rejection report. If the manufacturer is dissatisfied with the results of these tests, he may make claim for rehearing within that time.

14. Certification and Reports

14.1 The manufacturer shall furnish to the purchaser the number of properly certified test reports specified on the purchase order.

14.2 The following items shall be reported:

14.2.1 Purchaser order number,

14.2.2 Forging identification number,

14.2.3 Specification number, grade, and class,

14.2.4 Heat number (or numbers), heat chemical analysis (or analyses), and product, chemical analysis,

14.2.5 Results of all acceptance tests for mechanical properties and notch toughness,

14.2.6 Results of all nondestructive examinations plus sketches indicating the location and orientation of all recordable indications,

14.2.7 Final heat treatment cycle including austenitizing and tempering temperatures, holding times, and cooling methods, and

14.2.8 Results of any supplementary requirements that have been specified.

15. Packaging and Package Marking and Loading

15.1 Each forging shall be legibly stamped by the manufacturer with the manufacturer's name or symbol, the manufacturer's identification number, the specification number A 470, the appropriate grade and class number, and identification numbers specified by the purchaser on his drawings or order.

15.2 The location of such identification marks may be specified by the purchaser on his drawings or order.

15.3 Test specimens shall be identified with numbers corresponding to the forging identification numbers plus numbers corresponding to test location and type if specified on the purchaser's drawings or order.

15.4 The axial bores of bored forgings shall be protected and suitably plugged to prevent damage or corrosion during shipment or storage.

16. Keywords

16.1 steel forgings; turbine rotors; turbine shafts; vacuum-treated steel

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, and order. Details of these supplementary requirements shall be agreed upon by the manufacturer and purchaser.

S1. Molybdenum Content

S1.1 If desirable because of operating temperatures, the purchaser may specify a molybdenum content of 0.40 % min for Grades A, B, C, and E.

S2. Axial Bore Core Properties

S2.1 The purchaser may require the removal of an axial bore core from the forging after heat treatment for mechanical properties and subsequent approval of the usual surface mechanical property tests.

S2.1.1 The diameter of the axial bore core shall be subject to agreement between manufacturer and purchaser.

S2.1.2 The purchaser may require mechanical tests on tension or impact specimens from locations in the axial bore core is specified on the forging drawings furnished by the purchaser.

S2.1.3 The acceptable level of mechanical properties obtained from specimens from the axial bore core shall be as agreed upon between manufacturer and purchaser.

S3. Stress-Rupture Properties

S3.1 The purchaser may require that stress-rupture tests be made, by the manufacturer or by himself, on radial specimens taken from locations shown on the forging drawing.

S3.1.1 Stress-rupture tests shall be performed in accordance with Practice E 139.

S3.1.2 The size and shape of the test specimen and stress-rupture test requirements shall be mutually agreed upon between manufacturer and purchaser.

S4. Special Requirements to Minimize Temper Embrittlement

S4.1 Forgings to Grade C for special application may be specified with restricted chemical composition and the additional notch toughness requirements noted below.

S4.1.1 *Heat Analysis:*

Element	Composition, %
Carbon	0.28 max
Manganese	0.40 max
Phosphorus	0.012 max
Sulfur	0.015 max
Silicon	0.10 max
Nickel	3.25–4.00
Chromium	1.25–2.00
Molybdenum	0.25–0.45
Vanadium	0.05–0.15
Antimony	[A]
Tin	[A]

[A] To be reported for information.

S4.1.2 A sufficient number of impact test specimens to determine the $FATT_{50}$ in the step-cooled condition shall be taken from locations specified in 6.2.2. Specimens, before testing, shall be step-cooled as follows:

1100°F (594°C), hold 1 h, furnace cool to
1000°F (538°C), hold 15 h, furnace cool to
975°F (524°C), hold 24 h, furnace cool to
925°F (496°C), hold 48 h, furnace cool to
875°F (468°C), hold 72 h, furnace cool to
600°F (316°C), or lower, air cool to room temperature.

S5. Vertical Heat Treatment

S5.1 Heat treatment for mechanical properties shall be performed with the forging in the vertical position.

S6. Vacuum Carbon Deoxidation of Grade D Material

S6.1 Grade D material shall be vacuum carbon deoxidized during processing, in which case silicon shall be 0.10 % maximum.

S7. Secondary Melting

S7.1 Steel to this specification shall be produced by a secondary consumable electrode remelting process such as electroslag remelting or vacuum-arc remelting, provided the material remelted is made by the basic electric-furnace process and receives vacuum treatment equivalent to that prescribed in 4.2 during subsequent processing.

S7.2 Material for consumable electrode-electroslag remelting shall be vacuum-treated prior to remelting. Material for consumable electrode vacuum-arc remelting may be vacuum-treated prior to remelting or air-poured and vacuum-treated during remelting, at the option of the producer.

S7.2.1 The level of objectionable dissolved gases, particularly hydrogen, in the remelted material shall be comparable to the levels achieved in vacuum-treated steels of the same grade. This should preferably be attained by appropriate controls during remelting and ingot solidification. Alternatively, this may be accomplished by subsequent thermal treatments to reduce the gas content to the desired level by diffusion.

S7.3 The heat analysis of a consumable electrode remelted ingot shall comply with the heat analysis requirements of the grade of material specified.

S7.3.1 When the ingot is produced by remelting electrodes from a common master heat, the heat analysis shall be determined by taking the average of analyses from the zone corresponding to the second and next to last electrodes remelted respectively.

S7.3.2 When the electrodes from different master heats are remelted sequentially to produce the ingot, an analysis shall be made in each zone of the remelted ingot corresponding to each electrode from each master heat represented. Each such analysis shall comply with the heat analysis requirements of the material grade specified. The zone analysis of the portion of the remelt ingot used in a forging shall be reported, and their average shall be the heat analysis of the forging.

S8. Hydrogen Determination

S8.1 A hydrogen determination shall be made. The acceptable hydrogen limit as well as the stage in processing when sampling, the sample preparation procedure and the method of analysis shall be as agreed upon between manufacturer and purchaser.

S9. Magnetic Particle Examination

S9.1 A magnetic particle examination of the complete exterior and bore surfaces of the machined forging shall be made at the forging manufacturer's plant. The examination shall be performed in accordance with the latest issue of Test Method A 275/A 275M.

S9.2 Forgings with either cracks or linear indications of any length are subject to rejection unless they can be removed to the purchaser's satisfaction.

S10. Heat Treatment After Machining of Disks or Wheels, or Both

S10.1 When agreed upon between the manufacturer and the purchaser, the heat treatment for mechanical properties shall be performed after additional machining of the material between the rotor discs or wheels, or both. This agreement should also address the following:

S10.1.1 Machined finish allowances, radii, and surface finish before and after the heat treatment for mechanical properties.

S10.1.2 Locations of tension test specimens and test direction.

S10.1.3 Locations of impact test specimens and notch direction.

S10.1.4 Impact energy and FATT requirements.

S10.1.5 Ultrasonic examination of the cylindrical forging shapes following the preliminary heat treatment.

S10.1.6 Ultrasonic examination of the disc or wheels, or both, and remaining shaft diameters after the heat treatment for mechanical properties.

S10.1.7 Magnetic particle examination after the heat treatment for mechanical properties.

S11. Heat Stability Testing

S11.1 Each forging shall be subjected to a heat stability test in accordance with Section 9, regardless of grade.

APPENDIXES

(Nonmandatory Information)

X1. HEAT STABILITY TESTING

X1.1 Heat stability testing provides assurance that the process controls utilized in the manufacture of a rotor forging have produced a thermally stable product. This test is optional for Grades A, B, and C in this specification. Customers ordering a Grade A, B, or C rotor forging, but lacking experience with rotor forgings produced by the current manufacturer, may obtain the desired assurance by invoking Supplementary Requirement S11.

X2. PREVIOUS A470 AND CORRESPONDING CURRENT DESIGNATIONS

X2.1 Table X2.1 lists previous and corresponding current designations.

TABLE X2.1 Previous and Corresponding Current Designations

Previous Class	Corresponding Current Grade and Class
Class 2	Grade A, Class 2
Class 3	Grade B, Class 3
Class 4	Grade B, Class 4
Class 5	Grade C, Class 5
Class 6	Grade C, Class 6
Class 7	Grade C, Class 7
Class 8	Grade D, Class 8
Class 9	Grade E, Class 9

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since the last issue (A 470–01) that may impact the use of this standard.

(1) Added the term "grades" for the same chemical composition and used the term "class" for different strength levels.
(2) Deleted Footnote E from Table 2 for discontinued forging.
(3) Editorially restored Nickel minimum for Grade E instead of maximum.
(4) Added Appendix X2.

Designation: A 471 – 02

An American National Standard

Standard Specification for Vacuum-Treated Alloy Steel Forgings for Turbine Rotor Disks and Wheels[1]

This standard is issued under the fixed designation A 471; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers vacuum-treated alloy steel forgings intended for use as turbine rotor disks and wheels.

1.2 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings[2]

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys, and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved September 10, 2002. Published June 2003. Originally approved in 1962. Previous edition approved in 1994 as A 471 – 94 (1999).

***A Summary of Changes section appears at the end of this standard.**

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]
A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings[2]
E 30 Test Methods for Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron[4]
E 139 Practice for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials[5]

3. Ordering Information

3.1 The purchaser shall specify in the inquiry and order the class of steel desired and test and purchase options (see 4.5.5, 5.2.2, 6.1, 6.3, 7, and 15.1).

3.2 *Forging Drawing*—Each forging shall be manufactured in accordance with a purchaser-supplied drawing showing the finished dimensions and the locations of mechanical test specimens.

3.3 Supplementary requirements are provided and shall apply only when specified in the purchaser's order.

4. Materials and Manufacture

4.1 *Melting Process*—The steel shall be made by one or more of the following processes: electric-arc, electric-induction, or consumable-electrode.

4.2 *Vacuum Degassing*:

4.2.1 The molten steel shall be vacuum treated prior to or during the pouring of the ingot, in order to remove objectionable gases, particularly hydrogen.

4.2.1.1 When the vacuum stream degassing process[6] is used, the vacuum system must be of sufficient capacity to effect a blank-off pressure low enough (usually less than 1000 µm) to break up the normal tight, rope-like stream of molten metal into a wide-angled conical stream of relatively small droplets. The capacity of the system must also be sufficiently high to reduce the initial surge pressure at the start of the pour to a low level within 2 min.

4.2.1.2 When the vacuum-lift process[6] is utilized, the molten metal shall be repeatedly drawn into the evacuated vessel to give a recirculation factor (Note 1) of at least 2.5 to ensure thorough degassing and mixing of the entire heat. The evacuation system shall be capable of reducing the pressure surges, which occur each time a new portion of steel is admitted to the vessel, to increasingly lower levels until a blank-off pressure (usually less than 1000 µm) is achieved.

NOTE 1—The recirculation factor is obtained as follows:

$$\frac{\text{tons of steel lifted per cycle} \times \text{number of cycles}}{\text{heat weight in tons}}$$

4.2.1.3 When the ladle degassing process is used, the evacuation system shall be capable of reducing the system vacuum pressure to a low level (usually less than 1000 µm). The molten metal shall be adequately stirred for a sufficient length of time to maximize exposure to the evacuated atmosphere. When this process is used, hydrogen testing per Supplemental Requirement S2 is mandatory.

4.2.1.4 Other methods of degassing may be used if the supplier can demonstrate their adequacy to the satisfaction of the purchaser. When other processes are used, hydrogen testing per the supplemental requirement S2 is mandatory.

4.3 *Discard*—Sufficient discard shall be taken from each ingot to secure freedom from pipe and undue segregation in the finished forging.

4.4 *Forging Process*—The forgings shall receive their hot mechanical work under a press, hammer, or mill of sufficient power to work the metal throughout its section. The forgings shall be upset by forming from a block having an axial length before upsetting of at least two times the thickness of the forging after upsetting.

4.4.1 The as-forged dimensions of each forging shall be planned so the metal is shaped by forging as close as is practical to the dimensions shown on the purchaser's drawing so as to keep subsequent machining to a minimum.

4.4.2 The axial center of the forging shall be maintained in common with the axial center of the ingot.

4.5 *Heat Treatment*:

4.5.1 *Cooling Prior to Heat Treatment*— After forging and before reheating for heat treatment, the forging shall be allowed to cool in a manner to prevent damage and to accomplish transformation.

4.5.2 *Preliminary Heat Treatment*—The forgings shall be given such preliminary heat treatment as is proper for the design and composition. The forgings shall be heated to a suitable temperature for a sufficient length of time for complete austenitization and shall be suitably cooled to bring about complete transformation.

4.5.3 *Heat Treatment for Mechanical Properties*—The forgings shall be reheated to a temperature above the upper critical temperature, held a sufficient length of time for complete austenitization, and liquid quenched.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.
[3] *Annual Book of ASTM Standards*, Vol 01.03.
[4] *Annual Book of ASTM Standards*, Vol 03.05.
[5] *Annual Book of ASTM Standards*, Vol 03.01.
[6] Details of the vacuum stream degassing process may be found in the *Journal of the Iron and Steel Institute*, Vol 191, January 1959; "Vacuum Pouring of Ingots for Heavy Forgings" by J. H. Stoll.

4.5.4 *Tempering Temperature*—The forgings shall be tempered to develop the specified properties. The final tempering temperature for Class 1 to 6 and 11 through 14 shall be not less than 1100°F (593°C), and for Class 10 not less than 1200°F (649°C). The forgings shall be cooled under suitable conditions from the tempering temperature.

4.5.5 *Stress Relief*—Unless otherwise specified by the purchaser, the forgings shall be stress relieved after machining (see 4.6.2) by heating slowly to a temperature within 100°F (56°C) below the final tempering temperature but in no case below 1025°F (552°C) for Classes 1 to 6 and 11 through 14 and 1150°F (621°C) for Class 10. They shall be held for a sufficient length of time and then cooled under suitable conditions. This stress-relief temperature may be omitted provided the metal removed in accordance with 4.6.2, excluding test metal, does not exceed 3⁄16 in. (4.8 mm) on any surface.

4.6 *Machining*:

4.6.1 *Preliminary Machining*—The forgings shall be preliminarily machined on all surfaces prior to heat treatment for mechanical properties (see 4.5.3).

4.6.2 *Machining to Purchaser's Requirements for Shipment* —After heat treatment for mechanical properties (see 4.5.3), the forgings shall be machined to the dimensions of the purchaser's forging drawing or instructions on his order.

5. Chemical Composition

5.1 The steel shall conform to the requirements for chemical composition prescribed in Table 1.

5.2 *Chemical Analysis*:

5.2.1 *Heat Analysis*—An analysis of each heat of steel shall be made by the manufacturer to determine the percentages of those elements specified in Table 1. This analysis shall be made from a test ingot taken during the pouring of the heat.

5.2.1.1 If the test sample taken for the ladle analysis is lost or declared inadequate for chemical determinations, the manufacturer may take alternative samples from appropriate locations near the surface of the ingot or forging as necessary to establish the analysis of the heat in question.

5.2.2 *Product Analysis*—A product analysis may be made by the purchaser on each forging. Sample for an analysis may be taken from the forging at any point from the mid-radius to the outside diameter or from a full-size prolongation, or turnings may be taken from a test specimen. The chemical composition thus determined shall not vary from the requirements specified in Table 1 more than the amounts prescribed in Table 2.

5.3 *Test Methods of Analysis*—Test Methods E 30 shall be used for referee purposes.

6. Mechanical Properties

6.1 *Tension Test*—The material shall conform to the requirement for tensile properties prescribed in Table 3 when tested in accordance with Test Methods and Definitions A 370. Tension test specimens shall be the standard round, ½ -in. (12.7-mm) diameter, 2-in. (50.8-mm) gage length as shown in Test Methods and Definitions A 370. The yield strength prescribed in Table 3 shall be determined by the 0.2 % offset method of Test Methods and Definitions A 370. The offset shall be 0.2 % unless 0.02 % is specified in the ordering information.

6.2 *Impact Test*—The material shall conform to the requirements for impact (both transition-temperature and room-temperature impact value) as prescribed in Table 3. The impact tests shall be performed in accordance with Test Methods and Definitions A 370 using standard full-size specimens.

6.3 *Hardness*—Forgings made from Classes 11 to 14 and subjected to group testing in accordance with 6.4.1 shall conform to the Brinell hardness requirements prescribed in Table 3 when tested in accordance with Test Methods and Definitions A 370.

6.4 *Location and Number of Tests*—Classes 1 through 10 tension and impact test specimen shall be identified and taken from the locations as specified by the purchaser and agreed to by the producer. One tension test and a transition-temperature determination, including room-temperature impact strength shall be considered a minimum number of tests conducted on forgings made to this specification.

TABLE 1 Chemical Requirements

	Composition, %			
	Classes 1 to 6, incl	Class 10	Classes 11 to 13, incl	Class 14
Carbon	0.28 max[A]	0.27–0.37	0.38–0.43	0.45 max
Manganese	0.70 max	0.70–1.00	0.60–1.00	0.60–1.00
Phosphorus	0.012 max	0.012 max	0.012 max	0.012 max
Sulfur	0.015 max	0.015 max	0.015 max	0.015 max
Silicon[B]	0.15–0.35	0.20 min	0.15–0.35	0.15–0.35
Nickel	2.00–4.00	0.50 max	0.50 max	1.65–3.50
Chromium	0.75–2.00	0.85–1.25	0.80–1.10	0.50–1.25
Molybdenum	0.20–0.70	1.00–1.50	0.15 min	0.20 min
Vanadium	0.05 min	0.20–0.30	0.06 max	optional
Antimony	[C]	[C]	[C]	[C]

[A] 0.35 % C max for Classes 4 and 5; 0.40 % C, max, for Class 6.
[B] When vacuum deoxidation is specified, silicon content shall be 0.10 max.
[C] To be reported for information only.

TABLE 2 Permissible Variations in Product Analysis

NOTE—Product cross-sectional area is defined as either:
(*a*) maximum cross-sectional area of rough machined forging (excluding boring),
(*b*) maximum cross-sectional area of the unmachined forging, or
(*c*) maximum cross-sectional area of the billet, bloom, or slab.
Area taken at right angles to the axis of the original ingot or billet

Element	Unit or Maximum Specified Range, %	Permissible Variation Over the Specified Maximum Limit or Under the Specified Minimum Limit, %					
		Up to and including 100 in.^{2} (645 cm^2)	Over 100 to 200 in.^{2} (645 to 1290 cm^2), incl	Over 200 to 400 in.^{2} (1290 to 2580 cm^2), incl	Over 400 to 800 in.^{2} (2580 to 5160 cm^2), incl	Over 800 to 1600 in.^{2}(5160 to 10 320 cm^2), incl	Over 1600 in.^{2} (10 320 cm^2)
Carbon	. . .	0.03	0.04	0.04	0.05	0.06	0.06
Manganese	up to and including 0.90	0.03	0.04	0.05	0.06	0.07	0.08
	0.91 and over	0.06	0.06	0.07	0.08	0.08	0.09
Phosphorus	. . .	0.008	0.008	0.010	0.010	0.015	0.015
Sulfur	. . .	0.005	0.005	0.005	0.005	0.006	0.006
Silicon	. . .	0.02	0.03	0.04	0.04	0.05	0.06
Nickel	up to and including 1.00	0.03	0.03	0.03	0.03	0.03	0.03
	1.01 to 2.00, incl	0.05	0.05	0.05	0.05	0.05	0.05
	2.01 and over	0.07	0.07	0.07	0.07	0.07	0.07
Chromium	up to and including 0.90	0.03	0.04	0.04	0.05	0.05	0.06
	0.91 and over	0.05	0.06	0.06	0.07	0.07	0.08
Molybdenum	up to and including 0.20	0.01	0.02	0.02	0.02	0.03	0.03
	0.21 to 0.40, incl	0.02	0.03	0.03	0.03	0.04	0.04
	0.41 to 1.15, incl	0.03	0.04	0.05	0.06	0.07	0.08
	1.16 and over	0.05	0.06	0.08	0.10	0.12	0.12
Vanadium	up to and including 0.10	0.01	0.01	0.01	0.01	0.01	0.01
	0.11 to 0.25, incl	0.02	0.02	0.02	0.02	0.02	0.02
	0.26 and over	0.03	0.03	0.03	0.03	0.03	0.03

TABLE 3 Tensile and Charpy Impact Requirements

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Tensile strength, min, ksi (MPa)	100 (690)	105 (725)	110 (760)	120 830)	130 (900)	140 (965)
Yield strength, ksi (MPa)						
0.2 % offset	80–100 (550–690)	90–110 (620–760)	100–120 (690–825)	110–130 (760–895)	120–140 (825–965)	130–150 (895–1035)
0.02 % offset	75–95 (520–655)	85–105 (585–725)	95–115 (655–790)	105–125 (725–860)	115–135 (790–930)	125–145 (860–1000)
Elongation in 2 in. or 50 mm, min, %	20	19	18	17	16	15
Reduction of area, min, %	50	50	47	45	43	43
Charpy V-notch impact, room temperature, ft·lb, min	50	50	45	45	40	40
Transition temperature, FATT$_{50}$, °F, max	0	0	0	0	10	10
Brinell hardness number	. . .	. . .	. . .	. . .	. . .	. . .
	Class 10	Class 11	Class 12	Class 13	Class 14	
Tensile strength, min, ksi (MPa)	105 (725)	100 (690)	110 (760)	125 (860)	125 (860)	
Yield strength, ksi (MPa)						
0.2 % offset	90–105	. . .	. . .	. . .	. . .	
			. . .	. . .	. . .	
	(620–725)	. . .	. . .	. . .	. . .	
0.02 % offset	85–100 (585–690)	75–95 (515–655)	85–105 (585–725)	105–125 (725–860)	105–125 (725–860)	
Elongation in 2 in. or 50 mm, min, %	15	20.0	18.0	16.0	18.0	
Reduction of area, min, %	30	50.0	48.0	45.0	45.0	
Charpy V-notch impact, room temperature, ft·lb, min	10	15 (20)	15 (20)	15 (20)	15 (20)	
Transition temperature, FATT$_{50}$, °F, max	200	^{A}	^{A}	^{A}	^{A}	
Brinell hardness number	. . .	207–255	229–269	255–302	255–302	

^{A} Not required.

6.4.1 For Classes 11 through 14 unless otherwise specified by the purchaser, tests shall be made as follows:

6.4.1.1 Forgings 30 in. (762 mm) and under in diameter may be group tested. One tension test and one Charpy V-notch test shall be considered representative of each lot of forgings manufactured from the same heat of material and heat treated together. When group tested two Brinell tests, 180° apart, shall be made on the same face of each forging near the rim.

6.4.1.2 For forgings over 30 in. in diameter, at least one rim tension test and one Charpy V-notch test shall be made from each forging.

6.4.1.3 *Location*—Unless otherwise specified, tension and Charpy V-notch specimens shall be taken on full thickness prolongations on the forging periphery. The test specimen shall be taken as close as possible to the quarter thickness of the forging, with the axis of the specimen tangential.

6.5 *Removal of Test Specimens*—Removal of mechanical test specimens shall be done after all heat treatment, including the stress relief when required, has been completed.

7. Nondestructive Test Requirements

7.1 *General Requirements*—The forgings shall be free from cracks, seams, laps, shrinkage, and other similar imperfections.

7.2 *Ultrasonic Inspection*—An ultrasonic inspection of the forgings shall be made on all available surfaces to demonstrate freedom from detrimental internal indications. In making the ultrasonic inspection, reference shall be made to Practice A 388. Acceptance level shall be agreed upon between the purchaser and manufacturer.

7.3 Other nondestructive test methods such as dye penetrant, sulfur printing, or etching may be used upon request of the purchaser to evaluate the forging.

8. Dimensions and Tolerances

8.1 The forgings shall conform to the dimensions and tolerances specified on the purchaser's drawing or order.

9. Finish and Appearance

9.1 The forgings shall conform to the finish specified on the purchaser's drawing and shall have a good workmanlike appearance.

10. Retests

10.1 If the results of the mechanical tests do not conform to the requirements specified, retests are permitted as outlined in Test Methods and Definitions A 370 or as follows:

10.1.1 If the percentage of elongation of any tension test specimen is less than that specified because a flaw develops in the test specimen during testing, a retest shall be allowed if the flaw is not caused by ruptures, cracks, porosity, or flakes in the steel.

10.1.2 Room temperature impact values lower than the minimum specified, but not less than 80 % of the minimum shall be cause for retest. In this event, two additional adjacent bars shall be broken to represent each failed bar. Both specimens shall have an impact strength above the minimum specified and the average for the three bars shall be above the minimum specified. Room temperature impact values less than 80 % of the specified value are not acceptable.

11. Retreatment

11.1 If the results of the mechanical tests of any forging does not conform to the specified requirements, the manufacturer may retreat the forging one or more times, but not more than three additional times without approval of the purchaser.

12. Inspection

12.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operation. All tests and inspections shall be made at the place of manufacture, unless otherwise agreed upon.

13. Rejection

13.1 Any forging having nonconforming conditions observed prior to or subsequent to acceptance at the manufacturer's plant shall be subject to rejection.

13.2 Any rejection based on tests made in accordance with 5.2.2 shall be reported to the manufacturer within 60 days from the receipt of the forgings by the purchaser, except in the case where it is obvious that a gross variation from specified chemical analysis exists. In this case there shall be no time limit for rejection.

14. Certification and Reports

14.1 The manufacturer shall furnish the required (on purchase order) number of test reports to the purchaser.

14.2 The following items shall be reported:

14.2.1 Heat and product (when specified by the purchaser) analyses,

14.2.2 Results of acceptance tests for mechanical properties,

14.2.3 Report of all nondestructive tests including sketches when necessary,

14.2.4 Final austenitizing, tempering, and stress relieving temperatures, holding times, and methods of cooling, and

14.2.5 The results of the supplementary requirement when required.

15. Packaging, Package Marking, and Loading

15.1 Each forging shall be legibly stamped by the manufacturer with the manufacturer's name or trademark, the manufacturer's serial number, the specification number (A 471), and the appropriate class number.

15.2 Packaging and loading shall be done so that the forging is not damaged during shipment to the purchaser.

16. Keywords

16.1 steel forgings; turbine rotor disks; turbine rotor wheels; vacuum-treated low alloy steel

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser on the order.

S1. Creep Rupture

S1.1 In general, the procedure outlined in Practice E 139, shall be followed. A minimum of six test specimens shall be removed as instructed by the purchaser. The type test specimen and condition of the test shall be agreed upon between purchaser and manufacturer.

S2. Hydrogen Determination

S2.1 A hydrogen determination shall be made. The ac-ceptable hydrogen limit as well as the stage in processing when sampling, the sample preparation procedure and the method of analysis shall be agreed upon between manufacturer and purchaser.

S3. Magnetic Particle Examination

S3.1 A magnetic particle examination of the complete exterior and bore surfaces of the machined forging shall be made at the forging manufacturer's plant. The examination shall be performed in accordance with the latest issue of Test Method A 275/A 275M.

S3.2 Forgings with cracks of any length or linear indications of ⅛ in. (3.2 mm) length or greater that are caused by nonmetallic inclusions are subject to rejection unless they can be removed to the purchaser's satisfaction.

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 471/A 471M-94 (1999) that may impact the use of this standard.

(1) Product check requirement in 14.2.1 clarified

Designation: A 472 – 98 (Reapproved 2003)

Standard Test Method for Heat Stability of Steam Turbine Shafts and Rotor Forgings[1]

This standard is issued under the fixed designation A 472; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of heat stability of steam turbine shafts and rotor forgings to ensure stability at operating temperature. This test method is not ordinarily applicable to generator rotor forgings.

1.2 The values stated in inch-pound units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Ordering Information

2.1 The purchase order or forging drawing shall specify the minimum temperature for the heat stability test. The forging drawing shall show the portion of the forging to be subjected to the heat stability test temperature.

3. Procedure

3.1 The heat stability test shall be conducted by the forging supplier after final heat treatment and after the forging has been centered and machined with allowance to finish to the purchaser's drawing. Material for mechanical tests may be removed before or after the stability test at the manufacturer's option, unless check tests after the stability test are required by the purchaser.

3.2 With prior approval from the purchaser, the forgings may be stress relieved as part of the heat stability test. When this is done, the stress-relieving temperature shall be within 50 to 100°F (28 to 55.5°C) below final tempering temperature. Rotate the forgings at 2 to 4 r/min and hold at stress-relieving temperature for at least 2 h/in. (2 h/25.4 mm) of maximum radial thickness, after which the temperature may be decreased to the specified heat stability test temperature and the test performed.

4. Heat Stability Test Bands

4.1 The supplier shall mark positions A, B, C, and D, spaced 90° apart circumferentially, preferably on an end of the forging. Markings shall be retained throughout all subsequent operations.

4.2 Preferably there shall be a minimum of 5 test bands, denoted as 1, 2, 3, 4, and 5, machined on the circumference of the forging. Numbering shall start at the left side of the forging drawing. Bands 1 and 5 shall be located as close to the end of the forging as practical. Band 3 shall be located as near to midlength as practical. Bands 2 and 4 shall be located approximately equidistant between 1 and 3, and 3 and 5 respectively.

4.3 When the shipped length of the barrel portion of the forging is less than 8 ft (2.4 m), bands 2 and 4 may be omitted.

4.4 The purchaser's drawing may show the desired number and location of bands and shall indicate that portion of the forging that shall be located within the heating chamber. Bands 1 and 5 are to be located outside of the heating chamber. Preferably, the gland areas/packing seal areas are inside the heating chamber.

4.5 The test bands shall be machined with the forging running on centers except in the cases of forgings weighing over 125 000 lb (56.7 metric tons) the machining shall be performed with the forgings running on steady rests. Readings shall be taken with the forging running on centers except in the cases of forgings weighing over 125 000 lb where readings may be taken with the forgings running on steady rests. Between readings, the forgings may be rotated on steady rests.

5. Surface Preparation

5.1 Remove oil, grease, dirt, and other foreign material from the surface of the forging prior to the heat stability test. A suitable coating may be applied to provide uniform emissivity.

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[1] This test method is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved April 10, 2003. Published July 2003. Originally approved in 1962. Last previous edition approved in 1998 as A 472 –98.

6. Heating and Cooling

6.1 Place the forging in the heating chamber and rotate the forging at a speed of 2 to 4 r/min.

6.2 Place thermocouples in contact with the forging at each test band within the heating chamber. Shield the thermocouples from the heat source.

6.3 Apply heat uniformly to avoid localized overheating. Heat the forging at a rate not exceeding 200°F/h (111°C/h) to the stability test temperature specified by the purchaser. Maintain the specified testing temperature until the forging is heated uniformly. A uniform temperature condition shall be considered to exist when three consecutive hourly deflection measurements taken at the test temperature are within 0.0005 in. (0.0127 mm). To consider a uniform test temperature condition to exist, it is also necessary that the axial thermal expansion be consistent within 0.010 in. (0.254 mm) for three consecutive hourly readings at the test temperature.

6.4 After uniform test conditions as described in 6.3 have been reached, cool the forging, while rotating, to below 100°F (37.8°C). The heating chamber may be opened during cooling but the cover shall not be removed until the temperature of the forging is less than 500°F (260°C). After the forging has cooled to approximately room temperature, rotate it for at least 2 h before the second cold measurements (see 7.4) are recorded.

7. Stability Measurements

7.1 Use an indicator located outside the heating chamber to measure to the nearest 0.0005 in. (0.0127 mm). Actuate the indicator by a rod with one end contacting the forging at test bands described in 4.2 or 4.3. Take measurements at each test band at positions A, B, C, and D. For each band, the indicator may be set to zero for the minimum deflection at one of the positions A, B, C, or D or the figures may be reduced to minima by subtraction.

7.2 *First Cold Measurements*—Take measurements on each band after rotation is started but prior to heating. If the runout exceeds 0.002 in. (0.051 mm) at any band, continue rotation for 1 h. If runout continues to exceed 0.002 in., recenter the forging or remachine the bands until the runout does not exceed 0.002 in. in any band. Refer to the last measurements as the official first cold measurements.

7.3 *Hot Measurements*—Take measurements on all bands hourly during the heating cycle until the forging has been heated to the specified temperature. When three consecutive hourly deflection measurements at the specified temperature check within 0.0005 in. (0.0127 mm), cooling may commence. Refer to the last of these measurements as the official hot measurements.

7.4 *Second Cold Measurements*—After cooling in accordance with 6.4, take measurements on all bands at half-hour intervals until two consecutive deflection measurements check within 0.0005 in. (0.0127 mm). Refer to the last of these measurements as the official second cold measurements.

8. Interpretation of Results

8.1 The forging shall be acceptable if the movement of its center is not greater than 0.001 in. (0.0254 mm) when determined by the difference between the official hot and the official cold second measurements. This movement shall be determined for each band as follows:

8.1.1 From the official hot measurements at position A subtract the official cold measurement for position A.

8.1.2 Repeat the procedure for positions B, C, and D.

8.1.3 For each of these four results, numerically total the greatest plus value and the greatest minus value without regard to sign. The maximum deflection in any band as indicated by these totals shall not exceed 0.002 in. (0.051 mm).

8.2 In case of changes in measurements in bands 1 and 5, suitable corrections may be made to results obtained from bands 2, 3, and 4. The corrected figures shall be within the requirements of 8.1.3.

8.3 If the forging does not meet the requirements of the stability test, it may be retested, stress relieved before retest or completely reheat treated before retest.

9. Report

9.1 The forging supplier shall report to the purchaser the official first cold measurements, the hourly measurements during heating and holding at specified temperature, the official hot measurements and the official second cold measurements, as well as the temperature of the forging when these measurements were obtained. The report shall include the calculated change in measurements as determined under 8.1.3.

Designation: A 485 – 03

Standard Specification for High Hardenability Antifriction Bearing Steel[1]

This standard is issued under the fixed designation A 485; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers high hardenability modifications of high-carbon bearing quality steel to be used in the manufacture of antifriction bearings.

1.2 Supplementary requirements of an optional nature are provided and when desired shall be so stated in the order.

1.3 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 255 Test Method of End-Quench Test for Hardenability of Steel[2]

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products[3]

E 45 Test Methods For Determining the Inclusion Content of Steel[4]

E 381 Method of Macroetch Testing, Inspection, and Rating Steel Products, Comprising Bars, Billets, Blooms, and Forgings[4]

E 1019 Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel and in Iron, Nickel, and Cobalt Alloys[5]

E 1077 Test Method for Estimating the Depth of Decarburization of Steel Specimens[4]

2.2 *Other Standards:*

SAE J148a Grain Size Determination of Steel[6]

ISO 683 Part 17: Ball and Roller Bearing Steels[7]

3. Ordering Information

3.1 Orders for material under this specification should include the following information:

3.1.1 Quantity (weight or number of pieces),

3.1.2 Grade identification,

3.1.3 ASTM designation and year of issue,

3.1.4 Dimensions,

3.1.5 Supplementary requirements, if included.

4. Process

4.1 The steel shall be made by a process that is capable of providing a high quality product meeting the requirements of this specification.

5. Chemical Composition and Analysis

5.1 Typical examples of chemical compositions are shown in Table 1. Other compositions may be specified.

5.2 An analysis of each heat of steel shall be made by the steel manufacturer in accordance with Test Methods, Practices, and Terminology A 751. The chemical composition thus determined shall conform to the requirements specified in Table 1 for the ordered grade or to other requirements agreed upon between manufacturer and purchaser.

5.3 Product analysis may be made by the purchaser in accordance with Test Methods, Practice, and Terminology A 751. Permissible variations in product analysis shall be in accordance with Specification A 29/A 29M.

6. Sizes, Shapes, and Dimensional Tolerances

6.1 The physical size and shape of the material shall be agreed upon between manufacturer and purchaser.

6.2 Dimensional tolerances for hot-rolled or hot-rolled and annealed bars, in straight lengths or coils, and cold-finished bars furnished under this specification shall conform to the requirements specified in the latest edition of Specification A 29/A 29M.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys , and is the direct responsibility of Subcommittee A01.28 on Bearing Steels.

Current edition approved April 10, 2003. Published July 2003. Originally approved in 1963. Last previous edition approved in 2000 as A 485–00.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] *Annual Book of ASTM Standards*, Vol 03.06.

[6] Available from The Engineering Society for Advanced Mobility of Land, Sea, Air and Space, 400 Commonwealth Drive, Warrendale, PA 15096-001.

[7] Available from the International Organization for Standardization (ISO), 1, rue de Varembé, Case postale 56, CH-1211, Genève 20, Switzerland.

TABLE 1 Chemical Composition[A,B]

Number[C]	Name	C	Mn	P (max)	S (max)	Si	Cr	Ni (max)	Ti (max)	Cu (max)	Mo	O (max)[D]	Al (max)
1	Grade 1	0.90–1.05	0.90–1.20	0.025	0.015	0.45–0.75	0.90–1.20	0.25	0.0050	0.30	0.10 (max)	0.0015	0.050
2	Grade 2	0.85–1.00	1.40–1.70	0.025	0.015	0.50–0.80	1.40–1.80	0.25	0.0050	0.30	0.10 (max)	0.0015	0.050
3	Grade 3	0.95–1.10	0.65–0.90	0.025	0.015	0.15–0.35	1.10–1.50	0.25	0.0050	0.30	0.20–0.30	0.0015	0.050
4	Grade 4	0.95–1.10	1.05–1.35	0.025	0.015	0.15–0.35	1.10–1.50	0.25	0.0050	0.30	0.45–0.60	0.0015	0.050
B2	100CrMnSi4–4	0.93–1.05	0.90–1.20	0.025	0.015	0.45–0.75	0.90–1.20	. . .	[E]	0.30	0.10 (max)	0.0015	0.050
B3	100CrMnSi6–4	0.93–1.05	1.00–1.20	0.025	0.015	0.45–0.75	1.40–1.65	. . .	[E]	0.30	0.10 (max)	0.0015	0.050
B4	100CrMnSi6–6	0.93–1.05	1.40–1.70	0.025	0.015	0.45–0.75	1.40–1.65	. . .	[E]	0.30	0.10 (max)	0.0015	0.050
B5	100CrMo7	0.93–1.05	0.25–0.45	0.025	0.015	0.15–0.35	1.65–1.95	. . .	[E]	0.30	0.15–0.30	0.0015	0.050
B6	100CrMo7–3	0.93–1.05	0.60–0.80	0.025	0.015	0.15–0.35	1.65–1.95	. . .	[E]	0.30	0.20–0.35	0.0015	0.050
B7	100CrMo7–4	0.93–1.05	0.60–0.80	0.025	0.015	0.15–0.35	1.65–1.95	. . .	[E]	0.30	0.40–0.50	0.0015	0.050
B8	100CrMnMoSi8–4–6	0.93–1.05	0.80–1.10	0.025	0.015	0.40–0.60	1.80–2.05	. . .	[E]	0.30	0.50–0.60	0.0015	0.050

[A] Elements not quoted shall not be intentionally added to the steel without the agreement of the purchaser.
[B] Intentional additions of calcium or calcium alloys for deoxidation or inclusion shape control are not permitted unless specifically approved by the purchaser.
[C] Steels B2 through B8 meet the requirements of ISO 683, Part 17, Second Edition, Table 3.
[D] Oxygen content applies to product analysis and shall be determined in accordance with Test Methods E 1019.
[E] A maximum titanium content may be agreed upon at the time of inquiry and order.

TABLE 2 Inclusion Rating

Rating Units	
Thin Series	Heavy Series
A—2½	A—1½
B—2	B—1
C—½	C—½
D—1	D—1

TABLE 3 Hardenability Values

	Rockwell C		
	Minimum Rockwell C Values at Sixteenth of Inch		
Grade	10	20	28
1	46	. . .	. . .
2	. . .	52	32
3	46	. . .	. . .
4	. . .	52	35

7. Quality Tests

7.1 The supplier shall be held responsible for the quality of the material furnished and shall make the necessary tests detailed below: Quality tests shown in 7.1 through 7.4 are based upon procedures established in Practice E 45.

7.2 *Sampling*—Samples taken in accordance with the following paragraphs shall be obtained from 4 by 4 in. (102 by 102 mm) rolled billets or forged sections. Tests may be made on smaller or larger sections by agreement with the purchaser. A minimum of 3 to 1 reduction of rolled billets or forged sections is required for strand cast products.

7.2.1 For top poured products, a minimum of six samples representing the top and bottom of the first, middle and last usable ingots shall be examined.

7.2.2 For bottom poured products, a minimum of six samples shall be taken from semi-finished or finished product representing the top and bottom of three ingots. One ingot shall be taken at random from the first usable plate poured, one ingot at random from the usable plate poured nearest to the middle of the heat, and one ingot at random from the last usable plate poured. When a heat is constituted by two usable plates, two of the sample ingots shall be selected from the second usable plate poured. When a heat consists of a single usable plate, any three random ingots may be selected. Other methods of sampling shall be as agreed upon between manufacturer and purchaser.

7.2.3 For strand cast products, a minimum of six samples representing the first, middle, and last portion of the heat cast shall be examined. At least one sample shall be taken from each strand.

7.3 *Macroetch*—Specimens representative of cross-sections of billets shall be macroetched and rated in accordance with Method E 381 in hydrochloric acid and water (1.1) at 60 to 180°F (71 to 82°C). Such specimens shall not exceed S2, R2, C2 of Method E 381.

7.4 *Inclusion Rating*—Specimens approximately ⅜ by ¾ in. (9.5 by 19.1 mm) shall be taken from an area halfway between the center and outside of the billet. The polished face shall be longitudinal to the direction of rolling. The scale used for rating the specimens shall be the chart described in Practice E 45, Method A, Plate I-r. Inclusion fields with sizes or numbers intermediate between configurations shown on the chart shall be classified as the lesser of the rating number. The worst field of each inclusion type from each specimen shall be recorded as the rating for the specimen. Two thirds of all specimens and at least one from each ingot tested, or from the first, middle and last portion of the strands tested as well as the average of all specimens, shall not exceed the rating specified in Table 2.

8. Grain Size

8.1 The steels covered by this specification shall have the capability of showing fine fracture grain size (approximately ASTM No. 8) (SAE J418a) when quenched from normal austenizing temperatures not exceeding 1550°F (843°C).

9. Hardenability

9.1 Each heat shall be tested for hardenability. Normalizing followed by spheroidize annealing shall precede heating for end quenching. In heating for end quenching, the test specimens shall be held for a minimum of 30 min at 1500 ± 8°F (815 ± 4.5°C). End-quench procedure shall be in accordance

TABLE 4 Decarburization and Surface Imperfections for Bars and Tubes

Size, in. (mm)	Maximum Decarburization or Surface Imperfections per Side, in. (mm)				
	Hot-Rolled Bars	Hot-Rolled Annealed		Cold-Finished Annealed	
		Bars	Tubes	Bars	Tubes
Over 1.000 (25.4) to 2.000 (50.8), incl	0.017 (0.43)	0.022 (0.56)	0.020 (0.51)	0.017 (0.43)	0.014 (0.36)
Over 2.000 (50.8) to 3.000 (76.2), incl	0.025 (0.64)	0.030 (0.76)	0.030 (0.76)	0.025 (0.64)	0.019 (0.48)
Over 3.000 (76.2) to 4.000 (101.6), incl	0.035 (0.89)	0.045 (1.14)	0.035 (0.89)	. . .	0.024 (0.61)
Over 4.000 (101.6) to 5.000 (127.0), incl	0.055 (1.40)	0.065 (1.65)	0.040 (1.02)	. . .	0.028 (0.71)

TABLE 5 Hardness Limits for Annealed Material

Product	Condition	Maximum Hardness	
		Brinell	Rockwell
Coils	hot-rolled, annealed	. . .	B 97
Bars and tubes	hot-rolled, annealed	217	. . .
Coils	annealed, cold drawn (stress relieved)	. . .	B 92
Coils, bars, and tubes	annealed, cold drawn[A]	260	. . .

[A] Cold swaged material is not included.

with Test Method A 255. The "J" values for hardenability as shown in Table 3 shall apply.

10. Decarburization and Surface Imperfections

10.1 Decarburization and surface imperfections shall not exceed the limits specified in Table 4. Decarburization shall be measured using the microscopical methods described in Test Method E 1077.

11. Microstructure and Hardness

11.1 The material shall be free of excessive carbide segregation.

11.2 When annealing is specified in the order, the steel shall have a microstructure completely spheroidized, or as agreed upon, and the maximum hardness as specified in Table 5.

12. Inspection

12.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Mill inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspections shall be made at the place of manufacture, unless otherwise agreed to.

13. Certification and Reports

13.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the test results shall be furnished at the time of shipment. Special requirements agreed to at the time of purchase must be noted on the certification.

SUPPLEMENTARY REQUIREMENTS

One or more of the supplementary requirements described below apply when included in purchaser's order or contract. When so included, a supplementary requirement shall have the same force as if it were in the body of the specification. Supplementary requirements details not fully described shall be agreed upon between the purchaser and the supplier, but shall not negate any of the requirements in the body of the specification.

S1. "SAM" Inclusion Rating System

S1.1 The purchaser may specify that the "SAM" inclusion rating method, described in Method E of Practice E 45, be used in addition to the micro-inclusion rating method described in 7.4.

S1.2 *Sampling*—See Section 7.

S1.3 *Limits*—The "SAM" rating for Type B inclusions shall not exceed 15. The "SAM" rating for Type D inclusions shall not exceed 10.

S2. Magnetic Particle Method

S2.1 The purchaser may specify that the magnetic particles method described below be used in addition to the micro-inclusion rating system described in 7.4. The magnetic particle method measures bearing steel cleanliness by evaluating the total length of macro-inclusions for a stated area or per unit area. Results are commonly expressed in mm/m^2.

S2.2 *Sampling*—See 7.2.

S2.3 Test specimens shall be straight cylinder quarter section samples prepared and examined in accordance with the magnetic particle method of Practice E 45.

S2.4 For purposes of calculation, an inclusion length shall be taken as the mean length of the length bracket in which it falls; that is, an inclusion in the 1⁄16 to 1⁄8 in. bracket shall be taken as being 3⁄32 in length. The sum of all lengths for each specimen shall be determined and expressed as total length per area inspected. The average total length per area inspected of all six specimens shall not exceed 200 mm/m^2 (or equivalent).

S3. Sulfur Requirements for Machinability

S3.1 The sulfur content shall be 0.015–0.030 %.

S3.2 The sulfide (type A) rating units in Table 2 shall be 3.0 thin and 2.0 heavy.

S3.3 The manufacturer's certification shall state that material was produced to this supplementary requirement when applicable.

S4. Calculated Hardenability

S4.1 A calculated hardenability shall be used in lieu of the requirements in Section 9. The method used shall be agreed upon between the purchaser and the steel supplier at the time of inquiry and order.

S5. Sample Reduction Ratio

S5.1 For the sampling described in 7.2, the purchaser may specify that the reduction ratio from as-cast section to test section be provided.

Designation: A 499 – 89 (Reapproved 2002)

Standard Specification for Steel Bars and Shapes, Carbon Rolled from "T" Rails[1]

This standard is issued under the fixed designation A 499; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers carbon steel bars and shapes produced from standard rail steel. These bars are furnished in the as-wrought condition intended for structural use, or bar and shape uses, where high tensile properties are applicable. These materials are available in two strength levels as Grades 50 and 60.

1.2 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 1 Specification for Carbon Steel Tee Rails[2]

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[3]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[2]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 Rail steel bars and bar size shapes are available in the following sections and nominal sizes:

3.1.1.1 *Rounds, Squares, and Round Corner Squares* in sizes ranging from ⅜ to 1¼ in. (9.5 to 32 mm).

3.1.1.2 *Square and Round Edge Flats*, ⅝ to 5 in. (15.9 to 127 mm), inclusive, in width and thickness from 7⁄64 to 1 in. (2.8 to 25 mm), inclusive, within 6 lb/ft (8.8 kg/m) limit.

3.1.1.3 *Hexagons and Octagons*, in sizes ½ to 1 in. (12.7 to 25 mm) in 1⁄16-in. (1.6-mm) increments.

3.1.1.4 *Bar Size Shapes:*

(1) Equal and Unequal Angles, ¾ to 3 in. (19.0 to 76 mm) length of legs and thickness ranging from 7⁄64 to ⅜ in. (2.8 to 9.5 mm), inclusive.

(2) Tees, 1¼, 1⅜, 1½ by ⅛ and 3⁄16 in. thickness (32, 35, 38 mm by 3.2 and 4.8 mm thickness).

(3) Channels, 1 to 2½ in. (25 to 64 mm), inclusive, in depth and ⅜ to 1 in. (9.5 to 25 mm), inclusive, in width of flange.

3.1.1.5 *Special Bar Sections:*

(1) Ovals, from ⅝ to ⅞ in. (15.9 to 22.2 mm) in longest dimension by 5⁄16 to 7⁄16 in. (7.9 to 11.1 mm), inclusive, in the small dimension.

(2) Diamonds, ⅞ and 13⁄16 in. (22.2 and 20.6 mm) in the longest dimension by ⅝ to ¾ in. (15.9 to 19.0 mm), inclusive, in the smallest dimension.

(3) I-Beams, 1½ and 2⅛ in. (35 and 54 mm) in width and ⅛ to ¼ in. (3.2 to 6.4 mm), inclusive, in thickness.

(4) U-Bars, 1¼ and 1 5⁄16 in. (32 and 33 mm) in width and 5⁄32 to 5⁄16 in. (4.0 to 7.9 mm) in thickness.

(5) Channeled Flats, 1¼ to 2 in. (32 to 51 mm), inclusive, in depth, and 3⁄16 to ⅜ in. (4.8 to 9.5 mm), inclusive, in thickness.

4. Ordering Information

4.1 Orders for material under this specification should include the following information:

4.1.1 Quantity (weight or number of pieces),

4.1.2 Name of material (rail steel carbon bars),

4.1.3 Grade of steel (Grade 50 and Grade 60),

4.1.4 Dimensions (diameter, thickness, width, etc. and length),

4.1.5 Cross section (rounds, square, hexagon, etc.) (3.1),

4.1.6 ASTM designation and date of issue,

4.1.7 Certification, if required (Section 11), and

4.1.8 End use.

NOTE 1—A typical ordering description is as follows: 10 000 lb, rail steel carbon bars, 1.000 in. diameter by 10 ft, round, ASTM A 499 dated _______.

5. General Requirements

5.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 29/A 29M, unless otherwise provided herein.

6. Materials and Manufacture

6.1 *Material*—The material shall be hot wrought from standard section "T" rails. No other materials, such as those known by the terms "rerolled," "rail steel equivalent," or "rail steel quality," shall be substituted.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.15on Bar Steels.

Current edition approved Dec. 7, 1989. Published February 1990. Originally published as A 499–89. Discontinued June 1995 and reinstated as A 499–89 (1997)$^{\epsilon 1}$.

[2] *Annual Book of ASTM Standards*, Vol 01.04.

[3] *Annual Book of ASTM Standards*, Vol 01.05.

6.2 *Hot Forming*—The material shall be produced by hot forming slit railroad rail parts to yield straight lengths in the sections and nominal sizes specified in 3.1.1.

6.3 *Condition*:

6.3.1 The material shall be furnished hot wrought, as wrought.

6.3.2 The material shall be furnished in cut lengths or ranges of random lengths, as specified by the purchaser.

7. Chemical Composition

7.1 The chemical composition of rails does not change during use in track, reheating, slitting or rolling; consequently, the composition of rail steel products will fall within the limits specified in Specification A 1 for standard section "T" rails of open-hearth, basic-oxygen, electric-furnace, and Bessemer process.

7.2 Rail steel products are not supplied to definite composition limits. By mutual agreement with the manufacturer, material may be supplied from rails with a desired range of carbon and manganese when such rails are available.

8. Mechanical Properties

8.1 *Requirements*—The material as represented by the test specimens shall conform to the tensile or hardness requirements specified in Table 1.

TABLE 1 Mechanical Requirements

	Grade 50	Grade 60
Tensile strength, min, ksi (MPa)	80 (550)	90 (620)
Yield point, min, ksi (MPa)	50 (345)	60 (415)
Elongation in 8 in. or 200 mm, min, %	5	5
Elongation in 2 in. or 50 mm, min, %	7	7
Brinell hardness, min[A]	159	190
Rockwell B hardness, min[A]	83	91

[A] Hardness tests are an acceptable alternative for tension tests where the bar size precludes a tension test specimen in accordance with Test Methods and Definitions A 370.

8.2 *Test Specimens*—Test specimens may be taken from a full section or a machined section.

8.3 *Number of Tests*—One tension test or one hardness test, at the manufacturer's option, shall be made from each lot. A lot shall consist of one section of the same size produced in one continuous shift (turn) of operation (normally an 8-h period).

9. Dimensions and Permissible Variations

9.1 *Dimensions*—The permissible variations in dimensions shall be in accordance with the requirements specified in Tables 2-7. Due to differences in mill facilities, tolerances of special bar sections vary among the manufacturers and such tolerances are subject to agreement between manufacturer and purchaser.

9.2 *Length*—The permissible variations for length shall be in accordance with the requirements specified in Table 8.

9.3 *Straightness*—Variations in straightness shall not exceed ¼ in. (6.4 mm) in any 5 ft (1.52 m); or ¼ in. × number of feet of length divided by 5 (6.4 mm × number of metres of length divided by 1.52).

10. Workmanship, Finish, and Appearance

10.1 *Descaling*—The bars shall be furnished "not descaled."

11. Certification and Report of Testing

11.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the test results shall be furnished at the time of shipment.

12. Keywords

12.1 carbon steel bars; carbon steel shapes

TABLE 2 Permissible Variations in Thickness and Length of Leg for Angles

Specified Length of Leg, in. (mm)[A]	Permissible Variations in Thickness, for Thickness Given, Over and Under, in. (mm)			Permissible Variations in Length of Leg, for Thickness Given, Over and Under, in. (mm)		
	To 3⁄16 (4.8), incl	Over 3⁄16 to 3⁄8 (4.8 to 9.5), incl	Over 3⁄8 (9.5)	To 3⁄16 (4.8), incl	Over 3⁄16 to 1⁄4 (4.8 to 6.4), incl	Over 1⁄4 (6.4)
To 1 (25), incl	0.008 (0.203)	0.010 (0.255)	. . .	1⁄32 (0.8)	3⁄64 (1.2)	[B]
Over 1 to 2 (25 to 51), incl	0.010 (0.255)	0.010 (0.255)	0.012 (0.305)	3⁄64 (1.2)	1⁄16 (1.6)	[B]
Over 2 to 3 (51 to 76), incl	0.012 (0.305)	0.015 (0.380)	0.015 (0.380)	1⁄16 (1.6)	1⁄16 (1.6)	[B]

[A] The longer leg of an unequal angle determines the size for tolerance. The out-of-square tolerance in either direction is 1½ deg (0.03 rad).
[B] Due to differences in mill facilities and rolling techniques, these are subject to agreement between manufacturer and purchaser.

TABLE 3 Permissible Variations in Thickness and Width for Square and Round Edge Flats

Specified Width, in. (mm)	Permissible Variations in Thickness for Thickness Given, Over and Under, in. (mm)		Permissible Variations in Width, in. (mm)	
	To ½ (12.7), incl	Over ½ to 1 (12.7 to 25), incl	Over	Under
To 1 (25), incl	0.008 (0.203)	0.010 (0.255)	1⁄32 (0.8)	1⁄32 (0.8)
Over 1 to 2 (25 to 51), incl	0.012 (0.305)	0.015 (0.380)	1⁄32 (0.8)	1⁄32 (0.8)
Over 2 to 4 (51 to 102), incl	0.015 (0.380)	0.020 (0.510)	1⁄16 (1.6)	1⁄32 (0.8)
Over 4 to 6 (102 to 152), incl	0.015 (0.380)	0.020 (0.510)	3⁄32 (2.4)	1⁄16 (1.6)

TABLE 4 Permissible Variations in Cross Section for Rounds, Squares, and Round-Cornered Squares

Specified Size, in. (mm)	Permissible Variation from Specified Size, in. (mm)		Out-of-Round or Out-of-Square, in. (mm)[A]
	Over	Under	
Over 5⁄16 to 7⁄16 (7.9 to 11.1), incl	0.012 (0.305)	0.012 (0.305)	0.018 (0.455)
Over 7⁄16 to 1 (11.1 to 25), incl	0.015 (0.380)	0.015 (0.380)	0.022 (0.600)
Over 1 to 1¼ (25 to 32), incl	0.020 (0.510)	0.020 (0.510)	0.030 (0.760)

[A] Out-of-round is the difference between the maximum and minimum diameters of the bar, measured at the same cross section. Out-of-square is the difference in the two dimensions at the same cross section of a square between opposite faces.

TABLE 5 Permissible Variations for Octagons and Hexagons

Specified Size Between Opposite Faces, in. (mm)	Permissible Variations from Specified Size, in. (mm)		Out-of-Hexagon or Out-of-Octagon, in. (mm)[A]
	Over	Under	
To ½ (12.7), incl	0.010 (0.255)	0.007 (0.178)	0.015 (0.380)
Over ½ to 1 (12.7 to 25), incl	0.015 (0.380)	0.015 (0.380)	0.020 (0.510)

[A] Out-of-hexagon and out-of-octagon is the greatest difference between any two dimensions at the same cross section between opposite faces.

TABLE 6 Permissible Variations in Dimensions for Channels

Specified Size of Channel, in. (mm)	Permissible Variations in Size, Over and Under, in. (mm)				Out-of-Square of Either Flange, in./in. (mm/mm) of Flange Width
	Depth of Section[A]	Width of Flanges[A]	Thickness of Web for Thickness Given		
			To 3⁄16 (4.8), incl	Over 3⁄16 (4.8)	
To 1½ (38), incl	1⁄32 (0.8)	1⁄32 (0.8)	0.010 (0.255)	0.015 (0.380)	3⁄64 (1.2)
Over 1½ to 3 (38 to 76), incl	1⁄16 (1.6)	1⁄16 (1.6)	0.015 (0.380)	0.020 (0.510)	3⁄64 (1.2)

[A] Measurements for depth of section and width of flanges are over-all. This table does not include special channel sections.

TABLE 7 Permissible Variations in Dimensions for Tees

Specified Size of Tee, in. (mm)[A]	Permissible Variations in Size, in. (mm)				Thickness of Stem		Stem Out-of-Square[B]
	Width or Depth[C]		Thickness of Flange				
	Over	Under	Over	Under	Over	Under	
To 1¼ (32), incl	3⁄64 (1.2)	3⁄64 (1.2)	0.010 (0.255)	0.010 (0.255)	0.005 (0.127)	0.020 (0.510)	1⁄32 (0.8)
Over 1¼ to 2 (32 to 51), incl	1⁄16 (1.6)	1⁄16 (1.6)	0.012 (0.305)	0.012 (0.305)	0.010 (0.255)	0.020 (0.510)	1⁄16 (1.6)

[A] The longer member of the unequal tee determines the size for tolerances.
[B] Stem out-of-square is the variation from its true position of the center line of the stem measured at the point.
[C] Measurements for both width and depth are overall.

TABLE 8 Permissible Variations in Length

Specified Size of Rounds, Squares, Hexagons, and Octagons	Specified Size of Flats, in. (mm)		Permissible Variations Over Specified Length, in. (mm)[A,B]				
	Thickness	Width	To 5 ft (1.52 m), incl	Over 5 to 10 ft (1.52 to 3.05 m), incl	Over 10 to 20 ft (3.05 to 6.10 m), incl	Over 20 to 30 ft (6.10 to 9.14 m), incl	30 to 40 ft (9.14 to 12.19 m)
			Mill Shearing				
To 1 (25), incl	To 1 (25), incl	To 3 (76), incl	3⁄8 (9.5)	1⁄2 (12.7)	5⁄8 (15.9)	3⁄4 (19.0)	1¼ (32)
Over 1 to 2 (25 to 51), incl	To 1 (25), incl	Over 3 to 6 (76 to 152), incl	1⁄2 (12.7)	5⁄8(15.9)	3⁄4 (19.0)	1 (25)	1½ (38)
Other Sections Classified as Bar Size, Shapes, and Angles			1⁄2 (12.7)	5⁄8 (15.9)	3⁄4 (19.0)	1 (25)	1½ (38)

[A] No permissible variations under.
[B]Where a plus and minus tolerance from specified length is desired and the order so specifies, half of these tolerances may be taken over and half under.

Designation: A 503/A 503M – 01

An American National Standard

Standard Specification for Ultrasonic Examination of Forged Crankshafts[1]

This standard is issued under the fixed designation A 503/A 503M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This is an acceptance specification for the ultrasonic inspection of forged steel crankshafts having main bearing journals or crankpins 4 in. [100 mm] or larger in diameter.

1.2 This specification covers the testing equipment required and the test procedure to be followed, and it defines the critical and noncritical areas and limits of acceptance.

1.3 This specification is intended to cover both continuous grain flow (CGF) crankshafts for medium and high speed diesel engines as well as solid (slab) forged crankshafts for other applications.

1.4 The values stated in either inch-pound units or SI (metric) units are to be regarded separately as the standard. Within the text and tables, the SI units are shown in brackets. The values stated in each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.5 Unless the order specifies the applicable "M" specification designation, the inch-pound units shall be used.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings[2]

E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection[3]

2.2 *American National Standard:*[4]

ANSI B46.1, Surface Texture

3. Terminology

3.1 *Definitions:*

3.1.1 *continuous grain flow crankshafts*—produced by a process in which the solidification centerline of the original ingot or starting stock is maintained through the main bearings, webs, crankpins, and flanges of the finished crankshaft, usually by means of closed die forging.

3.1.2 *solid (slab) forged crankshafts*—made from open die forgings such that the grain flow in the webs is essentially parallel to the major axis of the forging and the crankpins are offset from the forging centerline by machining. They may be set in the correct orientation by a hot twisting operation.

4. Ordering Information

4.1 It is necessary that the crankshaft be identified as being either continuous grain flow or solid (slab) forged.

4.2 Unless otherwise specified by means of supplementary ordering information, the test methods and acceptance criteria for the appropriate crankshaft type shall be used.

5. Apparatus and Personnel Requirements

5.1 The apparatus and personnel requirements shall be in accordance with Practice A 388/A 388M. For standardization purposes, it is recommended that final acceptance be based on the use of 2–5 MHz transducers.

6. Critical Sections

6.1 The division of a crankshaft into three volumetric zones, as shown in Fig. 1 and Fig. 2, for the purpose of ultrasonic examination evaluation is applicable to both solid (slab) forged and continuous grain flow crankshafts.

6.2 The major critical sections shown as Zone 1 in Fig. 1 include the heavily loaded areas of the crankpins, webs, and main bearings.

6.3 The minor critical sections shown as Zone 2 in Fig. 1 include the balance of the surface areas of the main bearing and crankpin journals and adjacent fillets, flanges, and gear fit areas.

6.4 The balance of the crankshaft as shown in Fig. 1, including the remaining sections of the webs, is included in Zone 3.

7. Calibration of Ultrasonic Equipment on Crankshaft

7.1 For solid (slab) forged crankshafts, the sensitivity of the instrument shall be adjusted so that the thickness to be examined will give a full-scale back reflection. Such calibrations shall be done in an area free of interfering indications.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved March 10, 2001. Published March 2001. Originally published as A 503–64. Last previous edition A 503/A 503M–99.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 03.03.

[4] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

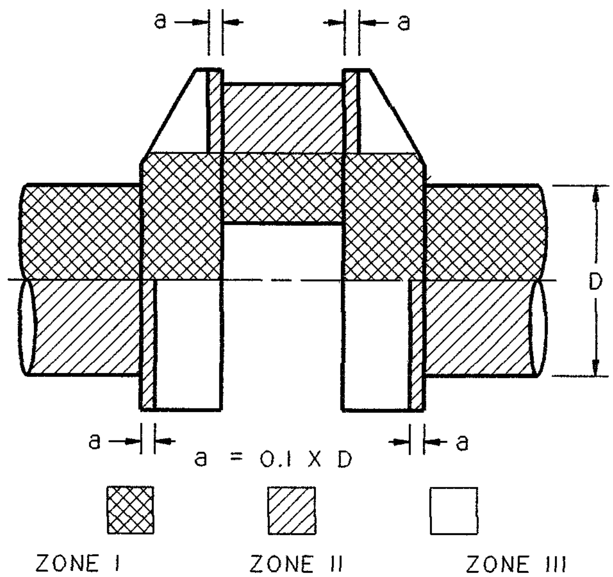


FIG. 1 Crankshaft UT Acceptance Zones

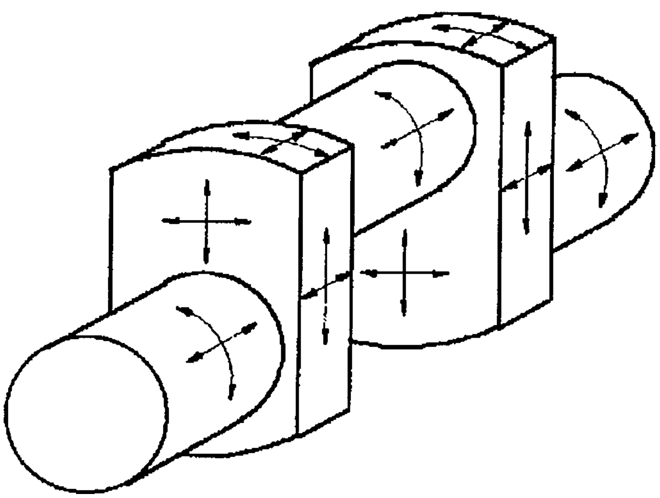


FIG. 2 Scanning Directions

7.2 For CGF crankshafts, 80 % of the full-scale back reflection is used when evaluating indications in accordance with Fig. 3.

8. Procedure

8.1 The crankshaft should be examined after heat treatment, but before machining geometric features such as chamfers and oil holes that could interfere with ultrasonic examination.

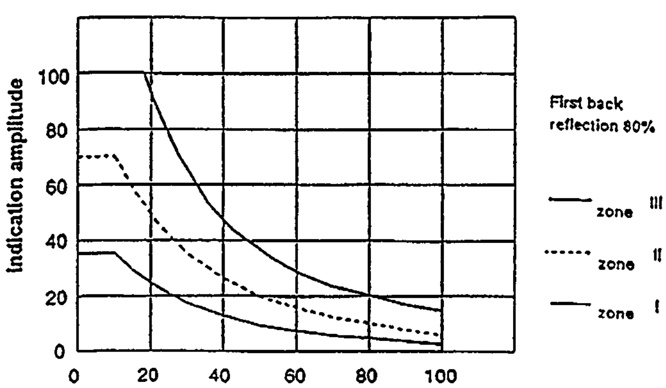


FIG. 3 Distance to Indication as Percentage of Cross-section

8.2 Unless otherwise specified by the purchase order, the scanned surfaces shall have a maximum surface roughness of 250 µin. [6.35 µm].

8.3 The crankshaft shall be scanned as shown in Fig. 2.

9. Acceptance Criteria

9.1 *Acceptance Zones*:

9.1.1 For acceptance purposes, the crankshaft shall be divided into three zones as shown in Fig. 1.

9.1.2 Because of crankshaft geometry, particularly for CGF crankshafts, the ultrasonic examination shall be carried out to the maximum extent possible.

9.2 *Solid Forged Crankshafts*:

9.2.1 In Zone 1, indications equal to or greater than 20 % of the back reflection as established in 7.1 shall be cause for rejection.

9.2.2 Indications in Zone 2 equal to or greater than 50 % of the back reflection shall be cause for rejection.

9.2.3 Indications in Zone 3 equal to or greater than 100 % of the back reflection shall be cause for rejection.

9.2.4 Loss of back reflection in excess of 50 % in any zone, and not caused by geometric configuration, shall be recorded in terms of size and location. Normally this condition shall be cause for rejection, but it may be referred to the purchaser for disposition.

9.3 *Continuous Grain Flow Crankshafts (CGF)*:

9.3.1 Ultrasonic indications detected in CGF crankshafts shall be evaluated in accordance with Fig. 3. Indications that exceed the appropriate zone curve are cause for rejection.

9.3.2 Loss of back reflection in excess of 50 % in any zone, and not attributable to geometric configuration shall be recorded in terms of percentage loss and location. Normally this condition shall be cause for rejection, but it may be referred to the purchaser for disposition.

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the inquiry or order. Details of these supplementary requirements shall be agreed upon by the manufacturer and the purchaser.

S1. Ultrasonic Testing: Reference Block Calibration

S1.1 A distance amplitude correction (DAC) curve shall be used to provide compensation for signal attenuation.

S1.1.1 Two or more reference specimens of incremental lengths shall be used to establish the DAC curve.

S1.1.2 The reference blocks shall be manufactured in accordance with Practice E 428.

S1.1.3 The DAC is established by placing the search unit on the reference block with the shortest distance to the test hole and adjusting the gain control to secure a signal response of 100 % full screen. The signal peak is marked on the screen. The procedure is repeated for succeeding greater test distances without altering the gain. The DAC curve is established by connecting adjoining peaks with a straight line.

S1.1.4 The basis for rejection shall be agreed upon between the purchaser and manufacturer.

S2. DGS Scales

S2.1 DGS scales similar to those described in Practice A 388/A 388M shall be used in the examination of either solid (slab) forged or CGF crankshafts.

S2.2 The acceptance curves shall be agreed upon between the purchaser and manufacturer.

Standard Specification for Wrought Carbon Steel Wheels[1]

This standard is issued under the fixed designation A 504; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers one-wear, two-wear, and multiple-wear wrought carbon steel wheels for locomotives and cars, designated Class U, untreated, and Classes L, A, B, and C, heat-treated, wheels.

1.2 The service for which the various classes are intended is as follows:

1.2.1 Class B or C wheels shall be used for freight cars in interchange service.

1.2.2 Class B or C wheels are recommended for use on locomotives.

1.2.3 For passenger car service, the various classes are intended generally as follows:

1.2.3.1 *Class L*—High speed with more severe braking conditions than other classes and light wheel loads.

1.2.3.2 *Class A*—High speed with more severe braking conditions, but moderate wheel loads.

1.2.3.3 *Class B*—High speed service with severe braking conditions and heavier wheel loads.

1.2.3.4 *Class C*—(*1*) Service with light braking conditions and heavier wheel loads.

1.2.3.5 *Class C*—(*2*) Service with heavier braking conditions where off-tread brakes are employed.

1.2.4 *Class U*—Wheels may be used in service in which the wheel load and braking are low.

1.3 The use of two-wear wheels is recommended for freight car service.

1.4 The values stated in inch-pound units are to be regarded as the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 59 Practice for Sampling Steel and Iron for Determination of Chemical Composition[2]

E 350 Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron[2]

E 415 Test Method for Optical Emission Vacuum Spectrometric Analysis of Carbon and Low-Alloy Steel[3]

E 1019 Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel and in Iron, Nickel, and Cobalt Alloys[3]

2.2 *SAE Documents:*

SAE J 442 Test Strip, Holder and Gage for Shot Peening[4]

SAE J 443 Recommended Practice for Procedures for Using Standard Shot Peening Test Strip[4]

SAE J 827 Recommended Practice for Cast Steel Shot[4]

2.3 *Military Standard:*

MIL-S-13165B Shot Peening of Metal Parts[5]

2.4 *AAR Standard:*

AAR Wheel and Axle Manual, Section G, M-107[6]

NOTE 1—The tables of tape sizes may be referred to in the AAR Wheel and Axle Manual, Section G, Part 2.

3. Ordering Information

3.1 Orders for wheels under this specification shall include the following information as appropriate:

3.1.1 Quantity (number of pieces),

3.1.2 Class (see Table 1),

3.1.3 Full identification of wheel design, including tread and flange contour, and dimensional drawing if required,

3.1.4 Rough bore size,

3.1.5 Intended service (see Section 1),

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved Dec. 15, 1993. Published February 1994. Originally published as A 504 – 64 to replace A 57 and A 186. Combined with A 25 in this edition. Last previous edition A 504 – 89.

[2] *Annual Book of ASTM Standards*, Vol 03.05.

[3] *Annual Book of ASTM Standards*, Vol 03.06.

[4] Available from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096.

[5] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

[6] Available from Association of American Railroads, 50 "F" St., Washington, DC 20001.

TABLE 1 Chemical Requirements

	Composition, %
Carbon:	
Class U	0.65–0.77
Class L, max	0.47
Class A	0.47–0.57
Class B	0.57–0.67
Class C	0.67–0.77
Manganese	0.60–0.85
Phosphorus, max	0.05
Sulfur, max	0.05
Silicon, min	0.15

3.1.6 ASTM designation and date of issue, and
3.1.7 Supplementary requirements (if any).

4. Manufacture

4.1 The steel shall be made by any of the following processes: open-hearth, electric-furnace, or basic-oxygen process.

4.2 *Discard*—Sufficient discard shall be made from each ingot to ensure freedom from piping and undue segregation.

4.3 *Temperatures*—During the manufacture, necessary care in the regulation of temperature gradients shall be exercised to obtain the physical properties to be expected from the chemical composition and mechanical work and to prevent the development of faulty structure. Immediately after the last hot fabricating operation (coning or dishing), all wheels shall be allowed to cool to a temperature below the critical range. The cooling shall be controlled to prevent injury by too rapid cooling below the critical range.

5. Heat Treatment

5.1 For Classes L, A, B, and C wheels, the heat treatment shall consist of treatment of the rim only.

5.2 *Rim-Quenching Treatment*—The wheels shall be reheated uniformly to the proper temperature to refine the grain and then the rims shall be quenched. Following quenching, the wheels shall be charged into a furnace for tempering to meet the requirements of Section 12, and subsequently cooled under controlled conditions.

6. Shot Peening

6.1 *Scope*—The plate surfaces of all wheels shall be shot-peened in accordance with the following requirements:

6.2 *Requirements*:

6.2.1 *Shot*—The shot shall be SAE No. 550 or larger hardened steel as specified in SAE Recommended Practice J 827.

6.2.2 *Shot Size Control*—The peening machines shall be equipped with a separator for continuously removing broken shot. Sufficient new shot shall be added to ensure that a minimum of 85 % of No. 550 or larger shot is maintained in the machines at all times.

6.2.3 *Peening Intensity*—The peening intensity shall be sufficient to produce an average arc height of not less than 0.008 Almen C-2 on the front plate near the hub fillet and on the back plate near the rim fillet of wheels of the standard design, and at back plate hub fillet and front plate rim fillet of the reverse plate design. The area to be peened is defined as the plate area extended approximately one half of the way into the hub and rim fillet radii on the front and on the back of the wheel.

6.2.4 *Arc Height Measurement*—Measurements of arc height shall be made in accordance with SAE Standard J 442 or SAE Recommended Practice J 443.

6.2.5 *Coverage*—The minimum peening time shall be sufficient to ensure that full coverage is attained on the Almen C strip as defined in the Alternate Procedure of SAE Recommended Practices J 443, or MIL-S-13165B, Paragraph 6.11.

6.2.6 *Sequence*—Shot peening shall be performed on all wheels and after any corrective surface preparation in the plate area. Plate area is defined in 6.2.3. Peening may be performed prior to inspection.

6.2.7 *Portable Peeners*—A portable peening device may be used to re-peen small reconditioned areas (no larger than about 2 by 3 in. (50.8 by 76.2 mm)) on wheel plate surfaces excluding the critical fillet areas (front hub and back rim). The portable equipment must be capable of peening an Almen C-2 Strip to develop the required average arc height of not less than 0.008 in. (0.203 mm) with a reasonable time of peening. Peening time of wheel plates must be at least as long as the time required to develop the 0.008-in. arc height. The equipment must be tested on an Almen C Strip each 8-h shift that the portable peener is used. A record of the Almen C test results shall be maintained.

6.3 *Quality Assurance Provisions*:

6.3.1 *Wheel Surface Condition*—The peened appearance of rim and hub shall not be cause for rejection.

6.3.2 *Frequency of Test*—Arc height determinations shall be made on Almen strips attached to a test wheel at the beginning and end of each production run but not less than once in each eight operating hours.

6.3.3 *Retest*—If a test fails to meet the arc height requirements of 0.008 Almen C-2, two retests shall be made. These retests shall be averaged with the first determination. The average shall be not less than 0.008 and no more than one value of the three shall be less than 0.008.

6.3.4 *Repeening*—When test values fail to meet the provisions of 6.3.3, corrective action shall be initiated and satisfactory test values secured before proceeding with production peening. If the average Almen value of the unsatisfactory test is 0.006 or 0.007, the last half of the wheels peened prior to the unsatisfactory test, but subsequent to a satisfactory test, shall be repeened with at least ½ exposure time. If the average Almen value is less than 0.006, all the wheels peened since the last satisfactory test shall be repeened with full exposure.

7. Retreatment

7.1 Any wheel failing to meet the requirements of Section 12 may be retreated and tested in accordance with 12.1 and 12.2.

8. Mating

8.1 Wheels shall be measured and marked to the lower tape number until the next graduation is reached. Wheels shall be shipped in pairs of the same measured tape size.

9. Permissible Variations

9.1 The wheels shall conform to the permissible dimension variations specified in Table 2. When the permissible dimension variations in Table 2 allow a certain percentage of the wheels to vary by a given amount from standard dimensions for tape size, the percentage of such wheels shipped by any manufacturer shall not exceed this percentage during a calendar year. No individual purchaser may receive more than this percentage in daily shipments of such wheels except by agreement with the manufacturer.

10. Finish

10.1 Wheels shall be rough bored and shall not have black spots in the rough bore. The front hub face of wheels (1-W, 2-W, and M-W) shall be parallel to the plane of the vertical reference line and may be smooth forged or machined. The back hub face may be smooth forged or machined.

10.2 Wheels shall be machined and finished smooth without excessive tool chatter.

10.3 Wheels shall be given a thorough surface examination and gaging at the place of manufacture before being offered for inspection. They shall have a workmanlike finish and must be free of conditions likely to develop in or cause removal from service.

10.4 Wheels shall not be covered with any substance to such an extent as to hide defects.

10.5 "As forged'' surfaces shall be free of abrupt changes in section or grooves and in a clean condition free of scale prior to final inspection. Where corrective machining or grinding has been employed, such surfaces shall not exceed a roughness of 500 µin. (12.7 µm) prior to final shot peening, and a uniform transition from the machined or ground surface into the plane of the "as forged'' surface must be provided.

11. Chemical Requirements

11.1 *Heat or Cast Analysis*:

11.1.1 The steel shall conform to the requirements for chemical composition shown in Table 1.

11.1.2 An analysis of each heat or cast of steel shall be made by the manufacturer to determine the percentages of the elements specified in Table 1. This analysis shall be made from a test sample taken preferably during the pouring of the heat. The chemical composition thus determined, together with such

TABLE 2 Permissible Variations in Wheel Dimensions

Wheel Dimensions	Narrow Flange Type		Wide Flange Type	
	in.	mm	in.	mm
Flange:				
Height of flange	+1⁄16 −0	+1.6 −0	+1⁄16 −0	+1.6 −0
Thickness of flange	+1⁄16 −0	+1.6 −0	+1⁄32 −3⁄32	+0.8 −2.4
Radius of throat	±1⁄16	±1.6	±1⁄16	±1.6
Rim:				
Tape sizes, less than 44 in. (1.18 m)	+14 −0 ^{A}	+14 −0 ^{A}	+14 −0 ^{A} 5 % −5 ^{B}	+14 −0 ^{A} 5 % −5 ^{B}
Inside diameter (back face of rim)				
(x) maximum governed by rim thickness and tape size	(x) − 3⁄8	(x) −9.5	(x) −3⁄8	(x) −9.5
Inside diameter (front face of rim)				
Maximum variation from back face diameter	+0 −1⁄4	+0 −6.4	±1⁄4	±6.4
Thickness of rim (measured with AAR steel wheel gage, or equivalent)	^{C}	^{C}	^{D}	^{D}
Corner at inside diameter of back rim face, radius, max (sharp corner preferable)	1⁄8	3.2	1⁄8	3.2
Rotundity, opening in ring gage, max	1⁄32	0.8	1⁄32	0.8
Width of rim	±1⁄8	±3.2	±1⁄8	±3.2
Plane of back face, distance from straightedge:				
Over entire rim face, max	. . .	. . .	1⁄16	1.6
Over rim face more than 1¼ in. (31.8 mm) from inside edge, max	1⁄32	0.8	. . .	. . .
Plate:				
Thickness of plate (may vary)	−0	−0	−0	−0
Hub:				
Diameter of hub	+1 −0	+25.4 −0	+1 −0	+25.4 −0
Wall thickness maximum variations:				
Outer surface machined	1⁄8	3.2	. . .	. . .
Not machined	3⁄8	9.5	3⁄8	9.5
Length of hub	±1⁄8	±3.2	±1⁄4	±6.4
Depression of hub:				
Back rim face to front hub face	+0 −1⁄8	+0 −3.2	+0 −1⁄4	+0 −6.4
Projection of hub (back rim face to back hub face)	±1⁄8	±3.2	±1⁄4	±6.4
Bore:				
Diameter of bore:				
Rough bore (finished bore not specified)	+1⁄16 −1⁄8	+1.6 −3.2	+1⁄16 −1⁄8	+1.6 −3.2
Rough bore (1⁄4 in. (6.4 mm) less than finished bore)	+1⁄16 −1⁄8	+1.6 −3.2	+1⁄16 −1⁄8	+1.6 −3.2
Eccentricity of bore—between rough bore and tread, max	1⁄16 ^{E}	1.6 ^{E}	1⁄16 ^{E}	1.6 ^{E}

[A] Tape sizes are not in inches or millimetres. The tables of tape sizes may be referred to in the Wheel and Axle Manual of the Association of American Railroads, latest edition.

[B] No shipment shall exceed this percentage except by agreement with the manufacturer.

[C] Not less than specified and in any one wheel shall not vary more than 1⁄8 in. (3.2 mm).

[D] Ninety-five percent shall not be less than specified. Five percent may be 1⁄8 in. (3.2 mm) less than specified. One hundred percent shall not vary more than 1⁄8 in. (3.2 mm) on any two radii in any one wheel.

[E] 5 % of wheels delivered may be over 1⁄16 in. (1.6 WM) total dial indicator reading (TDIR), and these must not exceed 3⁄32 in. (2.4 mm) TDIR.

identifying records as may be desired, shall be reported to the purchaser or his representative and shall conform to the requirements specified in Table 1.

11.2 *Chemical Analysis*—Chemical analysis of each heat of steel shall be made by one of the following test methods. All analyses should note which test method is used for the carbon or chemical determinations, or both.

11.2.1 *Test Method I*—Apply one of the procedures given below in 11.2.1.1 through 11.2.1.3 to determine total carbon:

11.2.1.1 Total carbon by the combustion gravimetric method, Test Method E 350;

11.2.1.2 Total carbon by the combustion thermal conductivity method, Test Methods E 1019; or

11.2.1.3 Total carbon by combustion, followed by quantitative infrared analysis, Test Methods E 1019, or report the standardization method used.

11.2.2 *Test Method II*—Use Test Method E 415.

11.3 *Product Analysis*—An analysis may be made by the purchaser from a wheel block or from a finished wheel selected from each heat by the purchaser's representative. The chemical composition thus determined shall conform to the requirements specified in Table 1, with a permissible carbon variation of −0.02 or +0.03 percentage points. Samples from wheel blocks shall be drilled from the end of the block midway between the center and outside. When a finished wheel is used, the sample shall be obtained from the rim face or the hub in a manner that will not impair the usefulness of the wheel. No drilling of the finished wheel plate shall be permitted. Each sample from any one block or wheel shall be thoroughly mixed together and shall be clean, and free of scale, oil, and other foreign substances. Total carbon shall be determined in accordance with 11.2.1 above.

11.4 *Sampling Method*—When wheel blocks or when whole wheels are not available for chemical analysis, the laboratory conducting the chemical analysis shall follow a standard sampling method. This standard method of sampling shall be Practice E 59, used in conjunction with Test Methods E 350, E 415, or E 1019 for chemical analysis (see 11.2).

12. Mechanical Requirements

12.1 The Brinell hardness of the rim, when measured in accordance with the requirements of 12.2, shall show the values as listed in Table 3.

12.2 *Method of Measurement*—Measurement shall be made on the front face of the rim with the edge of the impression not less than $3/16$ in. (4.8 mm) from the radius joining face and tread. Before making the impression, any decarburized metal shall be removed from the front face of the rim at the point chosen for measurement. The surface of the wheel rim shall be properly prepared to permit accurate determination of hardness.

TABLE 3 Rim Hardness Values

Class	Minimum Hardness, HB	Maximum Hardness, HB
L	197	277
A	255	321
B	277	341
C	321	363

12.3 *Number of Tests*:

12.3.1 Where continuous heat-treating furnaces are used, Brinell hardness measurements shall be made on 10 % of the wheels from each heat. Where batch-type heat-treating furnaces are used, Brinell hardness measurements shall be made on 10 % of the wheels from each heat-treatment lot, provided that at least one wheel is selected for test from each heat represented in the heat treatment lot. For either process, when there are less than 20 wheels from a heat, a minimum of two wheels shall be checked for hardness except when there is only one wheel from a heat, in which case a Brinell hardness measurement shall be made on the one wheel.

12.3.2 If all the wheels tested meet the requirements of Section 12, all of the wheels represented shall be accepted.

12.3.3 If any wheel tested fails to meet the requirements of Section 12, it shall be checked by making two additional hardness measurements, one on each side of the point first measured and each approximately 1 in. (25.4 mm) from that point. If both of these check measurements meet the requirements of Section 12, the wheel shall be considered to have met the requirements of Section 12.

12.3.4 When continuous heat-treating furnaces are used, should any of the wheels tested fail on check test to meet the requirements of Section 12, the manufacturer may test for individual hardness measurements all of the wheels of that heat in the lot submitted for inspection and those meeting the requirements of Section 12 shall be accepted. Where batch heat-treating furnaces are used, should any of the wheels tested fail on check test to meet the requirements of Section 12, the manufacturer may test all of the wheels in the heat-treatment lot for individual hardness measurement and those meeting the requirements of Section 12 shall be accepted.

13. Inspection

13.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Mill inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspection shall be made at the place of manufacture, unless otherwise agreed.

13.2 The purchaser may make tests to govern the acceptance or rejection of the wheels in his own laboratory or elsewhere. Such tests shall be made at the expense of the purchaser.

13.3 The gages and tapes shall conform to and be used as required by the standards of the Mechanical Division, Association of American Railroads.

NOTE 2—The tables of tape sizes may be referred to in the Wheel and Axle Manual of the Association of American Railroads, effective Oct. 1, 1978.

13.4 *Ultrasonic Examination*—For detecting internal discontinuities in the rims of all steel wheels, ultrasonic inspection shall be made by following the procedures and by using equipment that complies with the following requirements:

13.4.1 *Equipment*:

13.4.1.1 The instrument shall have a pulse echo receiver and shall operate at frequencies of 2¼ to 5 MHz required for the test method and type of equipment being used.

13.4.1.2 The transducers shall be of the type whose composition and dimensions are appropriate for the test method used.

13.4.1.3 An automatic flaw alarm system shall be used in conjunction with the ultrasonic instrumentation.

13.4.1.4 A suitable couplant shall be used between the test surface and the transducer.

13.4.2 *Time of Inspection*—Inspection shall be performed after final thermal processing.

13.4.3 *Calibration*:

13.4.3.1 Calibration shall be conducted using a reference standard of a wheel or portion of a wheel rim containing simulated defects. The instrument sensitivity level should be adjusted to produce an approximate ½ full-scale reflection from the reference standards of 13.4.3.2, 13.4.3.3, and 13.4.3.4.

13.4.3.2 For axial testing the reference standard shall be a ⅛-in. (3.2-mm) diameter flat-bottom hole drilled perpendicular to the rim face and to a depth of 1 in. (25.4 mm) to 1½ in. (38.1 mm) at the mid-thickness of the rim (Fig. 1).

13.4.3.3 For radial testing the reference standard shall be a ⅛-in. (3.2-mm) diameter flat-bottom hole drilled from the inside diameter of the rim essentially parallel to the rim face. It shall be a minimum of 1¼ in. (31.8 mm) from the tread surface (Fig. 2).

13.4.3.4 The side of a small-diameter hole on the order of ¹⁄₁₆-in. (1.6-mm) to ⅛-in. (3.2-mm) diameter may be used when it is drilled the same distance from the testing surface. The instrument shall be adjusted to give an equal test value to that of a ⅛-in. diameter flat-bottom hole. This practice is an alternative for the reference standards of 13.4.3.2 and 13.4.3.3 (Fig. 1 and Fig. 2).

13.4.3.5 Reference standards for the inspection of heat-treated and untreated wheels shall be fabricated from heat-treated and untreated wheels, respectively. The reference standard need not be the same design as the wheels being inspected.

13.4.4 *Scanning*:

13.4.4.1 Wheels shall be inspected axially from either the front or the back rim face and radially from the tread surface.

13.4.4.2 One or more transducers shall be designed and located to give maximum coverage of the rim section, both radially and axially.

13.4.4.3 Scanning speed shall permit detection of reference standards.

13.4.5 *Rejection Due to Ultrasonic Indication*:

13.4.5.1 Any wheel with a flaw indication equal to or larger than that the reference discontinuity shall be cause for rejection.

13.4.5.2 Ultrasonic indications that result from wheel geometry or spurious electrical signals shall not be valid cause for rejection.

13.4.5.3 When automated equipment is used, the final disposition of rejectable wheels may be determined by manual testing of questioned areas.

13.4.5.4 The final disposition of rejectable wheels may be determined by manual testing of questioned areas.

13.5 *Magnetic Particle Inspection*:

13.5.1 *Purpose*—To supplement visual inspection of the surface of new wheels by detecting discontinuities which may be harmful to wheel service.

13.5.2 *Scope*—This test method covers the wet fluorescent magnetic particle inspection of the plates of wheels ordered to this specification.

13.5.3 *Equipment*:

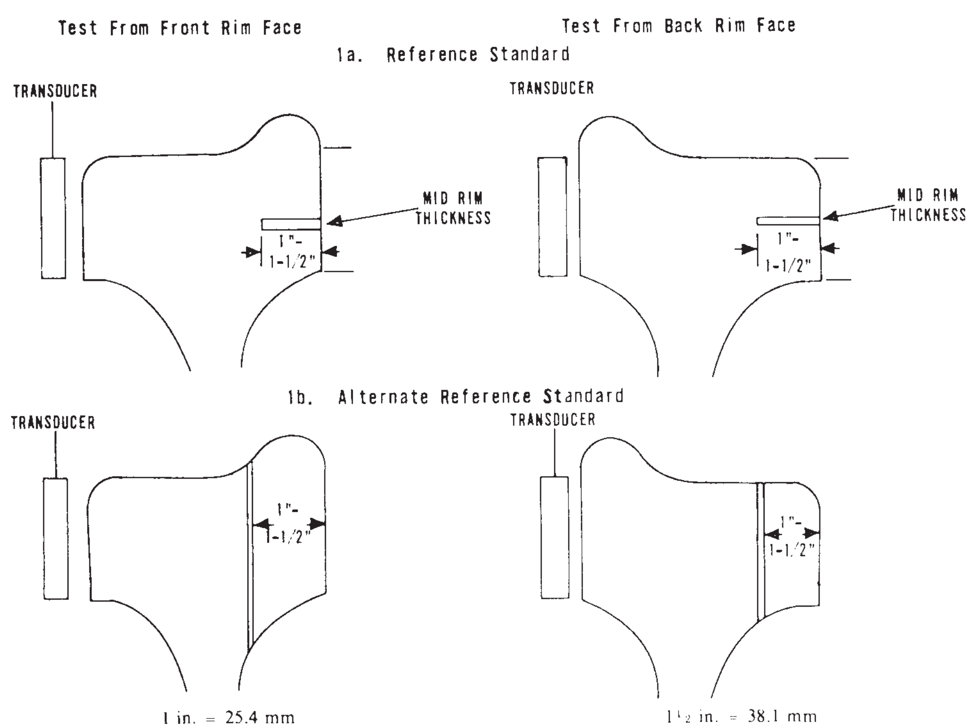


FIG. 1 Typical Reference Standards for Rim Face Test

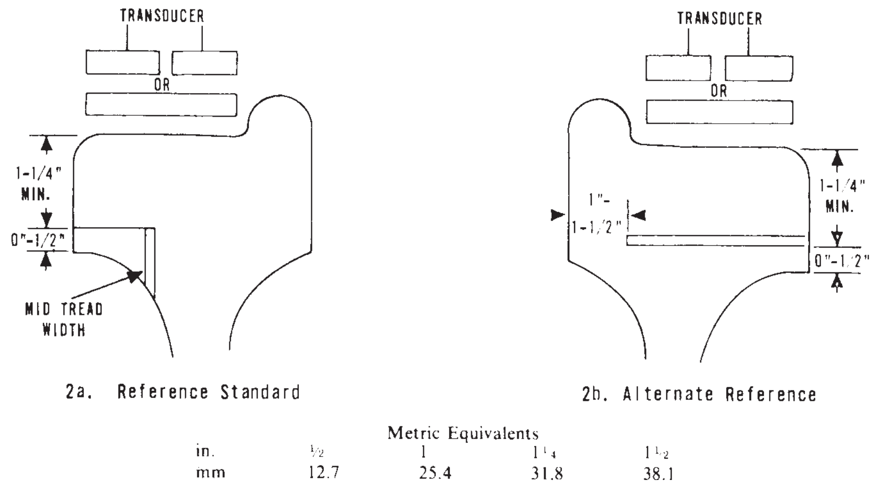


FIG. 2 Typical Reference Standards for Rim Tread Test

13.5.3.1 *Magnetizing Apparatus*—The magnetizing apparatus shall be capable of inducing suitable magnetic fields within the entire plate area of the wheel to facilitate the disclosure of both circumferentially and radially oriented discontinuities. The magnetizing currents used shall be large enough to induce magnetic fields of sufficient intensity to disclose surface discontinuities exceeding 0.015 in. (0.38 mm) in depth and ¼ in. (6.35 mm) long. The use of prod-type contacts is prohibited.

13.5.3.2 *Lighting Apparatus*—The inspection shall be performed in a darkened booth with the areas of the wheel to be inspected illuminated with properly filtered black light. The black light shall have a predominant wavelength of 4000 to 3400 Å (400 to 340 nm) and the intensity of the black light, measured at the surface to be inspected, shall be a minimum of 75 footcandles (807 lx) at point of inspection.

13.5.3.3 *Inspection Medium*—The bath or solution should be prepared, using a suitable carrier fluid and fluorescent magnetic particles, and renewed monthly or more often, if contamination is noted in weekly tests. Each time the bath is renewed the bath container should be cleaned out and the agitation and circulation system should be flushed with one or two gallons of clean carrier. Filtering screens should be removed and cleaned by blowing with air. In preparing the new bath, only recommended materials should be used. The amount of powder should be carefully weighed out in accordance with the material manufacturer's recommendation and added directly to the bath containing the correct amount of carrier. It is recommended that powder be added directly over the sump so that it will be drawn quickly into the sump and circulated. The amount of carrier and powder used and the date of preparation should be recorded on a regular form set up for this purpose as outlined in (*e*) below.

(a) (a) Concentration and contamination of the bath solution should be tested weekly as follows: the pump and agitation system should be circulated for 20 min and then the solution should be run through the hose and nozzle for 30 s. Using a regular 100-mL centrifuge tube, fill the centrifuge tube with 100 mL of the solution. Allow the bath solution to settle, for the time recommended by the manufacturer of the type of powder used, making sure that the tube is not subjected to excessive vibration during the settling period. Each horizontal division represents 0.1 mL, and correct readings in volume of particles must be as stipulated by the powder manufacturer. The check should also note contamination due to dirt, chips, or other foreign matter settling with the powder. Contamination is also indicated when the carrier appears to acquire more than usual fluorescence or when the magnetic particles appear to have lost fluorescent qualities. This condition can be readily observed when the settling tube is exposed to ultraviolet light. The readings obtained are to be shown on the regular report form.

(b) (b) The ultraviolet light should be tested weekly using a sight meter, such as a type having 75 footcandles (807 lx) scale with 10× multiplying disc or equivalent or a meter that responds specifically to the ultraviolet range of 3650 Å (365 nm). The latter type meters are calibrated in microwatts per square centimetre. The meter should be held a fixed distance of 15 in. (380 mm) from the light source (from black light filter surface to meter-sensing element) and should have a minimum meter reading of 525 $\mu W/cm^2$.

(c) (c) The conversion factor from footcandles (for sight meters) to microwatts per square centimetre is 5.7 times the footcandle readings (at 15 in. (380 mm) distance).

(d) (d) The maximum allowable footcandles will be left to the discretion of the user dependent on the degree of brilliance desired to obtain satisfactory inspection conditions. Before taking readings, it should be known that the glass black light filters are clean. Reports of this test are to be shown on regular form.

(e) (e) A regular form should be prepared embodying the information to be shown on monthly and weekly tests as outlined above. This form should be available at the wheel shop and to customer's inspectors.

13.5.4 *Preparation for Inspection*—The surface shall be scale-free before magnetic particle inspection.

13.5.5 *Procedure for Detection of Discontinuities*—Perform the inspection to detect discontinuities whose axes may be in any direction. Use continuous or residual magnetization with adequate coverage by the inspection medium.

13.5.6 *Time of Inspection*—The magnetic particle inspection shall be performed following final machining.

13.5.7 *Rejection*—Interpretation of magnetic particle discontinuity indications is based upon their location, size, direction, and shape. Experience with service performance and destructive testing shall be used for evaluation. Discontinuities may be removed by machining or grinding where sufficient stock remains. Such wheels shall be retested by magnetic particle inspection.

14. Rejection and Rehearing

14.1 Wheels that show injurious defects subsequent to original inspection and acceptance at the manufacturer's works, or elsewhere, shall be rejected, and the manufacturer shall be notified.

14.2 Samples tested in accordance with this specification, which represent rejected wheels, shall be held for a period of 14 days from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may request a rehearing within that time.

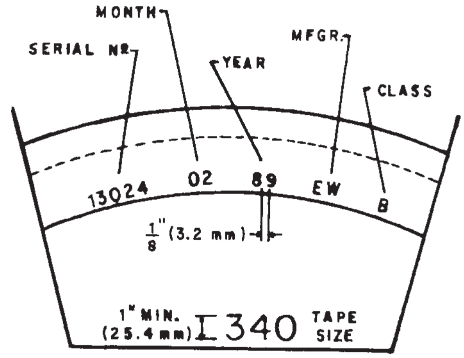
15. Certification

15.1 At the purchaser's request, a certification shall be made the basis of acceptance of the material. This shall consist of a copy of the manufacturer's test report that the material has been sampled, tested, and inspected in accordance with the provisions of this specification. Each certificate so furnished shall be signed by an authorized agent of the supplier or manufacturer. The specification year of issue and revision letter, if any, shall be included in the certification.

16. Marking

16.1 Identification markings shall be legibly stamped as shown in Fig. 3 or Fig. 4. Wheels for freight service must be hot stamped or cold stamped on the back hub face. If any stamped characters are missing or illegible, these shall be replaced by cold stamping in the proper place in the marking sequence. Passenger car wheels may be hot stamped or cold stamped on front or back (as specified by the purchaser) hub face. Locomotive wheels may be hot or cold stamped on the back rim face. When ordered, locomotive wheels may be cold stamped on the front hub face as shown in Fig. 4. Locomotive wheels that are to receive final hub machining by the purchaser may be ordered with markings paint stencilled on the wheel plate. After final machining, the purchaser will cold stamp the markings on the front hub face.

16.2 The tape size of all wheels shall be paint stenciled on back plates. An "H" shall also be paint stenciled on the front plate of curved plate, heat treated, freight car wheels for interchange use. The characters shall be at least 1 in. (25.4 mm) high.



NOTE 1—Stamping shall consist of manufacturer's serial number, date of manufacture, manufacturer's identification, and class of heat treatment. Stamping is limited to 14 characters, and the design designation shall be stencilled on the back plate with paint using characters at least 1 in. (25.4 mm) in height.

NOTE 2—Stamping shall be spaced a minimum of ⅛ in. (3.8 mm) between characters and 1⅜ in. (35 mm) between groups. The stamping shall be located not less than ¼ in. (6.35 mm) from the inner edge of the rim.

NOTE 3—Manufacturer's identification is limited to two initials: A—Armco (no longer in production); BW—Bethlehem (no longer in production); CW—U.S. Steel (Pittsburgh Plant) (no longer in production); EW—Edgewater; —Valdunes (Dunquerque Plant); G—U.S. Steel (Gary Plant) (no longer in production); JW—Sumitomo Metal Industries; KW—Klockner Inc.; —Terni; MW—Mafersa; P—British Steel (Templeborough & Ickles Works) (no longer in production); SW—Standard Steel; TW—British Steel (Trafford Park Works); VW—Valdunes (Valenciennes Plant); ZW—Canadian Steel Wheel.

NOTE 4—Dies used to produce characters shall be not less than ⅜ in. (9.5 mm) in nominal height at crest and hot stamping shall be nominally 3⁄32 in. (2.4 mm) in depth. Italicized characters (sloped upward to right) shall be used.

NOTE 5—All wheels shall be marked for class using letters U, L, A, B, or C, as appropriate.

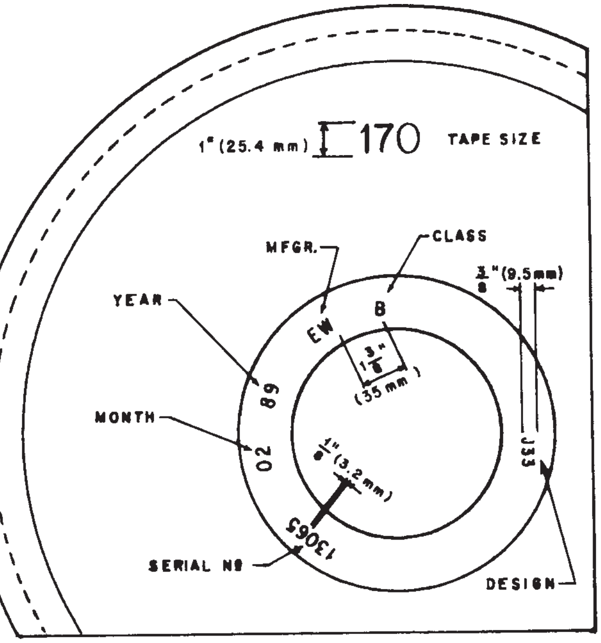
FIG. 3 Marking of Wrought Steel Locomotive Wheels—Rim Stamping

16.3 Stencil paint will be zinc chromate primer or equivalent that will have a minimum service life of one year.

16.4 In addition to the above required markings, bar code tags may be applied to the wheels. If these tags are applied, it is recommended that Bar Code 39 be used. The size and location of the tags, as well as the information to be included, shall be agreed upon by the purchaser and the manufacturer.

17. Keywords

17.1 rail applications; steel wheels; wrought steel



NOTE 1—Locomotive wheels are stamped on the front hub face; wheels for freight service are stamped on the back hub face and wheels for passenger service are stamped on the front or back (as specified by purchaser) hub face.

NOTE 2—Stamping shall consist of manufacturer's serial number, date of manufacture, manufacturer's identification, class of heat treatment and design designation in order as shown above. The hub stamping of locomotive wheels may be applied by the purchaser after final machining of the hub. Wheels that shall be marked by the purchaser should be furnished with all markings stencilled on the front plate with paint using characters at least 1 in. (25.4 mm) in height.

NOTE 3—The manufacturer's identification is limited to two initials: A—Armco (no longer in production); BW—Bethlehem (no longer in production); CW—U.S. Steel (Pittsburgh Plant) (no longer in production); EW—Edgewater; —Valdunes (Dunquerque Plant); G—U.S. Steel (Gary Plant) (no longer in production); JW—Sumitomo Metal Industries; KW—Klockner Inc.; —Terni; MW—Mafersa; P—British Steel (Templeborough & Ickles Works) (no longer in production); SW—Standard Steel; TW—British Steel (Trafford Park Works); VW—Valdunes (Valenciennes Plant); ZW—Canadian Steel Wheel.

NOTE 4—Stamping shall be spaced a minimum of ⅛ in. (3.18 mm) between characters and a minimum of 1⅜ in. (35 mm) between groups and located approximately central of the hub face.

NOTE 5—Stamps used to produce characters shall be not less than ⅜ in. (9.5 mm) in height and shall not have sharp edges. Italicized characters (sloped upward to the right) shall be used.

NOTE 6—All wheels will be marked for class using letters U, L, A, B, or C as appropriate.

NOTE 7—The three groups: (*1*) serial number; (*2*) date of manufacture, manufacturer, and class; and (*3*) design, shall be spaced approximately equidistant around the hub face.

FIG. 4 Marking of Wrought Steel Wheels—Hub Stamping

Designation: A 508/A 508M – 04a

Standard Specification for Quenched and Tempered Vacuum-Treated Carbon and Alloy Steel Forgings for Pressure Vessels[1]

This standard is issued under the fixed designation A 508/A 508M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification[2] covers quenched and tempered vacuum treated carbon and alloy steel forgings for pressure vessels such as those used in reactor systems. Specifically, it covers forgings for vessel closures, shells, flanges, tube sheets, rings, heads, and similar parts.

1.2 All grades are considered weldable under proper conditions. Welding technique is of fundamental importance, and it is presupposed that welding procedure and inspection will be in accordance with approved methods for the grade of material used.

1.3 The values stated in either inch-pound units or SI (metric) units are to be regarded separately as standards. Within the text and the tables, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independent of the other. Combining values from the two systems may result in nonconformance with the specification.

1.4 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch-pound units.

NOTE 1—Grades 1 and 1A are composed of different chemistries but have the same mechanical requirements.

NOTE 2—Designations have been changed as follows:

Current	Formerly
Grade 1	Class 1
Grade 1A	Class 1A
Grade 2 Class 1	Class 2
Grade 2 Class 2	Class 2A
Grade 3 Class 1	Class 3
Grade 3 Class 2	Class 3A
Grade 4N Class 1	Class 4
Grade 4N Class 2	Class 4A
Grade 4N Class 3	Class 4B
Grade 5 Class 1	Class 5
Grade 5 Class 2	Class 5A
Grade 22 Class 3	Class 22B
Grade 22 Classes 4, 5, 6, and 7	
Grade 3V	Class 3V

2. Referenced Documents

2.1 *ASTM Standards:* [3]

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings

A 788 Specification for Steel Forgings, General Requirements

E 208 Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels

E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection

2.2 *American Society of Mechanical Engineers Standard:*

Boiler and Pressure Vessel Code—Section III, Articles NB 2300, NC 2300, ND 2300, NE 2300, NF 2300, NG 2300[4]

3. Ordering Information

3.1 *Purchase Order*—In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order a detailed drawing that locates the areas of significant loading in the forging (when required), the method of selecting test locations (see 6.1.5 and 6.1.6), and purchase options (see 4.2.2, 6.2.1, and 10.1) and any supplementary requirements desired.

3.2 *Forging Drawing*—Each forging shall be manufactured in accordance with a purchaser-approved drawing showing the

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-508/SA-508M in Section II of that Code.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017.

***A Summary of Changes section appears at the end of this standard.**

prequenched dimensions, the finished dimensions, the surfaces that will be subjected to significant loading, and the locations of mechanical test specimens.

3.3 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

3.4 The optional minimum silicon content as expressed in Note A to Table 1, if required.

3.5 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

4. Materials and Manufacture

4.1 *Melting Process*:

4.1.1 The steel shall be made by the basic electric-furnace process except when secondary ladle refining or the remelting process is employed, in which case the melting processes of Specification A 788 are permitted.

4.1.2 The molten steel shall be vacuum treated in accordance with the methods described in Specification A 788, prior to or during the pouring of the ingot, in order to remove objectionable gases, particularly hydrogen.

Grade 22 Classes 4, 5, 6, and 7 liquid steel shall be produced to a fine grain melting practice which has been shown to result in a prior austenitic grain size of five or finer.

4.1.3 *Discard*—Sufficient discard shall be made from each ingot to secure freedom from piping and excessive segregation.

4.2 *Heat Treatment*:

4.2.1 *Preliminary Heat Treatment*—After forging and before reheating, the forgings shall be cooled to provide substantially complete transformation of austenite. Preliminary heat treatment may be applied to improve machinability and to enhance subsequent heat treatments.

4.2.2 *Heat Treatment for Mechanical Properties*—The forgings shall be heated to a temperature which produces an austenitic structure and then quenched in a suitable liquid medium by spraying or immersion. For Grade 4N, Classes 1 and 3, the austenitizing temperature shall be 1540°F [840°C] min to 1640°F [895°C] max. Quenching shall be followed by tempering at a subcritical temperature and holding at this temperature for a minimum time of one-half hour per inch of maximum section thickness. Except when Supplementary Requirement S 13 is specified for Grades 2 and 3, the minimum tempering temperatures shall be as follows:

Grades 1, 1A, 2 Class 2, and 3 Class 2	1150°F [620°C]
Grades 2 Class 1 and 3 Class 1	1200°F [650°C]
Grades 4N Classes 1 and 2, and 5 Classes 1 and 2	1100°F [595°C]
Grade 4N Class 3	1125°F [605°C]
Grades 3V and 3VCb	1250°F [675°C]
Grade 22, Class 3	1200°F [650°C]
Grade 22, Classes 4, 5, 6, and 7	1100°F [593°C]

Specific cooling rates from the tempering temperature shall be applied if Supplementary Requirement S14 is specified.

4.3 For Grades 1, 1A, 2, 2A, 3, or 3A, a multiple stage austenitizing procedure may be used whereby the forging is first fully austenitized and liquid quenched, followed by reheating within the intercritical temperature range to partially reaustenitize and again liquid quenched. On completion of the austenitizing/quenching cycles, the forgings shall be tempered at a subcritical temperature as described in 4.2.2.

5. Chemical Composition

5.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 shall comply with Table 1 except that the additional features of Supplementary Requirements S7, S8, S9, and S11 shall also apply as individually specified in the ordering information.

5.2 *Product Analysis*—The manufacturer shall use the product analysis provision of Specification A 788 to obtain a product analysis from a forging representing each heat or multiple heat. The permissible variations provided in the table on Permissible Variations in Product Analysis for Killed Steel in Specification A 788 apply for manganese, nickel, chromium, molybdenum and vanadium only. Boron is not subject to

TABLE 1 Chemical Requirements

	Composition, %									
	Grade 1	Grade 1A	Grade 2	Grade 3	Grade 4N	Grade 5	Grade 22[A]	Grade 3V	Grade 3VCb	Grade 6
Carbon	0.35 max	0.30 max	0.27 max	0.25 max	0.23 max	0.23 max	0.11–0.15	0.10–0.15	0.10–0.15	0.28–0.33
Manganese	0.40–1.05	0.70–1.35	0.50–1.00	1.20–1.50	0.20–0.40	0.20–0.40	0.30–0.60	0.30–0.60	0.30–0.60	0.75–1.15
Phosphorus	0.025 max	0.025 max	0.025 max	0.025 max	0.020 max	0.020 max	0.015 max	0.020 max	0.020 max	0.025 max
Sulfur	0.025 max	0.025 max	0.025 max	0.025 max	0.020 max	0.020 max	0.015 max	0.020 max	0.010 max	0.025 max
Silicon[B]	0.40 max	0.40 max	0.40 max	0.40 max	0.40 max	0.30 max	0.35 max	0.35 max	0.10 max	0.15–0.35
Nickel	0.40 max	0.40 max	0.50–1.00	0.40–1.00	2.8–3.9	2.8–3.9	0.25 max	. . .	0.25 max	0.75–0.95
Chromium	0.25 max	0.25 max	0.25–0.45	0.25 max	1.50–2.00	1.50–2.00	2.00–2.50	2.8–3.3	2.7–3.3	0.70–1.00
Molybdenum	0.10 max	0.10 max	0.55–0.70	0.45–0.60	0.40–0.60	0.40–0.60	0.90–1.10 max	0.90–1.10	0.90–1.10	0.30–0.45
Vanadium	0.05 max	0.05 max	0.05 max	0.05 max	0.03 max	0.08 max	0.02 max	0.20–0.30	0.20–0.30	0.05 max
Columbium	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.015–0.070	0.01 max[C]
Copper	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.25 max	...
Calcium	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.0005–0.0150	...
Boron	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.001–0.003	. . .	...
Titanium	. . .	. . .	. . .	. . .	. . .	. . .	[D]	0.015–0.035	0.015 max	[C]
Aluminum	...	...	...	...	...	...	0.025 max	...	...	0.05 max

[A] For Grade 22 Classes 5, 6, and 7 with section thickness at heat treat of 8 in.or greater, this carbon or manganese shall be held to 0.13 to 0.15 and 0.50 to 0.60 respectively.

[B] When required by the purchaser a minimum silicon content of 0.15 % shall apply for Grades 1, 1A, 2, 3, and 4N.

[C] Intentional addition of Cb and Ti not permitted.

[D] Intentional additions of Cb and Ti not permitted.

product analysis. The purchaser may also make this determination in accordance with Specification A 788.

6. Mechanical Properties

6.1 *Tension Test*:

6.1.1 The steel shall conform to the requirements of Table 2.

6.1.2 The location and number of tension test specimens for each forging or multiple forging shall be as follows:

6.1.2.1 *Multiple Forgings Separated into Identical Individual Forgings with Rough Machined Weights not Exceeding 1000 lb [455 kg] Prior to Quenching and Tempering Treatment*—At least one individual forging from each multiple forging in each heat-treating lot shall be tested using the test specimen locations of 6.1.5 or 6.1.6 as specified on the purchase orders, except that test specimens located at midlength may be closer to the ends of the production forging than the specified distance to the second surfaces. All forgings shall be quenched and tempered in the same furnace charge. All forgings from the multiple shall be Brinell hardness tested after heat treatment and forgings not tested for mechanical properties shall have a Brinell Hardness within 20 points of the Brinell Hardness of the forging that has been tested for mechanical properties.

6.1.2.2 *Forgings or Multiple Forgings (*Note 2*) with Rough Machined Weights Less than 10 000 lb [4540 kg] and Having a Heat-Treated Length (Exclusive of Test Prolongation) of 80 in. [2032 mm] or Less*—A test prolongation (Note 3) shall be located at one end. One tension test specimen shall be taken from the test prolongation.

6.1.2.3 *Forgings or Multiple Forgings with Rough Machined Weights Less than 10 000 lb [4540 kg] and Having a Heat-Treated Length (Exclusive of Test Prolongations) Exceeding 80 in. [2032 mm]*— A test prolongation shall be located at each end. One tension test specimen shall be taken from each test prolongation. An orientation of 180° shall be established between the two tension test specimens.

6.1.2.4 *Forgings or Multiple Forgings with Rough Machined Weights Over 10 000 lb [4540 kg] and Having a Heat-Treated Length (Exclusive of Test Prolongation) of 80 in. [2032 mm] or Less*—A test prolongation shall be located at one end. Two tension test specimens shall be taken from the test prolongation and shall be oriented 180° apart.

6.1.2.5 *Forgings or Multiple Forgings with Rough Machined Weights Over 10 000 lb [4540 kg] and Having a Heat-Treated Length (Exclusive of Test Prolongations) Exceeding 80 in [2032 mm]*—A test prolongation shall be located at each end. The tension test specimens oriented 180° apart from each other shall be taken from each test prolongation. The two tension specimens located in one test prolongation shall be oriented 90° in relation to the two tension specimens located in the other test prolongation.

NOTE 3—Multiple forgings in 6.1.2.2 through 6.1.2.5 are those which will be separated after the quench and temper treatment.

NOTE 4—A test prolongation is defined as that integral test metal located at an end of the forging or forging multiples.

6.1.3 Samples for mechanical test specimen shall be removed from forgings after the quenching and tempering heat treatment. The sample material shall be subjected to a simulated post weld heat treatment if Supplementary Requirement S1 is specified.

6.1.4 For upset disk forgings, the longitudinal axis of the test specimens shall be in the tangential direction. For all other parts, the longitudinal axis of the specimens shall be parallel to the direction of major working of the forging.

6.1.5 Each forging shall be manufactured in accordance with a purchaser-approved drawing, showing the prequenched dimensions, the finished dimensions, the surfaces that will be subjected to critical stresses, and the location of mechanical test specimens.

6.1.6 The tension test specimens shall be positioned so that the longitudinal axis and mid-length is in accordance with one of the following methods:

6.1.6.1 *Method 1—t* by 2*t*, where *t* is the distance from the area of significant loading (see 3.1) to the nearest quenched surface. However, they shall not be nearer to one quenched surface than ¾ in. [20 mm] and to the second quenched surface than 1½ in. [40 mm].

6.1.6.2 *Method 2*—¼ *T* by *T*, where *T* is the maximum thickness of the forging as heat treated. Where this method of testing is employed, the following limitations for as-treated thickness shall generally apply:

Grades 1 and 1a	3 in. [75 mm], max
Grades 2 Class 2 and 3 Class 2	6 in. [150 mm], max
Grades 2 Class 1 and 3 Class 1	8 in. [205 mm], max
Grade 4N Class 2 and 5 Class 2	16 in. [405 mm], max
Grade 4N Class 1 and 5 Class 1	30 in. [760 mm], max
Grade 4N Class 3	40 in. [1015 mm], max
Grades 3V and 3VCb	20 in. [510 mm], max
Grade 22 Class 3	20 in. [510 mm], max
Grade 22 Classes 4, 5, 6, and 7	12 in. [305 mm], max

6.1.6.3 *Method 3*—Test specimens shall be taken from a representative separate test forging made from the same heat of steel and shall receive substantially the same reduction and type of hot working as the production forgings that it represents and shall be of the same nominal thickness as the as-quenched production forgings. The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forgings. Test specimens shall be removed from the region midway between the mid-thickness and the surface, and not closer than *T* to a second heat treated surface with the same limitation on forging thickness as in 6.1.6.2. This method shall be limited to forgings with a rough machined weight of not more than 1000 lb [455 kg].

6.1.6.4 *Method 4*—A thermal buffer ring, at least *T* by *T* in cross section, or segments of such a ring at least 3*T* in length, shall be welded to the test end of a forging prior to heat treatment for mechanical properties. The buffer material may be any weldable carbon or low-alloy steel and shall be joined to the forging with a partial-penetration type weld which completely seals the buffered surface. The test coupons shall be removed from the forging in the region buffered by the ring or ring segments. If ring segments are used, the test coupons shall be removed from the forging in the area under the buffer ring segment at a minimum distance of *T* from each end of that segment. In either case, the test specimens shall be located at a minimum distance of ½ in. [13 mm] from the buffered

TABLE 2 Tensile Requirements

	Grades 1 and 1a	Grades 2 Class 1 and 3 Class 1	Grades 2 Class 2 and 3 Class 2	Grades 4N Class 1 and 5 Class 1	Grades 4N Class 2 and 5 Class 2	Grade 4N Class 3	Grade 22 Class 3	Grades 3V and 3VCb	Grade 6 Class 1	Grade 6 Class 2	Grade 6 Class 3	Grade 6 Class 4	Grade 22 Class 4	Grade 22 Class 5	Grade 22 Class 6	Grade 22 Class 7
Tensile strength, ksi [MPa]	70 – 95 [485 – 655]	80 – 105 [550 – 725]	90 –115 [620 – 795]	105 – 130 [725 – 895]	115 – 140 [795 – 965]	90 – 115 [620 – 795]	85 – 110 [585 – 760]	85 – 110 [585 – 760]	85 – 110 [585– 760]	95 – 120 [655 – 825]	100 – 125 [690 – 860]	105 – 130 [725 – 895]	85 – 110 [585 – 760]	95 – 120 [655 – 825]]	100 – 125 [690 – 860]	105 – 130 [725 – 895]
Yield strength, min [0.2 % offset], ksi [MPa]	36[250]	50[345]	65[450]	85[585]	100[690]	70[485]	55[380]	60[415]	60[415]	75[515]	80[550]	85[585]	60 [415]	75 [515]	80 [550]	85 [585]
Elongation in 2 in. or 50 mm, min, %	20	18	16	18	16	20	18	18	20	18	18	18	20	18	18	18
Reduction of area, min, %	38	38	35	45	45	48	45	45	35	35	35	35	35	35	35	35

surface of the forging, and at least ¼ T from a quenched surface of the forging.

NOTE 5—For forgings with a maximum thickness of 2 in. [50 mm], the specimens shall be taken at midthickness and at least 2 in. from a second surface. This provision is applicable to all four methods in 6.1.6.

6.1.7 Tension specimens shall be the standard 0.5 in. [12.5 mm] round by 2 in. [50 mm] gage length, as shown in Test Methods and Definitions A 370.

6.2 *Impact Test*:

6.2.1 The steel shall conform to the requirements of Table 3, or Supplementary Requirement S10 may be specified instead of these requirements.

6.2.2 *Number, Location, and Orientation of Specimens*:

6.2.2.1 One set of three Charpy V-notch specimens shall be taken from each tensile specimen location required in 6.1.2. Orientation shall be the same as in 6.1.4. When S10 is specified, the required number of tests shall be governed by NB, NC, ND, NE, NF, or NG 2300, as applicable.

6.2.2.2 The requirements of 6.1.3 also apply to impact specimens.

6.2.2.3 The longitudinal axis and mid-length of the impact specimen shall be located similarly to the longitudinal axis of the tension test specimens as defined in 6.1.6. The axis of the notch shall be normal to the nearest heat-treated surface of the forging. When S10 is specified the orientation shall be governed by NB, NC, ND, NE, NF, or NG 2300.

6.2.3 Impact specimens shall be Charpy V-notch as shown in Test Methods and Definitions A 370.

7. Workmanship and Quality Level Requirements

7.1 See requirements in 8.1, 8.2.2, 8.3.1.1, and 8.3.2.2.

8. Nondestructive Inspection Requirements

8.1 *General Requirements*—Dimensional and visual inspections, and magnetic particle and ultrasonic inspection shall be conducted by the manufacturer. Forgings shall be free of cracks, thermal ruptures, or other injurious indications.

8.2 *Magnetic Particle Inspection*:

8.2.1 Following final machining by the manufacturer all accessible surfaces of each forging shall be examined by the continuous current magnetic particle method in accordance with Test Method A 275/A 275M.

8.2.2 The following conditions are subject to rejection or removal:

8.2.2.1 Indications with major dimension exceeding 3⁄16 in. [4.8 mm].

8.2.2.2 Four or more indications exceeding 1⁄16 in. [1.6 mm] in major dimensions that are aligned and separated by 1⁄16 in. [1.6 mm] or less end to end.

8.2.2.3 Ten or more indications exceeding 1⁄16 in. [1.6 mm] in major dimensions contained in any 6 in.^{2} [39 cm^2] of surface, with the major dimension of this area not to exceed 6 in. [150 mm]. The area shall be taken in the most unfavorable location relative to the indications being evaluated.

8.3 *Ultrasonic Inspection*—Forgings shall be ultrasonically inspected in accordance with the procedures of Practice A 388/A 388M.

8.3.1 *Longitudinal Wave Inspection*:

8.3.1.1 Unless otherwise specified by Supplementary Requirement S2, the back reflection method of tuning shall be used in accordance with 7.2.2.1 of Practice A 388/A 388M. In addition to the reportable conditions in Section 7 of Practice A 388/A 388M, indications exceeding the resultant back reflection shall be recorded. The following conditions are considered rejectable:

8.3.1.2 Complete loss of back reflection not associated with forging configuration or surface and accompanied by an indication of a discontinuity. For this purpose, a back reflection less than 5 % of full screen height shall be considered complete loss of back reflection.

8.3.1.3 Indications whose amplitude equals or exceeds that of the back reflection established in an indication-free area of the forging.

8.3.2 *Angle Beam Inspection*:

8.3.2.1 Calibration notches shall be cut into the inside- and outside-diameter surfaces with a depth equal to 3 % of the nominal section thickness (or 3⁄8 in. [9.5 mm], max), a length of approximately 1 in. [25 mm], and a width not greater than twice its depth. Adjust instrument controls to obtain an indication from the inside-diameter notch approximately 75 % of full screen height. Measure the amplitude of indication from the outside-diameter notch. Draw a straight line on the shield in front of the cathode ray tube from this peak to that of the inside-diameter notch and continue it as a horizontal line to the initial pulse. This line constitutes the angle beam reference line.

8.3.2.2 A forging containing a discontinuity which results in an indication exceeding the amplitude of the reference line is subject to rejection.

NOTE 6—Signals from discontinuities within approximately ¼ in. [6.4 mm] of inside and outside surfaces are reinforced by wave trapping during angle beam inspection; they are therefore amplified in respect to internal discontinuities.

8.3.3 The report of the ultrasonic inspection shall be in compliance with Section 8 of Practice A 388/A 388M.

8.3.4 Additional nondestructive inspection or trepanning may be employed to resolve questions of interpretation of ultrasonic indications. The manufacturer shall accept responsibility for injurious indications which will not be removed in final machining.

9. Repair Welding

9.1 Repair welding of forgings may be permitted, but only at the option of the purchaser.

9.2 If repair welding is performed, welders and weld procedures shall be qualified in accordance with Section IX of the ASME Boiler and Pressure Vessel Code.

10. Certification and Reports

10.1 In addition to items to be reported by Specification A 788, the following items shall also be reported:

10.1.1 Product chemical analysis,

10.1.2 The method used for locating test specimens, and

10.1.3 Sketches showing the locations of all recordable indications in the report of all nondestructive examinations.

TABLE 3 Charpy Impact Requirements

	Grades 1 and 1a at +40°F [4.4°C]	Grades 2 Class 1 and 3 Class 1 at +40°F [4.4°C]	Grades 2 Class 2 and 3 Class 2 at +70°F [21°C]	Grades 4N (all classes) and 5 (all classes) at −20°F [−29°C]	Grade 22, Class 3, and Grades 3V and 3VCb at 0°F [−18°C]	Grade 6 Classes 1, 2, 3, and 4 at –75°F [−59°C]	Grade 22 Classes 4, 5, 6, and 7 at –75°F [−60°C]
Minimum average value of set of three specimens, ft·lbf (J)[A]	15[20]	30[41]	35[48]	35[48]	40[54]	20[27]	40 [55]
Minimum value of one specimen, ft lbf (J)	10[14]	25[34]	30[41]	30[41]	35[50]	15[20]	35 [50]

[A] Not more than one specimen from a set may be below this value.

10.1.4 Details of the heat treatment cycle, as listed in Specification A 788.

11. Product Marking

11.1 The purchaser may specify additional identification marking and the location of the stamping. The type of stamps to be used when impression stamping is performed shall be round-nosed or "interrupted-dot" die stamps having a minimum radius of 1⁄32 in. [0.8 mm].

12. Keywords

12.1 chromium-molybdenum steel; nickel-chromium-molybdenum alloy steels; pressure vessel service; quenched and tempered steels; steel forgings—alloy; steel forgings—carbon; vacuum-treated steels

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry or order. Details of these supplementary requirements shall be agreed upon between the manufacturer and the purchaser.

S1. Simulated Post-Weld Heat Treatment of Mechanical Test Samples

S1.1 All test coupons shall be subjected to single or multiple heat treatments at subcritical temperatures prior to testing. Such treatments are intended to simulate post-weld or other treatments to which the forgings will be subjected during subsequent fabrication. The purchaser shall furnish the manufacturer with details of the desired heat treatment for the test coupons, including temperatures, timers, and cooling rates.

S2. Ultrasonic Testing-Reference Block Calibration (for examining sections 24-in. [610 mm] thick or less)

S2.1 Reference blocks of acoustically similar metal shall be used for calibration. Blocks shall meet one of the following requirements:

S2.1.1 A comparison of the back reflections between equivalent thicknesses of the reference block material and the actual forging to be tested, without change in instrument setting shall not show a variation in excess of 25 %.

S2.1.2 The reference blocks shall be manufactured from steel that is similar in chemistry and processing history to the production forging being tested. The reference blocks shall be fabricated in accordance with the procedures of Practice E 428.

S2.2 For test sections up to 12 in. [305 mm] thick, the reference blocks shall contain a 1⁄4-in. [6.4-mm] diameter flat-bottom hole; for over 12 to 18 in. [305 to 457 mm], the hole diameter shall be 3⁄8 in. [9.5 mm]; and for over 18 to 24 in. [457 to 610 mm], it shall be 1⁄2 in. [13 mm].

S2.3 A distance-amplitude correction curve shall be established for the proper grade of steel and specified hole size.

S2.4 A forging containing one or more indications equal in amplitude to that of the applicable reference hole, when properly corrected for distance, is subject to rejection.

S3. Charpy V-Notch Impact Transition Curve

S3.1 Sufficient impact tests shall be made from the forging test material to establish a temperature-absorbed energy curve. The test-temperature range shall be wide enough to establish the upper and lower shelf foot-pound energies, with sufficient testing at intermediate temperatures to permit plotting a reasonably smooth curve.

S4. Additional Charpy Data

S4.1 The percent shear fracture and mils of lateral expansion, defined in Test Methods and Definitions A 370, shall be reported for each Charpy specimen tested.

S5. Alternative Impact Test

S5.1 Charpy impact tests shall be made in accordance with the provisions of 6.2 of the specification except that the test temperature shall be lower than specified in Table 3. This test shall be instead of that specified in 6.2.

S6. Drop-Weight Test

S6.1 Drop-weight tests shall be conducted in accordance with the requirements of Test Method E 208. The fracture plane of the specimens shall coincide with the location required for other mechanical test specimens as specified by the purchaser in accordance with 6.1.6. However, since the drop weight specimen can be taken in any orientation, the fracture plane of the specimen when tested to Method 1 (6.1.6.1) shall be a minimum distance of 7⁄16 in. [11 mm] from the nearest quenched surface, and 1½ in. [38 mm] from any second surface. The purchaser may specify either duplicate no-break performance when tested 10°F [6°C] warmer than a specified temperature or request a determination of the NDT temperature.

S7. Restrictive Chemistry for Grades 4N and 5

S7.1 Phosphorus and sulfur limits for Grades 4N and 5 shall be 0.015 % maximum heat and 0.018 % maximum product.

S8. Additional Vanadium

S8.1 The vanadium content for Grade 5 forgings shall be 0.05 to 0.15 %.

S9. Restrictive Chemistry for Grades 2, 3, or 4N

S9.1 Grades 2, 3, or 4N shall be specified with restricted phosphorus and copper limits, as follows:

S9.1.1 P 0.012 maximum heat and 0.015 maximum product; Cu 0.10 maximum heat and product, or

S9.1.2 P 0.015 maximum heat and 0.018 maximum product; Cu 0.15 maximum heat and product.

S9.2 Grades 2, 3, 4N shall be specified with restricted sulfur of 0.015 heat and 0.018 product.

S10. Alternative Fracture Toughness Requirements

S10.1 The fracture toughness requirements (drop weight and Charpy impact tests) for materials of the ASME Boiler and Pressure Vessel Code, Section III, Articles NB 2300, NC 2300, ND 2300, NE 2300, NF 2300, or NG 2300, as specified, shall be used instead of the Charpy impact test requirements of this specification.

S11. Vacuum Carbon-Deoxidized Steels

S11.1 Material made to Grades 1, 1a, 2, 3, 4N, or 5 shall be vacuum carbon-deoxidized, in which case the silicon content shall be 0.10 % max. The test report shall indicate that the steel was vacuum carbon-deoxidized.

S12. Vacuum-Treated Basic Oxygen Furnace Steels

S12.1 For Grades 1, 1a, 2, or 3 material, vacuum-treated basic oxygen furnace steel shall be used.

S13. Minimum Tempering Temperature

S13.1 For Grades 2 Class 1 and 3 Class 1 the minimum tempering temperature shall be 1175°F [635°C] and the simulated post weld heat treatment temperature shall not exceed 1150°F [620°C] when S1 is required.

S14. Cooling from the Tempering Temperature

S14.1 The purchaser shall provide specific cooling rates from the tempering temperature.

S15. Product Analysis

S15.1 More than one forging per heat shall be subject to product analysis by either the manufacturer or purchaser. The purchaser shall indicate in the ordering information the number of forgings to be tested, and whether the manufacturer, purchaser, or both shall perform the additional analyses.

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 508/A 508M-04 that may impact the use of this standard.

(1) References to new steel grade were placed throughout.
(2) Revised silicon content for Grade 22 from 0.50 pct. max. to 0.35 pct. max.
(3) Revised aluminum content for Grade 22 from 0.04 pct. max. to 0.025 pct. max.

Committee A01 has identified the location of selected changes to this standard since the last issue, A 508-03, that may impact the use of this standard.

(1) Changes in silicon requirements in Table 1 and reference in Ordering Information.
(2) Corrected metric units in 4.2.2 and Table 3.

Designation: A 521 – 03

Standard Specification for Steel, Closed-Impression Die Forgings for General Industrial Use[1]

This standard is issued under the fixed designation A 521; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers untreated and heat-treated steel, closed-impression die forgings (Note 1) for general industrial use.

NOTE 1—For the definition of a forging, refer General Requirements Specification A 788.

1.2 The Grades of forgings are as follows, the choice depending on design and stress or service to be imposed:

1.2.1 *Grade CA*—Untreated, carbon steel forgings,

1.2.2 *Grades CC, CC1, and CE*—Annealed, normalized and tempered, carbon steel forgings,

1.2.3 *Grade CF*—Normalized and tempered carbon steel forgings,

1.2.4 *Grade CF1*—Double normalized and tempered carbon steel forgings,

1.2.5 *Grade CG*—Quenched and tempered, or normalized, quenched and tempered carbon steel forgings,

1.2.6 *Grade AA*—Annealed, normalized, or normalized and tempered alloy steel forgings,

1.2.7 *Grades AB and AC*—Normalized and tempered alloy steel forgings, and

1.2.8 *Grades AD, AE, AF, AG, and AH*—Normalized, quenched, and tempered alloy steel forgings.

1.3 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings

A 322 Specification for Steel Bars, Alloy, Standard Grades

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 576 Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality

A 711 Specification for Steel Forging Stock

A 788 Specification for Steel Forgings General Requirements

A 921/A 921M Steel Bars, Microalloy, Hot-Wrought, Special Quality for Subsequent Hot Forging

E 3 Guide for Preparation of Metallographic Specimens

E 45 Practice for Determining the Inclusion Content of Steel

E 94 Guide for Radiographic Examination

E 112 Test Methods for Detemining the Average Grain Size

E 340 Macro Etching Metals and Alloys

E 381 Method of Macroetch Testing, Inspection and Rating Steel Products, Comprising Bars, Billets, Blooms, and Forgings

E 407 Practice for Microetching of Metals and Alloys

3. Ordering Information and General Requirements

3.1 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures,product analysis variations, marking, certification and additional supplementary requirements. Failure to comply with the requirements of Specification A 788 constitutes non-conformance with this specification

3.2 In addition to the ordering information required by Specification A 788, the purchaser may require that the tolerances stated in the appendices to this specification shall apply.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard.

3.3 If the requirements of this specification should conflict with the requirements of A 788, then the requirements of this specification shall prevail.

4. Forging Manufacture

4.1 Sufficient discard shall be taken from the ingot or forging stock to secure freedom from piping and undue segregation.

4.2 Manufacturing practice shall be in accordance with accepted commercial procedures designed to produce forgings free from harmful surface discontinuities, roughness, excessive scale, fins, indications of overheating, burning, or other injurious conditions. The manufacturer may be required to certify that furnaces used for all heating operations for forging and heat treating are controlled to minimize scaling and decarburization.

4.3 Heat treatment, if required, shall be in accordance with the ordered Grade description.

5. Chemical Requirements

5.1 Depending on the forging size, type of heat treatment and the requirements of the purchaser the chemical composition shall be as specified by the purchaser. To assist in this choice attention is drawn to the chemical requirements of Specification A 576 for carbon steels, Specification A 322 for Alloy Steels, and A 29/A 29M for both carbon and alloy steels, however the purchaser may wish to specify more restrictive sulfur and phosphorous limits than are provided in these specifications.

5.2 For microalloyed forgings forging stock to Specification A 921 may be used.

5.3 Attention is drawn to the supplementary requirements included in Specification A 788 regarding special chemical requirements.

5.4 The heat and product analyses requirements of A 788 shall apply.

6. Metallurgical Requirements

6.1 Provision has been made, through the use of supplementary requirements in Specification A 788 and this specification, for the Purchaser to specify preferred grain flow and limits for grain size as well as any microscopic examination requirements.

7. Dimensional Tolerances

7.1 The purchaser may specify tolerances for impression die forgings according to Appendix X1 or X2 as appropriate.

8. Tensile Properties

8.1 The material shall conform to the requirements for tensile properties prescribed in Table 1 when tested in accordance with the latest issue of Test Methods and Definitions A 370.

8.2 The yield strength shall be determined by the offset method, using an offset value of 0.2 % of the gage length, or by the total extension under load method, using an extension value of 0.005 in./in. (0.5 %) for Grades AD and AE, 0.006 in./in. (0.6 %) for Grades AF and AG, and 0.007 in./in. (0.7 %) for Grade AH.

8.3 Tests for acceptance shall be made after final heat treatment of the forgings.

9. Number of Tests and Orientation

9.1 Unless otherwise specified, one tension test shall be made for each heat of steel for each heat treat charge. For untreated forgings (Grade CA) no tension tests need be made unless when specified in the purchase order, when one tension test shall represent each heat.

9.2 For the purpose of tests of heat-treated forgings, the necessary extra forgings shall be provided. When it is impracticable to provide extra forgings for test purposes, test bars may be made from the same billet or bar material, provided they represent the maximum cross section of the forging, do not exceed the production forging reduction and are heat treated with the forgings they represent.

9.3 Unless otherwise specified, the axis of the specimen shall be located at any point midway between the center and the surface of solid forgings or at any point midway between the inner and outer surfaces of the wall of hollow forgings, and shall be parallel to the direction of maximum metal flow.

10. Test Specimen

10.1 Location, size, and number of test specimens shall be specified by the purchaser. Unless otherwise stated in the contract or purchase order, test bars may be separately forged or swaged from the same bars, billets, or blooms used in manufacture of the forgings. The percentage reduction given the forged tests bars shall not be greater than the minimum amount of reduction given the forging itself. The test bars shall be heat treated with the forgings they represent. The manufacturer may elect to submit an extra forging in lieu of forged test bars.

10.2 Unless otherwise specified, the axis of the specimen shall be located at any point midway between the center and the surface of solid forgings or at any point midway between the inner and outer surfaces of the wall of hollow forgings, and shall be parallel to the direction of maximum metal flow.

10.3 The specimens shall be machined to the form and dimensions shown in Test Methods and Definitions A 370 for the standard or subsize round tension test specimens.

11. Cleaning

11.1 The forgings shall be furnished in a scale-free condition. Unless otherwise specified, the manufacturer may clean by acid pickling, grit blasting, sand blasting, or other abrasive method.

12. Keywords

12.1 alloy steel; carbon steel; closed die; forging tolerances; heat treated; impression die; Steel Forgings

TABLE 1 Tensile Requirements

Grade	Solid Diameter or Thickness, in. (mm) Over	Solid Diameter or Thickness, in. (mm) Not Over	Bored Wall Thickness in. (mm) Over	Bored Wall Thickness in. (mm) Not Over	Tensile Strength, min, ksi (MPa)	Yield Strength, min, ksi (MPa)	Elongation in 2 in. or 50 mm, min, %	Reduction of Area, min, %
AA (Annealed, normalized, or	...	12 (305)	...	...	80 (550)	50 (345)	24	40
normalized, and tempered)	12 (305)	20 (508)	...	...	80 (550)	50 (345)	22	38
AB (Normalized and tempered)	...	7 (178)	...	4 (102)	80 (550)	55 (380)	26	52
	7 (178)	20 (508)	4 (102)	7½ (191)	80(550)	55(380)	24	50
AC (Normalized and tempered)	...	7 (178)	...	4 (102)	90 (620)	60 (415)	22	44
	7 (178)	20 (508)	4 (102)	7½ (191)	90 (620)	58 (400)	21	42
AD (Normalized, quenched, and	...	7 (178)	...	3½ (89)	96 (655)	70 (485)	20	50
tempered)	7 (178)	10 (254)	½ (89)	5 (127)	90 (620)	65 (450)	20	50
AE (Normalized, quenched, and	...	7 (178)	....	3½ (89)	105 (725)	80 (550)	20	50
tempered)	7 (178)	10 (254)	3½ (89)	5 (127)	100 (690)	75 (520)	19	50
	10 (254)	20 (508)	5 (127)	8 (203)	95 (655)	70 (485)	19	50
AF (Normalized, quenched, and	...	4 (102)	...	2 (51)	125 (860)	105 (725)	16	50
tempered)	4 (102)	7 (178)	2 (51)	3½ (89)	115 (795)	96 (655)	16	45
	7 (178)	10 (254)	3½ (89)	5 (127)	110 (760)	85 (585)	16	45
AG (Normalized, quenched, and	...	4 (102)	...	2 (51)	145 (1000)	120 (830)	15	45
tempered)	4 (102)	7 (178)	2 (51)	3½ (89)	140 (965)	115 (795)	14	40
	7 (178)	10 (254)	3½ (89)	5 (127)	135 (930)	110 (760)	13	40
AH (Normalized, quenched, and	...	4 (102)	...	2 (51)	170 (1175)	140 (965)	13	40
tempered)	4 (102)	7 (178)	2 (51)	3½ (89)	165 (1140)	135 (930)	12	35
	7 (178)	10 (254)	3½ (89)	5 (127)	160 (1105)	130 (895)	11	35
CA (Untreated)				No tenile requirement except as covered by 8.1				
CC (Annealed, normalized, or	...	12 (305)	...	...	60 (415)	30 (205)	25	36
normalized, and tempered)	12 (305)	...	...	...	60 (415)	30 (205)	24	36
CC1 (Annealed, normalized, or	...	12 (305)	...	...	66 (455)	33 (230)	23	36
normalized and tempered)	12 (305)	20 (508)	...	...	66 (455)	33 (230)	22	34
CE (Annealed, normalized, or	...	8 (203)	...	...	75 (520)	37 (290)	24	40
normalized and tempered)	8 (203)	12 (305)	...	...	75 (520)	37 (290)	22	35
	12 (305)	20 (508)	...	...	75 (520)	37 (290)	20	32
	20 (508)	...	...	...	75 (520)	37 (290)	19	30
CF (Normalized and tempered)	...	8 (203)	...	...	80 (550)	40 (275)	22	36
	8 (203)	12 (305)	...	...	80 (550)	40 (275)	21	33
	12 (305)	20 (508)	...	...	80 (550)	40 (275)	20	31
CF1 (Double normalized and tempered)	...	8 (203)	...	...	85 (585)	44 (305)	25	40
	8 (203)	12 (305)	...	...	83 (570)	43 (295)	23	37
	12 (305)	20 (508)	...	...	83 (570)	43 (295)	22	35
CG (Quenched, and tempered or	...	4 (102)	...	2 (51)	90 (620)	55 (380)	20	39
normalized, quenched and tempered)	8 (203)	7 (178)	2 (51)	3½ (89)	85 (585)	50 (345)	20	39
	7 (178)	10 (254)	3½ (89)	5 (127)	85 (585)	50 (345)	19	37
	...	...	5 (127)	10 (254)	82 (565)	48 (330)	19	36

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, and order. Details of these supplementary requirements shall be specified by purchaser.

S1. Magnetic Particle Test

S1.1 When magnetic particle inspection of forgings is required, the areas to be inspected, and the acceptance standards shall be specified by purchaser.

S1.2 Unless otherwise required by the Purchaser Test Method A 275 shall be used.

S2. Grain Flow

S2.1 When a specific pattern of grain flow is required by the purchaser, a sample forging shall be sectioned as specified. The section shall be ground and subjected to acid etching, using the type of acid, temperature and time of etching agreed upon to reveal flow lines. The section may be preserved using a coating of mineral oil or clear lacquer.

S2.2 Unless otherwise specified by the purchaser Methods E 381 or E 340 shall be used.

S3. Microscopic Examination

S3.1 When microscopical examination is specified, the steel shall be inspected by utilizing samples cut from the undistorted portion of tension test specimens. Requirements for number of microscopical tests, grain size, cleanliness, or microstructure shall be specified by purchaser.

S3.2 For grain size determination Method E 112 or the grain size provisions of Specification A 29/A 29M shall be used, and the grain size requirement shall be as specified by the purchaser.

S3.3 For non-metallic inclusion rating method E 45 shall be used, and the acceptance limits shall be specified by the purchaser.

S3.4 Test Methods E 3 and E 407 shall be used for the determination of the microstructure. Acceptance criteria shall be specified by the purchaser.

S4. Impact Test

S4.1 Impact testing in accordance with Test methods A 370 shall be done on specimens taken adjacent to the tension test . The test temperature and acceptance criteria shall be as specified by the purchaser.

S5. Ultrasonic Examination

S5.1 Ultrasonic examination shall be conducted in accordance with A 388 unless otherwise specified by the purchaser who will also specify the acceptance criteria.

S6. Radiographic Tests

S6.1 When radiographic tests are required, the number of tests, location, and ASTM standards of acceptance shall be specified by the purchaser. Reference shall be made to Practice E 94.

S7. Brinell Hardness

S7.1 When hardness is required, Brinell hardness tests taken in accordance with Test Method A 370 shall be made of sample forgings from each furnace charge of heat treated forgings. Number of samples per charge and location of the hardness impressions shall be specified by the purchaser.

S7.2 The acceptance criteria shall be specified by the purchaser, but shall be consistent both with the tensile properties specified in Table 1, and the relative locations of the tension test specimens and the specified surfaces to be hardness tested.

APPENDIXES

(Nonmandatory Information)

X1. FORGINGS PRODUCED ON HAMMERS AND PRESSES

X1.1 Units of Measure

X1.1.1 Where direct tolerances are not provided, use Table X1.1 in converting to fractional units of measure after making computations.

X1.2 Length and Width Tolerances

X1.2.1 Length and width tolerances represent variations in dimensions measured parallel to the fundamental parting line of the dies. Normally, they are combined with tolerances for die wear.

X1.2.1.1 *Tolerance*—The length and width tolerance is ±0.003 in./in. and applies to all dimensions of length and width including diameters. This tolerance includes allowance for shrinkage, die sinking, and die polishing variations.

X1.2.1.2 *Units of Measure*—Length and width tolerances, normally combined with tolerances for die wear, are expressed as fractions of an inch, in units of 1⁄32 in. or greater as shown in Table X1.1. Decimals used in computing tolerances are totaled, rounded off to two places after the decimal point, then converted to the next higher fractional unit of measure.

X1.3 Die Wear Tolerances

X1.3.1 Die wear varies according to the material forged and the shape of the forging. Consequently, die wear tolerances for various materials are applied in addition to length and width tolerances on dimensions pertaining to forged surfaces only. Die wear tolerances do not apply on center-to-center dimensions.

X1.3.1.1 *Tolerance*—Die wear tolerances for all *external* length, width, and diameter dimensions are computed by multiplying the *greatest external length or outside diameter* (measured parallel to the fundamental parting line of the dies) by the appropriate factor in Table X1.2 and are then combined with *plus* values of length and width tolerances. Die wear tolerances on *external* dimensions are expressed as *plus* values only.

X1.3.1.2 Die wear tolerances for all *internal* length, width and diameter dimensions are also computed by multiplying the

TABLE X1.1 Units of Measure

Dimensions, ft (m)		Units of Measure to the Closest
Over	Under	
...	2 (0.61)	1⁄32 in.
2 (0.61)	5 (1.52)	1⁄16 in.
5 (1.52)	10 (3.05)	1⁄8 in.
10 (3.05)	...	1⁄4 in.

TABLE X1.2 Die Wear Tolerances

Materials	Factor (per inch)
Carbon	0.004
Low Alloy	0.005
400 Series Stainless	0.006
300 Series Stainless	0.007
Super Alloy	0.008

greatest external length or outside diameter (measured parallel to the fundamental parting line of the dies) by the appropriate factor in Table X1.2, but are then combined with the *minus* values of length and width tolerances. Die wear tolerances on *internal* dimensions are expressed as *minus* values only.

X1.3.1.3 Allowances for die wear occurring on dimensions measured perpendicular to the fundamental parting line of the dies are included in die closure tolerances.

X1.3.1.4 Die wear tolerances, per surface, on both external and internal dimensions are one half the computed amount.

X1.3.1.5 *Units of Measure*—Die wear tolerances combined with length and width tolerances are expressed as fractions of an inch in units of 1⁄32 in. or greater as shown in Table X1.1. Decimals used in computing tolerances are totaled, rounded off to two places after the decimal point, then converted to the next higher fractional unit of measure.

X1.4 Die Closure Tolerances

X1.4.1 Die closure tolerances relate to variations in thickness of forgings as affected by the closing of the dies and die wear, and pertain to variations in dimensions crossing the fundamental parting line.

X1.4.1.1 *Tolerance*—Die closure tolerances on forgings having no portions extending more than 6 in. (152 mm) from the parting line are based on the projected area of the forging at the trim line—not including flash, but including all areas to be subsequently punched out. Except as explained in the following paragraph, they are applied as plus tolerances only and are applicable to the thickness of the forging at all sections. (See Table X1.3.)

X1.4.1.2 Tolerances on extremities of forgings extending perpendicularly *more* than 6 in. from the parting line include the die closure tolerance, and, *in addition*, a length tolerance of ±0.003 in./in. This tolerance is added to that derived from Table X1.3, but applies only to such extremities.

X1.4.1.3 *Units of Measure*—Die closure tolerances are expressed as fractions of an inch in units of 1⁄32 in. or greater. When decimals are used in computing tolerances, they are rounded off to two places after the decimal point, then converted to the next higher fractional unit of measure.

X1.5 Match Tolerances

X1.5.1 Match tolerances relate to displacement of a point in one die half from the corresponding point in the opposite die half in any direction parallel to the fundamental parting line of the dies. Match tolerances are applied separately and independently of all other tolerances. Where possible, measurements are made at areas of the forging unaffected by wearing of the dies.

X1.5.1.1 *Tolerance*—Match tolerances are based on weight of the forging after trimming and are expressed as fractions of an inch according to Table X1.4.

X1.5.1.2 *Measuring for Match Tolerances*— In cases where measurements for determining match tolerances must be made from surfaces of the forging where uneven wearing of the dies has caused surplus stock, accuracy depends on making the proper allowances for these wear-caused surpluses, and eliminating their influence from the computation.

X1.5.1.3 *Units of Measure*—Match tolerances are measured in units of 1⁄64 in. or greater.

X1.6 Flash Extension Tolerances

X1.6.1 Flash extension tolerances are based on the weight of the forging after trimming and relate to the amounts of flash extension. Flash is measured from the body of the forging to the trimmed edge of the flash.

X1.6.2 *Tolerance*—Flash extension tolerances are expressed in fractions of an inch according to Table X1.5.

X1.7 Straightness Tolerances

X1.7.1 Straightness tolerances relate to deviations of surfaces and centerlines from the specified contour as caused primarily by manipulation of the piece in post-forging processes and, in addition, by the effects of cooling from the forging operation, both of which may produce slight and gradual variations in straightness.

X1.7.2 Since the general shape of the forging determines the effect of cooling and post-forging manipulation on straightness, four classes of shape have been selected as guides in choosing appropriate straightness tolerances. Agreement between purchaser and forging engineer on tolerances and inspection methods may be desirable where the forging is not easily classified according to shape and may be subject to a combination of straightness tolerances. Straightness tolerances are applied independently of, and in addition to, all other tolerances.

X1.7.3 It is contemplated that, at times, straightening operations may be required in order to achieve the tolerances indicated in the following text. These tolerances are not intended to apply to refractory alloys, high-density alloys, titanium, and some stainless steels. Straightness tolerances for forgings of such materials are best determined on the basis of

TABLE X1.3 Die Closure Tolerances

NOTE 1—Tabulated figures are plus values only, expressed in inches.

Materials	Area at the Trim Line Flash not included, expressed in in.^{2}(cm^2)						
	10 (65) and under	Over 10 to 30 (65 to 194), incl	Over 30 to 50 (194 to 323), incl	Over 50 to 100 (323 to 645), incl	Over 100 to 500 (645 to 3225), incl	Over 500 to 1000 (3225 to 6450), incl	Over 1000 (6450)
Carbon, low alloys	1⁄32 (0.79)	1⁄16 (1.58)	3⁄32 (2.38)	1⁄8 (3.18)	5⁄32 (3.97)	3⁄16 (4.78)	1⁄4 (6.35)
400 series stainless	1⁄32 0.79)	1⁄16 (1.58)	3⁄32 (2.38)	1⁄8 (3.18)	3⁄16 (4.78)	1⁄4 (6.35)	5⁄16 (7.94)
300 series stainless	1⁄16 (1.58)	3⁄32 (2.38)	1⁄8 (3.18)	5⁄32 (3.97)	3⁄16 (4.78)	1⁄4 (6.35)	5⁄16 (7.94)
Super alloys	1⁄16 (1.58)	3⁄32 (2.38)	1⁄8 (3.18)	3⁄16 (4.78)	1⁄4 (6.35)	5⁄16 (7.94)	3⁄8 (9.52)

TABLE X1.4 Match Tolerances

NOTE 1— Tabulated figures are amounts of displacement, expressed in inches, of a point in one die-half from the corresponding point in the opposite die-half in any direction parallel to the parting line of the dies.

Materials	Weights of Forgings After Trimming, lb (kg)								
	Less than 2 (0.91)	Over 2 to 5 (0.91 to 2.3), incl	Over 5 to 25 (2.3 to 11.3), incl	Over 25 to 50 (11.3 to 22.7), incl	Over 50 to 100 (22.7 to 45.4), incl	Over 100 to 200 (45.4 to 90.6), incl	Over 200 to 500 (90.6 to 226.5), incl	Over 500 to 1000 (226.5 to 453.0), incl	Over 1000 (453.0)
Carbon, low alloys	customarily negoti-	1⁄64 (0.4)	1⁄32 (0.79)	3⁄64 (1.19)	1⁄16 (1.58)	3⁄32 (2.38)	1⁄8 (3.18)	5⁄32 (3.97)	3⁄16 (4.76)
Stainless steels	ated with pur-	1⁄32 (0.79)	3⁄64 (1.19)	1⁄16 (1.58)	3⁄32 (2.38)	1⁄8 (3.18)	5⁄32 (3.97)	3⁄16 (4.76)	1⁄4 (6.35)
Super alloys	chaser	1⁄32 (90.79)	3⁄64 (1.19)	1⁄16 (1.58)	3⁄32 (2.38)	1⁄8 (3.18)	5⁄32 (3.97)	3⁄16 (4.76)	1⁄4 (6.35)

TABLE X1.5 Flash Extension Tolerance

NOTE 1—Tabulated figures are ranges of flash extension, expressed in inches (mm)

Weights of Forgings After Trimming, lb (kg)	Materials		
	Carbon & Low Alloy	Stainless	Super Alloys
10 (4.5) and under	0 to 1⁄32 (0.79)	0 to 1⁄16 (1.58)	0 to 1⁄16 (1.58)
Over 10 to 25 (4.5 to 11.3), incl	0 to 1⁄16 (1.58)	0 to 3⁄32 (2.38)	0 to 3⁄32 (2.38)
Over 25 to 50 (11.3 to 22.7), incl	0 to 3⁄32 (2.38)	0 to 1⁄8 (3.18)	0 to 1⁄8 (3.18)
Over 50 to 100 (22.7 to 45.4), incl	0 to 1⁄8 (3.18)	0 to 3⁄16 (4.76)	0 to 3⁄6 (4.76)
Over 10 to 200 (45.4 to 90.6), incl	0 to 3⁄16 (4.76)	0 to 1⁄4 (6.35)	0 to 1⁄4 (6.35)
Over 200 to 500 (90.6 to 226.5), incl	0 to 1⁄4 (6.35)	0 to 5⁄16 (7.94)	0 to 5⁄16 (7.94)
Over 500 to 1000 (226.5 to 453.0), incl	0 to 5⁄16 (7.94)	0 to 3⁄8 (9.52)	0 to 3⁄8 (9.52)
Over 1000 (453.0)	0 to 3⁄8 (9.52)	0 to 1⁄2 (12.7)	0 to 1⁄2 (12.7)

each individual forging design, since the configuration substantially influences the tendency of a forging to deviate from the specified contour. Straightness tolerances for these special forgings are commonly agreed upon by buyer and seller in advance of production.

X1.7.4 *Units of Measure*—Straightness tolerances are expressed as fractions of an inch in units of 1⁄32 in. or greater, as shown in Table X1.1. Decimals used in computing tolerances are rounded off to two places after the decimal point, then converted to the next higher fractional unit of measure.

X1.7.5 *Tolerances and Applications (*Table X1.6*)*:

X1.7.5.1 *Class A Shapes (Elongated*—Long in relation to width and height) Tolerance: 0.003 in./in. of the greatest dimension.

X1.7.5.2 *Class B Shapes (Flat, Relatively Thin) Tolerance*—Straightness tolerance for Class B shapes as shown in Table X1.7 below.

X1.7.5.3 *Class C Shapes (Thin, Flat Shapes with Appreciable Protrusion at Right Angles to the Parting Line) Tolerance*—Straightness tolerance on the flat disc portion of Class C shapes is computed first. It is considered separately from the tolerance on the protruding portion and is determined in an identical manner as for Class B shapes using Table X1.7. Straightness tolerance on protuberance is 0.003 in./in. of length.

X1.7.5.4 *Class D Shapes (Massive, Block-type Forgings) Tolerance*—Since departures from the specified configuration are seldom caused by subsequent handling, straightness tolerances are not provided. Where tolerances are desired, agreement between purchaser and forging engineer is normally reached before production proceeds.

X1.8 Surface Tolerances

X1.8.1 Surface tolerances relate to depth of dressouts and scale pits on the forging, based on purchaser's specification or drawing.

X1.8.1.1 *Tolerances and Conditions*—Localized dressouts or scale pits are commonly allowed on surfaces to be finish machined unless purchaser's specification or drawing states otherwise. Where purchaser specifies stock for machining, dressouts or scale pits are commonly permitted to within 1⁄16 in. (1.59 mm) of the finished surface or to within one-half of the stock allowance, whichever is smaller.

TABLE X1.6 Classes of Shapes

NOTE 1—For use in selecting appropriate Straightness Tolerances.

Class	Shape of Forging	Examples
A	Elongated—Length dimensions great in relation to width and height	long connecting rods, shafts, levers, etc.
B	Flat, relatively thin	disc, plates, etc.
C	Flat, relatively thin, with appreciable protrusion at right angles to the parting line	wear plates, crawler track shoes, disc with hub, etc.
D	Massive block-type forgings with neither length, nor width, nor thickness being predominant	hydraulic pump bodies, high pressure steam chests, etc

TABLE X1.7 Straightness Tolerances, Class B Shapes

Materials	Area at the Trim Line, expressed in in.^{2}(cm^2) Flash not included						
	10 (65) and under	Over 10 to 30 (65 to 194), incl	Over 30 to 50 (194 to 323), incl	Over 50 to 100 (323 to 645), incl	Over 100 to 500 (645 to 3225), incl	Over 500 to 1000 (3225 to 6450), incl	Over 1000 (6450)
Carbon, low alloy	1⁄32 (0.79)	1⁄16 (1.58)	3⁄32 (2.38)	1⁄8 3.18)	5⁄32 (3.97)	3⁄16 (4.76)	1⁄4 (6.35)
400 series stainless	1⁄32 (0.79)	1⁄16 (1.58)	3⁄32 (2.38)	1⁄8 (3.18)	3⁄16 (4.76)	1⁄4 (6.35)	5⁄16 (7.93)
300 series stainless	1⁄16 (1.58)	3⁄32 (2.38)	1⁄8 (3.18)	5⁄32 (3.97)	3⁄16 (4.76)	1⁄4 (6.35)	5⁄16 (7.93)

X1.8.1.2 Where surfaces of forgings are intended for use in "as forged" condition, dressouts or scale pits are commonly permitted on these surfaces to a depth equal to ½ of the die closure tolerance.

X1.9 Draft Angle Tolerances

X1.9.1 Draft angle tolerances apply to all draft angles, relate to variation from draft angle specifications, and are commonly measured as an addition to tolerances for die wear.

X1.9.1.1 *Tolerance*—Draft angle tolerances are +2° and −1° on all draft angles, unless modified by prior agreement between buyer and seller.

X1.10 Finish Allowances for Machining

X1.10.1 Finish allowance refers to the amount of material that is to be machined from the forging to obtain the finished part. Forging dimensions are commonly analyzed independently, with consideration given to all applicable tolerances, in making certain that a minimum desired clean-up exists after the forging is completed. (See Table X1.8.)

TABLE X1.8 Finish Allowances

Greatest Dimension		Minimum Finish Stock per Surface in. (mm)
Over, in. (mm)	But Not Over, in. (mm)	
...	8 (203)	1⁄16 (1.58)
8 (203)	16 (406)	3⁄32 (2.38)
16 (406)	24 (610)	1⁄8 (3.18)
24 (610)	36 (914)	5⁄32 (3.97)
36 (914)	...	3⁄16 (4.76)

X2. FORGINGS PRODUCED ON FORGING MACHINES (UPSETTERS)

X2.1 Length Tolerances

X2.1.1 Length tolerances relate to variations in dimensions measured parallel to the axis of the stock and apply to all intermediate and over-all dimensions of length *except* flange thickness dimensions and internal length (gap) dimensions between flanges (see X2.2). Length tolerances include allowances for die wear, shrinkage, die sinking and die polishing variations.

X2.1.2 *Tolerance*—Length tolerances are plus values only, expressed in fractions of an inch according to Table X2.1.

X2.2 Flange Tolerances

X2.2.1 Flange tolerances relate to variations in flange thickness measured parallel to the axis of the stock. When more than one flange is formed, these tolerances also apply to the dimension (gap) between flanges. Flange tolerances are applied separately and independently of other tolerances.

X2.2.1.1 *Tolerance*—Tolerances for flange thickness and dimensions (gaps) between flanges are such that the effect is to add stock on both internal and external dimensions. The amount of flange tolerance is dependent on the flange diameter (see Table X2.2).

X2.2.1.2 When two flanges are formed, the tolerance on the dimension (gap) between them is a minus tolerance only, with a value identical to the thickness tolerance for the flange nearest the unforged stem.

X2.2.1.3 Flange tolerances are shown in Table X2.2.

X2.3 Diameter Tolerances

X2.3.1 Diameter tolerances relate to variation in dimensions measured perpendicularly to the axis of the stock, and are applied separately for each of a forging's diameters and only to those diameters formed in the heading tool or dies.

TABLE X2.1 Length Tolerances

NOTE 1—Tabulated figures are plus values only and apply to overall and intermediate dimensions of length, except flange thickness and gap dimensions.

Length Dimensions		Tolerances	
Over, in. (mm)	But Not Over, in. (mm)	Intermediate Length, in. (mm)	Over-All Length, in. (mm)
...	3⅛ (79)	1⁄32 (0.79)	1⁄16 (1.58)
3⅛ (79)	6¼ (159)	1⁄16 (1.58)	3⁄32 (2.38)
6¼ (159)	9 5⁄16 (236)	3⁄32 (2.38)	⅛ (3.18)
9 5⁄16 (236)	12½ (318)	⅛ (3.18)	⅛ (3.18)
12½ (318)	15⅝ (397)	5⁄32 (3.97)	5⁄32 (3.97)
15⅝ (397)	18¾ (476)	3⁄16 (4.76)	3⁄16 (4.76)
18¾ (476)	21⅞ (557)	7⁄32 (5.56)	7⁄32 (5.56)
21⅞ (557)	25 (635)	¼ (6.35)	¼ (6.35)
25 (635)	...	Commonly determined by special agreement between buyer and seller in advance of production	

TABLE X2.2 Flange Tolerances

NOTE 1—Based on diameters of flange (or flanges) formed.

Diameters		Tolerances	
Over, in. (mm)	But Not Over, in. (mm)	Plus, in. (mm)	Minus[A]
...	7 (178)	1⁄16 (1.59)	...
7 (178)	...	3⁄32 (2.38)	...

[A] Determined individually as defined in X2.2.

X2.3.2 Diameter tolerances are commonly applied and measured in a plane other than that described by the parting line of the forging.

X2.3.3 Permissible variations in diameter on *unforged stem portions* of the forging are commonly governed by steel mill tolerances. Tolerance provisions for shear-cut ends and slight irregularities in diameter on the unforged stem caused by grip dies are commonly determined by special agreement between buyer and seller.

X2.3.4 These tolerances apply only to forgings with circular shapes. Tolerances for non-circular forgings are customarily determined by special agreement between buyer and seller in advance of production.

X2.3.4.1 *Tolerance*—Tolerances for all external forged diameters are expressed as plus tolerances only, according to Table X2.3.

X2.3.4.2 Tolerances for internal diameters of holes formed by the heading tool are commonly +0 in.; −1⁄16 in.

X2.4 Match Tolerances

X2.4.1 Match tolerances relate to the amount of die displacement in a direction parallel to the parting line of the grip dies. These tolerances are applied independently of, and in addition to, all other tolerances.

X2.4.2 *Tolerance*—Match tolerances are expressed as fractions of an inch in units of 1⁄64 in. or greater, according to Table X2.4. They are based on the weight of the forging exclusive of the weight of the unforged stem. The weight of the stem is deducted from the weight of the forging *before* Table X2.4 is used.

X2.5 Concentricity Tolerances

X2.5.1 Concentricity tolerances apply to contours formed by the heading tool and relate to variations of the axis of the contour from the axis of the stock. This tolerance is commonly

TABLE X2.3 Tolerances on Forged Diameters

Diameters		Tolerances	
Over, in. (mm)	But Not Over, in. (mm)	Plus, in. (mm)	Minus
...	2 (51)	1⁄32 (0.79)	...
2 (51)	7 (178)	1⁄16 (1.59)	...
7 (178)	...	3⁄32 (2.38)	...

TABLE X2.4 Match Tolerances

NOTE 1—Tabulated figures are amounts of die displacement in a direction parallel to the parting line of the grip dies, expressed in inches.

Materials	Weights of Forgings, lb (kg)					
	10 (4.54) and under	Over 10 to 25 (4.54 to 11.3), incl	Over 25 to 50 (11.3 to 22.7), incl	Over 50 to 100 (22.7 to 45.4), incl	Over 100 to 200 (45.4 to 90.6), incl	Over 200 to 500 (90.6 to 226.5), incl
Carbon and low alloy	(0.4)	(0.4)	(1.19)	(1.59)	(2.38)	(3.16)
Stainless steels	(0.79)	(1.19)	(1.69)	(2.38)	(3.18)	(3.97)
Super alloys	(0.79)	(1.19)	(1.59)	(2.38)	(3.18)	(3.97)

applied only to contours of a depth not less than one diameter. Concentricity tolerances are applied independently of, and in addition to, match tolerances.

X2.5.1.1 *Tolerance*—Concentricity tolerances are expressed in fractions of an inch as total indicator readings (TIR), according to Table X2.5.

X2.6 Straightness Tolerances

X2.6.1 Straightness tolerances relate to deviations of the centerline of the stem and body of the forging from the true centerline as caused by manipulation of the piece after forging, and by the effects of cooling from the forging operation—both of which may produce slight and gradual variations in straightness.

X2.6.1.1 *Tolerance*—Straightness tolerances on the original bar stock as provided by the material suppliers commonly apply.

X2.7 Draft Angle Tolerances

X2.7.1 When draft angles are required on a forging, the size of the angles is generally dependent on the contour of the forging and is therefore commonly determined by agreement between buyer and seller.

X2.7.2 Draft angle tolerances apply to all draft angles and relate to variation from draft angle specifications.

X2.7.3 *Tolerance*—Draft angle tolerances are +2° and −1° on all draft angles, unless modified by prior agreement between buyer and seller.

TABLE X2.5 Concentricity Tolerances on Holes

Depth of Hole		Total Indicator Reading (Tolerance)
Over, in. (mm)	But Not Over, in. (mm)	
...	8 (203)	⅛ (3.18) TIR
8 (203)	12 (305)	5⁄32 (3.97) TIR
12 (305)	...	3⁄16 (4.76) TIR

X2.8 Radii Tolerances

X2.8.1 Radii tolerances relate to variation from purchaser's radii specifications on all fillet radii and on corner radii where draft is not subsequently removed by trimming or punching.

X2.8.1.1 *Tolerance*—Radii tolerances are plus or minus one-half the specified radii, except where corner radii are affected by subsequent removal of draft, in which case the minus tolerance is commonly modified to allow a square corner to be formed.

X2.9 Surface Tolerances

X2.9.1 Surface tolerances relate to depth of dressouts and scale pits on the forging, based on purchaser's specification or drawing.

X2.9.1.1 *Tolerances and Conditions*—Localized dressouts or scale pits are commonly allowed on surfaces to be finish machined unless purchaser's specification or drawing states otherwise. Where purchaser specifies stock for machining, dressouts or scale pits are commonly permitted to within 1⁄16 in. (1.59 mm) of the finished surface or to within one-half of the stock allowance, whichever is smaller.

X2.9.1.2 Where surfaces of forgings are intended for use in "as forged" condition, dressouts or scale pits are commonly permitted on these surfaces to a depth equal to ½ of the die closure tolerance.

X2.10 Finish Allowances for Machining

X2.10.1 Finish allowance refers to the amount of material that is to be machined from the forging to obtain the finished part. Forging dimensions are analyzed independently, with consideration given to all applicable tolerances, in making certain that a minimum desired clean-up exists after the forging is completed.

X2.10.1.1 *Allowances*—Table X2.6 indicates finish allowances commonly applied.

TABLE X2.6 Finish Allowances

Greatest Diameter		Minimum Finish Stock per Surface, in. (mm)
Over, in. (mm)	But Not Over, in. (mm)	
...	2 (51)	1⁄16 (1.58)
2 (51)	8 (203)	3⁄32 (2.38)
8 (203)	...	1⁄8 (3.18)

SUMMARY OF CHANGES

Committe A01 had identified the location of the following change since A 521–96(2001) that may impact the use of this standard.

(1) The specification has been revised throughout.

Standard Practice for Ultrasonic Examination of Turbine-Generator Steel Retaining Rings[1]

This standard is issued under the fixed designation A 531/A 531M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the procedures to be followed when performing ultrasonic shear and longitudinal wave tests on turbine-generator retaining rings with an inside diameter to wall thickness ratio equal to or greater than 5:1 and with wall thicknesses from 1 to 4 in. (25 to 102 mm).

1.2 Although this practice describes methods of ultrasonically testing retaining rings by either the contact or immersion method, it shall not restrict the use of improved inspection methods as they are developed. It is recognized that techniques for examination and evaluation may be chosen in order to enhance or improve the results or to accommodate variations in procedures, equipment, or capabilities. Considering these characteristics, forgings may be inspected by a combination of both the contact and the immersion methods, as mutually agreed upon between the manufacturer and the purchaser.

1.3 This practice and the applicable material specifications are expressed in both inch-pound units and SI units. However, unless the order specifies the applicable "M" specification designation SI units, the material shall be furnished to inch-pound units.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 127 Practice for Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks[2]

2.2 *Other Document:*

Recommended Practice for Nondestructive Personnel Qualification and Certification SNT-TC-1A, Supplement C-Ultrasonic Testing[3]

3. Personnel Requirements

3.1 The manufacturer shall be responsible for assigning qualified personnel to perform ultrasonic examination in conformance with the requirements of this practice.

3.2 Personnel performing ultrasonic examinations in accordance with this practice shall be familiar with the following:

3.2.1 Ultrasonic terminology,

3.2.2 Instrument calibration,

3.2.3 Effect of transducer material, size, frequency, and mode on test results,

3.2.4 Effect of material structure (grain size, cleanliness, etc.) on test results,

3.2.5 Effect of test distance on test results,

3.2.6 Effect of nonlinearity on test results,

3.2.7 Effect of thickness and orientation of discontinuities on test results, and

3.2.8 Effect of surface roughness on test results.

3.3 A qualification record (see Note 1) of personnel considered suitable by the manufacturer to perform examination in accordance with this practice shall be available upon request.

NOTE 1—SNT-TC-1 A, Ultrasonic Testing Method, provides a recommended procedure for qualifying personnel. Other personnel qualification requirement documents may be used when agreed upon between the purchaser and supplier.

4. Ordering Information

4.1 When this practice is to be applied to an inquiry, contract, or order, the purchaser shall so state and shall also furnish the following information:

4.1.1 The method or combination of methods to be used for inspection.

4.1.2 The frequency to be used for conducting each inspection.

[1] This practice is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved Dec. 15, 1991. Published February 1992. Originally published as A 531 – 65. Last previous edition A 531/A 531M – 90.

[2] *Annual Book of ASTM Standards,* Vol 03.03.

[3] Available from the American Society for Nondestructive Testing, 914 Chicago Ave., Evanston, IL 60202.

4.1.3 Report requirements including C-scan plot, if applicable.

5. General Requirements

5.1 As far as possible the entire volume of the retaining rings shall be subject to ultrasonic inspection. Circumferential and axial faces shall be machined flat and parallel to one another.

5.2 The ultrasonic inspection shall be performed after final processing and heat treatment for properties, unless otherwise specified in the order or contract.

5.3 Rings may be tested either stationary (contact) or while rotating (immersion). If not specified by the purchaser, a combination of methods may be used at the manufacturer's option. Scanning speed shall not exceed 6 in./s (152 mm/s), unless automatic recording (C-scan) equipment is employed.

5.4 To ensure complete coverage, (during contact testing) the search unit shall be indexed approximately 75 % of the transducer width with each pass of the search unit. During immersion testing establish a transducer index adjustment which will ensure complete coverage with sufficient overlap.

5.5 During the testing, a combination of methods and frequencies of 1 MHz, 2¼ MHz, and 5 MHz may be used for accurately locating, determining orientation, and defining specific discontinuities detected during overall scanning.

5.6 For reporting purpose, location of indications shall be circumferentially defined by clock position. The test notch or a similar locator, such as a reference line bisecting the serial number, shall be used to define and identify the 12 o'clock position.

6. Apparatus

6.1 *Ultrasonic, Pulsed, Reflection Type of Instrument*, shall be used for the examination. The system shall have a minimum capability for examining at frequencies from 1 to 5 MHz.

6.1.1 The amplifier and the cathode ray tube shall provide linear response (within 5 %) for at least 75 % of the screen height (sweep line to top of screen).

6.1.2 The instrument shall contain a calibrated gain control or signal attenuator (in each case, accurate within $\pm$ 5 %) that will allow indications beyond the linear range of the instrument to be measured.

6.1.3 When the immersion method of inspection is employed, suitable equipment must be available so that the retaining rings can be immersed in a liquid coupling agent or can be subject to inspection by the use of a column or stream of the couplant through an appropriate container attached to the part or transducer. Equipment must also include fixturing for smooth mechanical rotation of the part or the transducer during scanning.

6.2 *Search Units*:

6.2.1 *Contact Method*:

6.2.1.1 A 2.25 or 1.0-MHz, 45° angle beam shear wave search unit shall be employed for shear wave testing. (2.25 MHz shall be used unless acoustic attenuation of the material is such that 1 MHz must be employed to obtain adequate penetration of the ring section.) Adequate penetration is the ability to clearly resolve the calibration notch above resultant noise level.

6.2.1.2 A 5, 2.25, or 1-MHz, ¾ to 1⅛ -in. (19.0 to 28.6-mm) diameter, longitudinal wave transducer shall be used for performing the longitudinal wave test.

6.2.1.3 Acrylic resin shoes ground to the curvature of the retaining ring may be used to maintain the optimum contact angle between the transducer and outside diameter of the ring.

6.2.1.4 When agreed upon between the purchaser and supplier, alternative test frequencies may be used to perform the required tests.

6.2.2 *Immersion Method*:

6.2.2.1 A 5, 2.25, or 1-MHz transducer, ¾ to 1 in. (19.0 to 25.4 mm) in diameter, suitable for water immersion, shall be used for performing the required test.

6.2.2.2 The manipulator (holder) for the search tube or transducer, or both, shall provide for angular manipulation of the transducer for optimum response from the internal discontinuities. The tolerance or play present in the manipulation and in the traversing unit should not be excessive so as to prevent ultrasonic examination at the required sensitivity level.

6.2.2.3 When agreed upon between the purchaser and supplier, alternative test frequencies may be used to perform the required tests.

6.2.2.4 *Accessory Equipment*—Coaxial cables and search tubes used in conjunction with the electronic apparatus capable of conducting the electrical pulses while immersed in a liquid, and collimators for shaping the sound beam may be used.

6.3 Recording instruments or alarm systems, or both, may be used, provided sufficient range and sensitivity are available to properly monitor the test.

7. Preparation of the Forging for Ultrasonic Examination

7.1 Surface roughness on the outside and inside diameter and radical face surfaces of the ring shall not exceed 125 µin. (3.18 µm) and waviness shall not exceed 0.001 in. (0.02 mm) measured in both the axial and circumferential directions. The radical faces of the ring shall be sufficiently perpendicular to the axis of the forging to permit axial tests.

7.2 All surfaces of the ring to be examined shall be free of extraneous material such as surface tears, loose scale, machining or grinding particles, paint, and other foreign matter.

8. Ultrasonic Couplants

8.1 For contact testing, a suitable couplant, such as clean SAE 20 motor oil, shall be used to couple the transducer to test surfaces.

8.2 For immersion testing, a liquid such as water, oil, glycerin, etc., capable of conducting ultrasonic vibrations from the transducer to the material being tested shall be used. Rust inhibitors, softeners, and wetting agents may be added to the couplant. The couplant liquid with all additives should not be detrimental to the surface condition of the test specimen or the container, and it should wet the surface of the material to provide an intimate contact. Couplant may be heated to a comfortable working temperature and must be free of air bubbles.

9. Method for Shear Wave Testing

9.1 *Calibration Reference*:

9.1.1 Place a calibration V-shaped notch, with an included angle of 60 to 90° and ¼ in. (6.35 mm) long, in the outside diameter surface of the ring at a sufficient distance from the end of the ring to eliminate side wall interference. Determine the location of the notch by scanning the ring at a sensitivity high enough to show the material structure and with the shear wave beam directed circumferentially. Using this procedure, then locate the notch in an area representative of the ring material.

9.1.2 Place the notch axially in the ring to a depth of 1 % of the wall thickness or 0.020 in. (0.51 mm), whichever is greater. Make the depth measurement after removal of the upset material adjacent to the notch.

9.1.3 For the inspection of finish machined rings, an outside reference block of the same alloy, wall thickness, and curvature as the ring being tested may be used. The block must be at least 4 in. (102 mm) wide and long enough to permit three bounces from the reference notch.

9.1.4 For axial shear wave examination by the immersion method, place a circumferentially oriented notch into the outside diameter surface of the ring at a sufficient distance from the end of the ring so that it can be clearly resolved from the outside diameter corner reflection. Dimensions of notch shall be the same as described in 9.1.1.

9.2 *Contact Method for Equipment Calibration*:

9.2.1 Connect the 2.25-MHz or 1-MHz angle beam search unit to the test instrument and place it directly over the calibration notch with the crystal directed circumferentially. Move the search unit circumferentially, directing the sound beam toward the notch until an indication from the notch appears. Continue to move the search unit in the same direction until a maximized second bounce indication appears.

9.2.2 Adjust the sweep length so that the first and second bound indications from the notch are about 1½ in. (38 mm) apart. Mark and designate the first and second bounce positions on the sweep line.

9.2.3 Adjust the gain until the first bounce indication has a sweep-to-peak amplitude of 1.5 in. (38 mm). Mark the upper tip of this indication and the point midway between the tip and the sweep line. Check the notch in the reverse direction; if a marked difference in amplitude is found, make a new notch.

9.2.4 In a similar manner, locate and mark the position of the tip and point midway between the tip and sweep line of the second bounce notch indication. Draw a line connecting the two points designating the amplitudes of the first and second notch indications. Likewise, draw a line through the half-amplitude points. Refer to these lines as the amplitude and half-amplitude reference lines.

9.3 *Immersion Method for Equipment Calibration*:

9.3.1 *Circumferential*:

9.3.1.1 With the transducer located perpendicular to the outside diameter so as to obtain a 3 ± ¼ -in. (76 ± 6.35-mm) water path, adjust the sweep delay and sweep length to position the water steel interface reflection at the left of the screen, and the first back reflection from the outside diameter of the ring slightly to the left of center of the screen, so that at least two angular passes through the ring will be visible on the screen. Position the transducer over the calibration reference and adjust the angle and horizontal position to maximize the indication from the reference notch. Check the notch in the reverse direction; if a marked difference in amplitude is noted, make a new notch.

9.3.1.2 Adjust the gain until the first bounce indication has a sweep-to-peak amplitude of 1.5 in. (38 mm). Mark the upper tip of this indication and the point midway between the tip and the sweep line.

9.3.1.3 In a similar manner, locate and mark the position of the tip and point midway between the tip and sweep line of the second bounce notch indication. Draw a line connecting the two points designating the amplitudes of the first and second notch indications. Likewise, draw a line through the half-amplitude points. Refer to these lines as the amplitude and half-amplitude reference lines.

9.3.2 *Axial*:

9.3.2.1 With the transducer located perpendicular to the outside diameter so as to obtain a 3 ± ¼ -in. (76 ± 6.35-mm) water path as previously described in 9.3.1.1, position the transducer over the circumferential reference notch, and adjust the angle and horizontal position to maximize the indication from the reference notch while directing the ultrasonic beam toward the nearest end face of the ring.

9.3.2.2 Adjust the gain until the first bounce indication has a sweep-to-peak amplitude of 1.5 in. (38 mm). Mark the upper tip of this indication and the point midway between the tip and the sweep line.

9.3.2.3 In a similar manner, locate and mark the position of the tip and point midway between the tip and sweep line of the second bounce notch indication. Draw a line connecting the two points designating the amplitudes of the first and second notch indications. Likewise, draw a line through the half-amplitude points. Refer to these lines as the amplitude and half-amplitude reference lines.

9.4 *Scanning*:

9.4.1 *Contact Method*:

9.4.1.1 *Circumferential*—With the search unit held by hand or in a mechanical fixture, place it on the outside diameter surface of the ring with the sound beam directed circumferentially. Move the search unit in the circumferential direction while maintaining the proper contact angle as determined during calibration. Make successive parallel passes, each overlapping the previous pass at least 15 % of the transducer (not search unit) width, until the entire surface of the ring has been scanned. Rotate the search unit 180° and repeat the procedure.

9.4.1.2 *Axial*—The sensitivity established for the circumferential test shall also be used for the axial test. Place the search unit near one end of the ring and direct the sound axially toward this end. Move the search unit circumferentially over successive parallel passes, each overlapping the previous pass until the opposite end is reached. Reverse the direction of the search unit and repeat the procedure. In this manner, completely scan the entire outside surface of the ring.

9.4.2 *Immersion Method*:

9.4.2.1 *Circumferential*—With the transducer positioned as described in 9.3.1, rotate the part or the transducer in the circumferential direction (or traverse the transducer in the axial direction) while maintaining the proper angle as determined during calibration. Make successive parallel passes, each overlapping the previous pass by a minimum of 15 % of the transducer diameter, until the entire surface of the ring has been scanned. With the search unit repositioned to scan in the opposite circumferential direction, repeat this scanning procedure.

9.4.2.2 *Axial*—With the equipment calibrated in accordance with 9.3.2, rotate the ring or the transducer in the circumferential direction (or traverse the transducer in the axial direction) while maintaining the proper angle as determined during calibration. Make successive parallel passes until the entire surface of the ring has been scanned. With the search unit repositioned to scan in the opposite axial direction, repeat the scanning procedure.

9.5 *Report*:

9.5.1 The amplitudes of indications from discontinuities near (within approximately ¼ in. (6.35 mm)) the inside and outside diameter surfaces are influenced by trapping of the ultrasonic beam so that their amplitudes are greater than equivalent discontinuities that are below the surface (deeper than ¼ in.). Therefore, rate those discontinuities near the surface against the amplitude reference line and rate internal discontinuities against the half-amplitude reference line.

9.5.2 As the test proceeds, mark on the ring the locations of all indications exceeding the appropriate reference line. Recheck all indications found with the ring rotating, and record while the ring is stationary.

9.5.3 Record the number, amplitude, and location (axial, radial, and clock relative to 12 o'clock positions) of all indications reaching or exceeding their respective amplitude reference lines. Report indication amplitudes as percentages of their respective reference lines in increments of 10 %.

9.5.4 Where reportable indications are numerous, individually count and record the outstanding indications (see 9.5.3), and make an estimate of the number and amplitude of the remaining indications. A C-scan report may also be used to supply additional information.

10. Method for Longitudinal Wave Testing

10.1 *Reference Blocks (Radial Test)*:

10.1.1 In order to correct for the many variables involved in ultrasonic testing, it is necessary to use references to establish instrument settings, assist reproducibility of techniques, and evaluate discontinuities. The fabrication of reference blocks should be governed by the requirements described in Practice E 127.

10.1.2 The ultrasonic reference blocks should have ultrasonic characteristics, such as attenuation, noise level, and velocity similar to the metal being tested, or suitable correction should be made.

10.1.3 *Dimensions*—Calibration blocks prepared in accordance with the preceding paragraphs containing flat bottom holes of ⅛ -in. (3.18-mm) diameter shall have metal travel within the following tolerances:

Wall Thickness (*T*) of Ring Being Tested, in. (mm)	Metal Travel Tolerance of Reference Test Block, in. (mm)
1 to 1½ (25 to 38)	$T \pm$ ¼ (±6.35)
1½ to 4 (38 to 101)	$T \pm$ ½ (±12.7)

10.2 *Calibration*:

10.2.1 *Contact Method (Radial Test)*:

10.2.1.1 Connect a longitudinal wave search unit (5 MHz for alloy steel rings and 2.25 MHz or 1 MHz for nonmagnetic rings) to the test equipment. Select an acoustically compatible calibration reference block with metal travel that is $T -$ ¾ in. (19.0 mm) or $T - 1$ in. (25 mm) where T equals the wall thickness of the ring to be inspected.

10.2.1.2 Place the search unit on the entry surface of the calibration reference block and adjust the gain control of the instrument so as to obtain a 1.5-in. (38-mm) sweep-to-peak indication from the ⅛ -in. (3.18-mm) flat bottom hole interface.

10.2.1.3 Place the search unit on the outside diameter of the ring to be inspected and adjust the sweep line so that at least two back reflections are displayed on the face of the cathode ray tube (CRT).

10.2.2 *Immersion Method (Radial Test)*:

10.2.2.1 Mount the transducer (5 MHz for alloy steel rings and 2.25 MHz or 1 MHz for nonmagnetic rings) in the holder or manipulator which has been coupled to the test equipment. Select an acoustically compatible reference block having ¾ in. (19.0 mm) metal travel (flat bottom hole in interface to test surface distance).

10.2.2.2 Position the transducer so as to obtain a 3 ± ¼ -in. (76 ± 6.35-mm) water path, perpendicular to the front face of the calibration reference block.

10.2.2.3 With the transducer positioned over the entry surface of the reference standard, adjust the sweep delay and sweep length to position the water-steel interface reflection at the left of the screen. Adjust sensitivity or gain control to give a 1.5-in. (38-mm) sweep-to-peak indication from the ¾ -in. (19.0-mm) deep reference hole.

10.2.2.4 Without changing the sensitivity setting, position the transducer normal to a circumferential surface of the retaining ring so there is a 3 ± ¼ -in. (76 ± 6.35-mm) water path from the transducer to the surface of the ring. (Scanning can be performed from the inside diameter or outside diameter surface of the ring, depending on the supplier's equipment capabilities.) Adjust the sweep controls so that the first back reflection from the opposite surface is slightly to the left of center of the screen, so that at least two passes through the ring are visible on the screen.

10.2.3 *Axial Calibration*—When axial longitudinal wave examination is specified, perform it by the contact method. Adjust the sweep length to position the back reflection on the right hand side of the screen. Adjust the instrument controls so that the back reflection from the opposite face of the ring measures 1.5 in. (38 mm) sweep-to-peak. This standard amplitude shall represent a 100 % indication.

10.3 *Scanning by the Contact Method*:

10.3.1 *Radial Test*—With the search unit held by hand or in a mechanical fixture, place it on the outside diameter surface of the ring and move it in a circumferential direction while maintaining the proper contact angle as determined during calibration. Make successive parallel passes, each overlapping the previous pass until the entire surface of the ring has been scanned.

10.3.1.1 Note any indications of magnitude greater than ⅜ in. (9.52 mm) in either the first or second pass.

10.3.1.2 Mark the location on the ring, and record all indications greater than ⅜ in. (9.52 mm). Also report any noticeable fluctuations or loss of back reflection associated with an indication.

10.3.2 *Axial Test*—Place the search unit on the shrink-fit end face of the retaining ring and move circumferentially. Make successive parallel passes, each overlapping the previous pass until the entire face of the ring has been scanned. Mark the location of indications exceeding 10 % of the first back reflection on the ring as encountered while the test is proceeding. Consider a back reflection loss of 50 % as an indication and report as such.

10.4 *Scanning by the Immersion Method*:

10.4.1 *Radial Test*—Scan the entire ring in overlapping passes by rotating the ring or the transducer (or traverse the transducer in the axial direction). The scan paths of the transducer shall be such that each pass overlaps the preceding pass.

10.4.1.1 Note any indications of magnitude greater than ⅜ in. (9.52 mm) sweep-to-peak in either the first or second pass.

10.4.1.2 Mark the location on the forging, and record all indications. Without changing sensitivity, report any loss of back reflection associated with an indication and any fluctuations or shift in back reflection.

10.5 *Report*:

10.5.1 *Radial Test*:

10.5.1.1 Recheck all indications found with the ring rotating, and record while the ring is stationary.

10.5.1.2 With the test notch or other locator designated as the 12 o'clock position, record the number, amplitudes, and location (axial, radial, and clock position) of all indications in excess of 25 % of the reference standard, in increments of 10 %, at estimated discontinuity depth. Additional reference standards, with ⅛ -in. (3.18-mm) flat bottom holes, may be used to evaluate indication size at their depth from the testing surface.

10.5.1.3 Record as indications those areas showing a definite loss or shift of the multiple order pattern in radial testing and describe. Further explore them by expanding the sweep line and searching for discontinuities at higher frequencies or by use of other search units.

10.5.2 *Axial Test (Contact Method Only)*:

10.5.2.1 Recheck all indications found with the ring rotating, and record while the ring is stationary.

10.5.2.2 With the test notch designated as the 12 o'clock position, record the number, amplitudes, and location (axial, radial, and clock position) of all indications in increments of 10 % of the back reflection.

11. Report

11.1 Report the following information:

11.1.1 The results of the ultrasonic test shall be recorded and described in a written report, along with pertinent ring identification.

11.1.2 The following information shall be included: dimensions of the test notch, including width and depth; number, amplitudes, and relative locations of recordable indications (see 9.5 and 10.5). Identify those cases where a discontinuity is recorded from more than one direction.

11.1.3 Comments regarding abnormal travel or measured surface extent shall be made when discontinuities in these categories are detected.

12. Disposition

12.1 Rings containing no recordable indications are acceptable.

12.2 Rings of such coarse grain size or microstructure that the indication from the test notch cannot be distinguished above the noise level are subject to rejection.

12.3 All rings containing recordable ultrasonic indications shall be referred to the purchaser's engineering department for individual consideration.

Designation: A 534 – 04

Standard Specification for Carburizing Steels for Anti-Friction Bearings[1]

This standard is issued under the fixed designation A 534; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers the requirements for carburizing bearing-quality steel to be used in the manufacture of anti-friction bearings.

1.2 Supplementary requirements of an optional nature are provided and when desired shall be so stated in the order.

1.3 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold Finished, General Requirements for

A 255 Test Methods for Determining Hardenability of Steel

A 304 Specification for Carbon and Alloy Steel Bars Subject to End-Quench Hardenability Requirements

A 510 Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel

A 519 Specification for Seamless Carbon and Alloy Steel Mechanical Tubing

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products

A 752 Specification for General Requirements for Wire Rods and Coarse Round Wire, Alloy Steel

E 45 Test Methods for Determining the Inclusion Content of Steel

E 112 Test Methods for Determining the Average Grain Size

E 381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings

E 1019 Test Methods for Determination of Carbon, Sulfur, Nitrogen, Oxygen, and Hydrogen in Steel and in Iron, Nickel, and Cobalt Alloys

E 1077 Test Methods for Estimating the Depth of Decarburization of Steel Specimens

2.2 *ISO Standard:*

ISO 683 Part 17: Ball and Roller Bearing Steels

3. Ordering Information

3.1 Orders for material under this specification should include the following information:

3.1.1 Quantity,

3.1.2 Alloy grade identification,

3.1.3 Specification designation and year of issue,

3.1.4 Dimensions, shape, and

3.1.5 Supplementary requirements.

4. Materials and Manufacture

4.1 The steel shall be made by a process that is capable of providing a high quality product meeting the requirements of this specification.

5. Chemical Composition and Analysis

5.1 Typical examples of chemical compositions are shown in Table 1. Other compositions may be specified.

5.2 An analysis of each heat of steel shall be made by the steel manufacturer in accordance with Test Methods, Practices, and Terminology A 751. The chemical composition thus determined shall conform to the requirements specified in Table 1 for the ordered grade, or to other requirements agreed upon between manufacturer and purchaser.

5.3 Product analysis may be made by the purchaser in accordance with Test Methods A 751. Permissible variations in product analysis shall be in accordance with Specification A 29/A 29M, Practices, and Terminology.

6. Dimensions, Mass, and Permissible Variations

6.1 The size and shape of the material shall be agreed upon between manufacturer and purchaser.

6.2 Dimensional tolerances shall conform to the requirements specified in Specifications A 29/A 29M, A 510, A 519, or A 752 as appropriate for the material or as agreed between manufacturer and purchaser.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.28 on Bearing Steels.

Current edition approved March 1, 2004. Published April 2004. Originally approved in 1965. Last previous edition approved in 2001 as A 534–01.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard.**

TABLE 1 Chemical Composition[A,B]

Number[C]	Name	C	Mn	P (max)	S (max)	Si	Cr	Ni	Mo	Cu (max)	O (max)[D]	Al (max)
. . .	4118H	0.17 - 0.23	0.60 - 1.00	0.025	0.015	0.15 - 0.35	0.30 - 0.70	. . .	0.08 - 0.15	0.30	0.0020	0.050
. . .	4320H	0.17 - 0.23	0.40 - 0.70	0.025	0.015	0.15 - 0.35	0.35 - 0.65	1.55 - 2.00	0.20 - 0.30	0.30	0.0020	0.050
. . .	4620H	0.17 - 0.23	0.35 - 0.75	0.025	0.015	0.15 - 0.35	. . .	1.55 - 2.00	0.20 - 0.30	0.30	0.0020	0.050
. . .	4720H	0.17 - 0.23	0.45 - 0.75	0.025	0.015	0.15 - 0.35	0.30 - 0.60	0.85 - 1.25	0.15 - 0.25	0.30	0.0020	0.050
. . .	4817H	0.14 - 0.20	0.30 - 0.70	0.025	0.015	0.15 - 0.35	. . .	3.20 - 3.80	0.20 - 0.30	0.30	0.0020	0.050
. . .	4820H	0.17 - 0.23	0.40 - 0.80	0.025	0.015	0.15 - 0.35	. . .	3.20 - 3.80	0.20 - 0.30	0.30	0.0020	0.050
. . .	5120H	0.17 - 0.23	0.60 - 1.00	0.025	0.015	0.15 - 0.35	0.60 - 1.00	. . .	. . .	0.30	0.0020	0.050
. . .	8617H	0.14 - 0.20	0.60 - 0.95	0.025	0.015	0.15 - 0.35	0.35 - 0.65	0.35 - 0.75	0.15 - 0.25	0.30	0.0020	0.050
. . .	8620H	0.17 - 0.23	0.60 - 0.95	0.025	0.015	0.15 - 0.35	0.35 - 0.65	0.35 - 0.75	0.15 - 0.25	0.30	0.0020	0.050
. . .	9310H	0.07 - 0.13	0.40 - 0.70	0.025	0.015	0.15 - 0.35	1.00 - 1.45	2.95 - 3.55	0.08 - 0.15	0.30	0.0020	0.050
B20	20Cr3	0.17 - 0.23	0.60 - 1.00	0.025	0.015	0.40 max	0.60 - 1.00	. . .	. . .	0.30	0.0020	0.050
B21	20Cr4	0.17 - 0.23	0.60 - 0.90	0.025	0.015	0.40 max	0.90 - 1.20	. . .	. . .	0.30	0.0020	0.050
B22	20MnCr4-2	0.17 - 0.23	0.65 - 1.10	0.025	0.015	0.40 max	0.40 - 0.75	. . .	. . .	0.30	0.0020	0.050
B23	17MnCr5	0.14 - 0.19	1.00 - 1.30	0.025	0.015	0.40 max	0.80 - 1.10	. . .	. . .	0.30	0.0020	0.050
B24	19MnCr5	0.17 - 0.22	1.10 - 1.40	0.025	0.015	0.40 max	1.00 - 1.30	. . .	. . .	0.30	0.0020	0.050
B25	15CrMo4	0.12 - 0.18	0.60 - 0.90	0.025	0.015	0.40 max	0.90 - 1.20	. . .	0.15 - 0.25	0.30	0.0020	0.050
B26	20CrMo4	0.17 - 0.23	0.60 - 0.90	0.025	0.015	0.40 max	0.90 - 1.20	. . .	0.15 - 0.25	0.30	0.0020	0.050
B27	20MnCrMo4-2	0.17 - 0.23	0.65 - 1.10	0.025	0.015	0.40 max	0.40 - 0.75	. . .	0.10 - 0.20	0.30	0.0020	0.050
B28	20NiCrMo2	0.17 - 0.23	0.60 - 0.95	0.025	0.015	0.40 max	0.35 - 0.65	0.40 - 0.70	0.15 - 0.25	0.30	0.0020	0.050
B29	20NiCrMo7	0.17 - 0.23	0.40 - 0.70	0.025	0.015	0.40 max	0.35 - 0.65	1.60 - 2.00	0.20 - 0.30	0.30	0.0020	0.050
B30	18CrNiMo7-6	0.15 - 0.21	0.50 - 0.90	0.025	0.015	0.40 max	1.50 - 1.80	1.40 - 1.70	0.25 - 0.35	0.30	0.0020	0.050
B31	18NiCrMo14-6	0.15 - 0.20	0.40 - 0.70	0.025	0.015	0.40 max	1.30 - 1.60	3.25 - 3.75	0.15 - 0.25	0.30	0.0020	0.050
B32	16NiCrMo16-5	0.14 - 0.18	0.25 - 0.55	0.025	0.015	0.40 max	1.00 - 1.40	3.80 - 4.30	0.20 - 0.30	0.30	0.0020	0.050

[A] Elements not quoted shall not be intentionally added to the steel without the agreement of the purchaser.
[B] Intentional additions of calcium or calcium alloys for deoxidation or inclusion shape control are not permitted unless specifically approved by the purchaser.
[C] Steels B20 through B32 meet the requirements of ISO 683, Part 17, Second Edition, Table 3.
[D] Oxygen content applies to product analysis and shall be determined in accordance with Test Methods E 1019.

6.3 The dimensional tolerances for the forgings shall conform to the requirements of the engineering drawing.

7. Quality Assurance

7.1 The supplier shall be held responsible for the quality of the material furnished and shall make the necessary tests to ensure this quality. The supplier shall be required to report on the results of the macroetch and micro-inclusion rating tests detailed below. Quality tests shown in 7.2 through 7.4 are based upon procedures established in Test Methods E 45.

7.2 *Sampling*—Samples taken in accordance with the following paragraphs shall be obtained from 4 by 4-in. (102 by 102-mm) rolled billets or forged sections. Tests may be made on smaller or larger sections by agreement with the purchaser. A minimum 3 to 1 reduction of rolled billets or forged sections is required for strand cast products.

7.2.1 For top poured products, a minimum of six samples representing the top and bottom of the first, middle, and last usable ingots shall be examined.

7.2.2 For bottom poured products, a minimum of six samples shall be examined and they shall represent the top and bottom of three ingots. One ingot shall be taken at random from the first usable plate poured, one ingot, at random, from the usable plate poured nearest to the middle of the heat and one ingot, at random, from the last usable plate poured. When two usable plates constitute a heat, two of the sample ingots shall be selected from the second usable plate poured. Where a single usable plate constitutes a heat, any three random ingots may be selected. Other methods of sampling shall be as agreed upon by manufacturer and purchaser.

7.2.3 For strand cast products, a minimum of six samples representing the first, middle, and last usable portion of the heat cast shall be examined. At least one sample shall be taken from each strand.

7.3 Macroetch specimens or forged sections representative of cross sections of billets shall be macroetched and rated in accordance with Method E 381 in hydrochloric acid and water (at a ratio of 1 to 1) at 160 to 180°F (71 to 82°C). Such specimens shall not exceed S2, R2, and C2 of Method E 381.

7.4 *Inclusion Rating*—The polished face of the specimens shall be ⅜ by ¾ in. (9.5 by 19.1 mm) and shall be taken from an area halfway between the center and outside of the billet or forged sections. The polished face shall be longitudinal to the direction of rolling. The scale used for rating the specimens shall be the Jernkontoret chart described in Test Methods E 45, Method A, Plate I-r. Fields with sizes or numbers of all types of inclusions intermediate between configurations shown on the chart shall be classified as the lesser of the rating number. The worst field of each inclusion type from each specimen shall be recorded as the rating for the specimen. Two thirds of all specimens and at least one from each ingot tested, or from the first, middle, and last portion of the strands tested, as well as the average of all specimens, shall not exceed the rating specified in Table 2.

8. Grain Size

8.1 The grain size shall be six or finer as defined in Test Methods E 112 (see Plate 4, austenitic grain size in steels). Material not meeting this requirement may be normalized at 1700°F (927°C) or above and retested.

TABLE 2 Inclusion Rating

Rating Units	
Thin Series	Heavy Series
A 2½	A 1½
B 2	B 1
C ½	C ½
D 1	D 1

TABLE 3 Decarburization and Surface Imperfections for Coils and Bars for Balls and Rollers

Size, in. (mm)	Decarburization or Surface Imperfections per side, max, in. (mm)	
	Hot-Rolled or Hot-Rolled Annealed	Cold-Finished
through 0.250 (6.35)	0.005 (0.13)	0.003 (0.08)
over 0.250 (6.35) to 0.500 (12.7), incl	0.006 (0.15)	0.004 (0.10)
over 0.500 (12.7) to 0.750 (19.1), incl	0.008 (0.20)	0.006 (0.15)
over 0.750 (19.1) to 1.000 (25.4), incl	0.010 (0.25)	0.008 (0.20)

TABLE 4 Decarburization and Surface Imperfections for Bars and Tubes

Decarburization and Surface Imperfections per side, max, in. (mm)					
Size, in. (mm)	Hot-Rolled Bars	Annealed		Cold-Finished	
		Bars	Tubes	Bars	Tubes
through 1.000 (25.4)	0.012 (0.31)	0.015 (0.38)	0.012 (0.31)	0.012 (0.31)	0.010 (0.21)
over 1.000 (25.4) to 2.000 (50.8), incl	0.017 (0.43)	0.022 (0.56)	0.020 (0.51)	0.015 (0.38)	0.014 (0.36)
over 2.000 (50.8) to 3.000 (76.2), incl	0.025 (0.64)	0.030 (0.76)	0.030 (0.76)	0.025 (0.64)	0.019 (0.48)
over 3.000 (76.2) to 4.000 (101.6), incl	0.035 (0.89)	0.045 (1.14)	0.035 (0.89)	...	0.024 (0.61)
over 4.000 (101.6) to 5.000 (127.0), incl	0.055 (1.40)	0.065 (1.65)	0.040 (1.02)	...	0.028 (0.71)

9. Hardenability

9.1 Each heat shall be tested for hardenability in accordance with Test Methods A 255. The "J" values for hardenability shall conform to limits specified in Specification A 304 or as agreed upon by manufacturer and purchaser.

10. Decarburization and Surface Imperfections

10.1 Decarburization and surface imperfections shall not exceed the limits specified in Tables 3 and 4. Decarburization shall be measured using the microscopical methods described in Test Methods E 1077.

11. Inspection

11.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Mill inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspections shall be made at the place of manufacture, unless otherwise agreed upon.

12. Certification and Reports

12.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification, together with a report of the test results, shall be furnished at the time of shipment. Special requirements agreed to at the time of purchase must be noted on the certification.

SUPPLEMENTARY REQUIREMENTS

One or more of the supplementary requirements described below apply when included in the purchaser's order or contract. When so included, a supplementary requirement shall have the same force as if it were in the body of the specification. Supplementary requirements' details not fully described shall be agreed upon between the purchaser and the supplier, but shall not negate any of the requirements in the body of the specification.

S1. Titanium Content

S1.1 The purchaser may specify that the analysis of titanium be provided by agreement with the steel manufacturer.

S2. Residual Elements

S2.1 The purchaser may specify that the analysis of titanium, aluminum, and/or oxygen, be provided by agreement with the steel manufacturer. The number and location of samples shall be by agreement between the purchaser and manufacturer.

S3. "SAM" Inclusion Rating System

S3.1 The purchaser may specify that the "SAM" inclusion rating method described in Test Methods E 45, Method E, be used in addition to the micro-inclusion rating method described in 7.4.

S3.2 *Sampling*—See 7.2.

S3.3 *Limits*—The "SAM" rating for B-type inclusions shall not exceed 15. The "SAM" rating for D-type inclusions shall not exceed 10.

S4. Magnetic Particle Method

S4.1 The purchaser may specify that the magnetic particle method described below be used in addition to the micro-inclusion rating system described in 7.4. The magnetic particle method measures bearing steel cleanliness by evaluating the total length of macro-inclusions for a stated area or per unit area. Results are commonly expressed in mm/m^2.

S4.2 *Sampling*—See 7.2.

S4.3 Test specimens shall be straight cylinder quarter section samples prepared and examined in accordance with the magnetic particle method of Test Methods E 45.

S4.4 For purposes of calculation, an inclusion length shall be taken as the mean length of the length bracket into which it falls; that is, an inclusion in the 1⁄16 to 1⁄8 in. bracket shall be taken as being 3⁄32 in. in length. The sum of all lengths for each specimen shall be determined and expressed as total length per area inspected. The average total length per area inspected of all six specimens shall be agreed upon between manufacturer and purchaser.

S5. Banding

S5.1 *Hardness Method*—The samples used may be the same as those used in 7.2. The sample shall be hardened and in the as-quenched condition. Micro-hardness measurements are to be taken using loads of 200 g or higher. After conversion to Rockwell "C" values, the hardness in the banded area shall not vary by more than five RC points.

S6. Microstructure

S6.1 A suitable microstructure may be specified by agreement between manufacturer and purchaser.

S7. Calculated Hardenability

S7.1 A calculated hardenability shall be used in lieu of the requirements in Section 9. The method used shall be agreed upon between the purchaser and the steel supplier at the time of inquiry and order.

S8. Sulfur Requirement for Machinability

S8.1 The sulfur content shall be 0.015–0.030 %.

S8.2 The sulfide (Type A) rating units in Table 2 shall be 3.0 thin and 2.0 heavy.

S8.3 The manufacturer's certification shall state that material was produced to this supplementary requirement when applicable.

S9. Sample Reduction Ratio

S9.1 For the sampling described in 7.2, the purchaser may specify that the reduction ratio from as-cast section to test section be provided.

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 534–01 that may impact the use of this standard.

(1) The chemical composition of 4820H and the ISO types (Numbers B20 through B32) were corrected in Table 1.

Designation: A 541/A 541M – 04

Standard Specification for Quenched and Tempered Carbon and Alloy Steel Forgings for Pressure Vessel Components[1]

This standard is issued under the fixed designation A 541/A 541M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification[2] covers requirements for quenched and tempered carbon and alloy steel forgings for pressure vessel components.

1.2 All grades are considered weldable under proper conditions. Welding technique is of fundamental importance, and it is presupposed that welding procedure and inspection will be in accordance with approved methods for the grade of material used.

NOTE 1—Grades 1 and 1A have different chemistries but the same mechanical requirements.

NOTE 2—Designations have been changed as follows:

Current	Formerly
Grade 1	Class 1
Grade 1A	Class 1A
Grade 1C	Class 4
Grade 2 Class 1	Class 2
Grade 2 Class 2	Class 2A
Grade 3 Class 1	Class 3
Grade 3 Class 2	Class 3A
Grade 4N Class 1	Class 7
Grade 4N Class 2	Class 7A
Grade 4N Class 3	Class 7B
Grade 5 Class 1	Class 8
Grade 5 Class 2	Class 8A
Grade 11 Class 4	Class 11C
Grade 22 Class 3	Class 22B
Grade 22 Class 4	Class 22C
Grade 22 Class 5	Class 22D
Grade 22V	Class 22V
Grade 3V	Class 3V

1.3 The values stated in either inch-pound units or SI (metric) units are to be regarded separately as the standard. Within the text and tables, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.4 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:* [3]

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings

A 788 Specification for Steel Forgings, General Requirements

E 208 Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels

3. Ordering Information and General Requirements

3.1 In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order a detailed drawing that locates areas of significant loading in the forging (when required); the method of selecting test locations (see 6.2); purchase option (if any) in accordance with 9.1, and any supplementary requirements desired.

3.2 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

3.3 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

4. Chemical Composition

4.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 shall comply with

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys, and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved March 1, 2004. Published April 2004. Originally approved in 1965. Last previous edition approved in 1999 as A 541/A 541M – 95 (1999).

[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-541/SA-541M in Section II of that Code.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard.**

Table 1 except that the additional features of Supplementary Requirements S8, S9, S10, S12, and S15 shall also apply as individually specified in the ordering information.

4.2 *Product Analysis*—The manufacturer shall use the product analysis provision of Specification A 788 to obtain a product analysis from a forging representing each heat or multiple heat. The permissible variations of Table 1 of Specification A 788 do not apply to carbon, phosphorus, silicon and sulphur for all classes, vanadium for Grade 1C and columbium and calcium for Grades 22V and 3VCb. Boron is not subject to product analysis. The purchaser may also make this determination in accordance with Specification A 788.

5. Heat Treatment for Mechanical Properties

5.1 After complete austenitization, the forgings shall be quenched in a suitable liquid medium by spraying or immersion. For Grade 22V forgings, the minimum austenitizing temperature shall be 1650°F [900°C]. Quenching shall be followed by tempering at a subcritical temperature and holding at this temperature for a minimum time of ½ h/in. [25 mm] of maximum section thickness. Minimum tempering temperatures shall be:

Grade	°F [°C]
1, 1A, 2 Class 2, 3 Class 2	1150 [620]
2, 3 Class 1, 22 Class 3	1200 [650]
1C, 11 Class 4, 22 Class 4, 4N Class 1, 4N Class 2, 5 Class 1, 5 Class 2	1100 [595]
22 Class 15	1050 [565]
4N Class 3	1125 [605]
3V, 3VCb	1250 [675]
22V	1250 [675]

5.2 For Classes 1, 1A, 2, 2A, 3, or 3A, a multiple stage austenitizing procedure may be used whereby the forging is first fully austenitized and liquid quenched, followed by reheating within the intercritical temperature range to partially reaustenitize, and again liquid quenched. On completion of the austenitizing/quenching cycles, the forgings shall be tempered at a subcritical temperature as described in 5.1.

6. Mechanical Properties

6.1 *General Requirements*—The forgings shall conform to the requirements of Table 2. The forgings shall also conform to the requirements of Table 3 unless either Supplementary Requirement S6 or S13 is specified, in which case the requirements of those sections shall apply. The largest obtainable tension test specimen as specified in Fig. 4 of Test Methods and Definitions A 370 shall be used. Impact specimens shall be Charpy V-notch, as shown in Fig. 10 of Test Methods and Definitions A 370. The usage of subsize impact specimens due to material limitations must have prior purchaser approval.

6.2 *Sampling*—The longitudinal axis and mid-length of tension and impact test specimens shall be positioned in accordance with one of the following methods as specified by the purchaser:

6.2.1 *Method 1*—This method shall always be used when the maximum quenched thickness does not exceed 2 in. [50 mm]. Specimens shall be located in the production forging or test forging (as described in Method 4) at mid-thickness and at least 2 in. from other quenched surfaces.

6.2.2 *Method 2—t* by 2*t*, where *t* is the distance from the area of significant loading (see 3.1) to the nearest quenched surface. However, the specimens shall not be nearer to one quenched surface than ¾ in. [20 mm] and to the second quenched surface than 1½ in. [40 mm]. When this method of testing is employed, forgings are usually manufactured in accordance with a purchaser-approved drawing showing prequenched dimensions and the location of mechanical test specimens.

6.2.3 *Method 3*—¼ *T* by *T*, where *T* is the maximum thickness of the forging as heat treated. Where this method of

TABLE 1 Chemical Requirements Composition, %

	Grade 1	Grade 1A	Grade 2	Grade 3	Grade 1C	Grade 11 Class 4	Grade 22 Classes 4 and 5	Grade 4N	Grade 5	Grade 3V	Grade 22 Class 3	Grade 22V	Grade 3VCb
Carbon	0.35 max	0.30 max	0.27 max	0.25 max	0.18 max	0.10–0.20	0.05–0.15	0.23 max	0.23 max	0.10–0.15	0.11–0.15	0.11–0.15	0.10-0.15
Manganese	0.40–0.90	0.70–1.35	0.50–0.90	1.20–1.50	1.30 max	0.30–0.80	0.30–0.60	0.20–0.40	0.20–0.40	0.30–0.60	0.30–0.60	0.30–0.60	0.30-0.60
Phosphorus	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.020 max	0.015 max	0.015 max	0.020 max
Sulfur	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.020 max	0.015 max	0.010 max	0.010 max
Silicon[A]	0.15–0.35	0.15–0.40	0.15–0.35	0.15–0.35	0.15–0.35	0.50–1.00	0.50 max	0.30 max	0.30 max	0.10 max	0.50 max	0.10 max	0.10 max
Nickel	0.40 max	0.40 max	0.50–1.00	0.40–1.00	0.25 max	0.50 max	0.50 max	2.8–3.9	2.8–3.9	. . .	0.25 max	0.25 max	0.25 max
Chromium	0.25 max	0.25 max	0.25–0.45	0.25 max	0.15 max	1.00–1.50	2.00–2.50	1.25–2.00	1.25–2.00	2.8–3.3	2.00–2.50	2.00–2.50	2.7-3.3
Molybdenum	0.10 max	0.10 max	0.55–0.70	0.45–0.60	0.05 max	0.45–0.65	0.90–1.10	0.40–0.60	0.40–0.60	0.90–1.10	0.90–1.10	0.90–1.10	0.90-1.10
Vanadium	0.05 max	0.05 max	0.05 max	0.05 max	0.02–0.12	0.05 max	0.05 max	0.03 max	0.08 max	0.20–0.30	0.02 max	0.25–0.35	0.20-0.30
Titanium	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.015–0.035	. . .	0.030 max	0.015 max
Boron	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.001–0.003	. . .	0.0020 max	. . .
Copper	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.20 max	0.25 max
Columbium	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.07 max	0.015-0.070
Calcium	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.015 max[B]	0.0005-0.0150

[A] When vacuum carbon-deoxidation is required for the classes included in Supplementary Requirements S10, the silicon content shall be 0.10 % max.

[B] For Grade 22V, rare earth metals (REM) may be added in place of calcium, subject to agreement between the producer and the purchaser. In that case the total amount of REM shall be determined and reported.

TABLE 2 Tensile Requirements

	Grade 1 and 1A	Grades 2 Class 1, 3 Class 1, 1C and 11 Class 4	Grade 2 Class 2 and Grade 3 Class 2	Grade 22 Class 4	Grade 22 Class 5	Grade 4N Class 1 and Grade 5 Class 1	Grades 4N Class 2 and 5 Class 2	Grade 4N Class 3	Grades 3V and 22V	Grade 22 Class 3	Grade 3VCb
Tensile strength, ksi [MPa]	70–95 [485–655]	80–105 [550–725]	90–115 [620–795]	105–130 [725–895]	115–140 [795–965]	105–130 [725–895]	115–140 [795–965]	90–115 [620–795]	85–110 [585–760]	85–110 [585–760]	85–110 [585-760]
Yield strength (0.2 % offset), min, ksi [MPa]	36 [250]	50 [345]	65 [450]	85 [585]	100 [690]	85 [585]	100 [690]	70 [485]	60 [415]	55 [380]	60 [415]
Elongation in 2 in. or 50 mm, min, %	20	18	16	16	15	18	16	20	18	18	18
Reduction of area, min, %	38	38	35	45	40	48	45	48	45	45	45

TABLE 3 Charpy V-Notch Impact Requirements at 40°F (4°C) (Except for 2A)[A,B]

	Grades 1, 1A, and 11 Class 4	Grade 2 Class 2 and 3 Class 2	Grade 2 Class 1, 3 Class 1 and 1C	Grade 22 Class 5	Grades 22 CL 4 4N Classes 1, 2, 3 5 Classes 1, 2	Grades 3V and 3VCb, Grade 22, Class 3 and Grade 22V
Minimum average value of set of three specimens, ft·lbf (J)[C]	15 [20]	35 [47][D]	30 [41]	25 [34]	35 [47]	40 [54][E]
Minimum value of one specimen, ft·lbf (J)	10 [14]	30 [41][D]	25 [34]	20 [27]	30 [41]	35 [47][E]

[A] These Charpy values are for tests made on standard 10–mm square specimens. If sub-size impact specimens are used, the required minimum ft·lbf values shall be determined by multiplying the ft·lbf values in Table 3 by 5⁄6 for 7.5 by 10-mm specimens, and by 2⁄3 for 5 by 10–mm specimens.
[B] These values apply for tests at lower temperatures if Supplementary Requirement S6 is specified in the order.
[C] Not more than one specimen from a set may be below this value.
[D] Tested at 70°F [21°C].
[E] Tested at 0°F [−18°C].

testing is employed, the following limitations for as-treated thickness shall apply, unless otherwise agreed upon:

Grade	in. [1 mm], max
1 and 1A	3 [75]
2 Class 2 and 3 Class 2	6 [150]
2 Class 1 and 3 Class 1	8 [200]
1C	4 [100]
11 Class 4	5 [125]
22 Class 4, 4N Class 2, 5 Class 2	6 [150]
22 Class 5	8 [200]
4N Class 1, 5 Class 1, 4N Class 3, 3V, 3VCb, 22V, and 22 Class 3	10 [250]

6.2.4 *Method 4*—Test specimens shall be taken from a representative separate test forging or bar made from the same heat of steel which shall receive substantially the same reduction and type of hot working as the production forgings which it represents, except that a longitudinally forged bar may be used to represent a rolled ring of similar cross section. It shall be of the same nominal thickness as the as-quenched production forgings and shall be heat treated in the same furnace charge and under the same conditions as the production forgings. Test specimens shall be removed using the ¼ T by T procedure referenced in Method 3 with the same limitation on forging thickness as in 6.2.3. This method shall be limited to forgings with a rough machined weight of not more than 1000 lb [450 kg].

6.3 *Metal Buffers*—The required distances from quenched surfaces may be obtained with metal buffers instead of integral extensions. Buffer material may be carbon or low-alloy steel, and shall be joined to the forging with a partial penetration weld that seals the buffered surface. Specimens shall be located at least ½ in. [13 mm] from the buffered surface of the forging. Buffers shall be removed and the welded areas subjected to magnetic particle test to ensure freedom from cracks unless the welded areas are completely removed by subsequent machining.

6.4 Samples shall be removed from forgings after the quenching and tempering heat treatments. This sample material shall be subjected to a simulated post-weld heat treatment if supplementary requirement S1 is specified.

6.5 *Orientation*—For upset disk forgings, the longitudinal axis of all test specimens shall be oriented in the tangential direction. For all other forgings, the longitudinal axis of the specimens shall be oriented in the direction of maximum working of the forging unless Supplementary Requirements S11 or S14 are imposed.

6.6 *Number of Tests*:

6.6.1 *Forgings under 500 lb* [*230 kg*] *As Treated*—For duplicate forgings weighing less than 500 lb [230 kg] as treated, one tension test and one impact test (three specimens) shall be made to represent each heat in each heat-treatment charge. When heat treatment is performed in continuous-type furnaces with suitable temperature control and equipped with recording pyrometers so that complete heat-treatment records are available, a heat-treatment charge shall be considered as any continuous run not exceeding an 8-h duration.

6.6.2 *Forgings weighing 500 to 10 000 lb* [*230 to 4500 kg*] *As-Heat Treated*—One tension and one impact test (3 specimens) shall be made for each forging.

6.6.3 Each forging weighing over 10 000 lb [4500 kg] shall require two tension tests and two impact tests, located at opposite ends if the length is 1½ times the diameter or more, or 180 deg apart otherwise.

7. Repair Welding

7.1 Repair welding of forgings may be permitted, but only at the option of the purchaser.

7.2 If repair welding is performed, welders and weld procedures shall be qualified in accordance with Section IX of the ASME Boiler and Pressure Vessel Code.

8. Workmanship and Quality Level Requirements

8.1 Dimensional and visual inspections shall be conducted by the manufacturer. Forgings shall be free of cracks, thermal ruptures, or other imperfections.

9. Certification and Reports

9.1 In addition to items required to be reported by Specification A 788, the following items shall also be reported:

9.1.1 Product chemical analysis.

9.1.2 The method used for locating test specimens.

9.1.3 Sketches included in the report of non-destructive examinations.

9.1.4 Details of the heat treatment cycle, as listed in Specification A 788.

10. Product Marking

10.1 The purchaser may specify additional identification marking and the location of the marking. If stamps are used, they shall be round-nosed or "interrupted-dot" die stamps having a minimum radius of $\frac{1}{32}$ in. [0.8 mm].

11. Keywords

11.1 chromium-molybdenum steel; nickel-chromium-molybdenum alloy steel; pressure vessel service; quenched and tempered steel; steel forgings—alloy; steel forgings—carbon

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry or order. Details of these supplementary requirements shall be agreed upon by the manufacturer and the purchaser.

S1. Simulated Post-Weld Heat Treatment of Mechanical Test Samples

S1.1 All test coupons shall be subjected to single or multiple heat treatments at subcritical temperatures prior to testing. Such treatments are intended to simulate post-weld or other treatments to which the forgings will be subjected during subsequent fabrication. The purchaser shall furnish the manufacturer with details of the desired heat treatment for the test coupons, including temperatures, times, and cooling rates.

S2. Ultrasonic Inspection

S2.1 Forgings shall be ultrasonically examined in accordance with the procedures of Practice A 388/A 388M.

S2.1.1 *Longitudinal Wave Test:*

S2.1.1.1 Unless otherwise specified, the back reflection method of tuning shall be used in accordance with the Procedure Section (the paragraph regarding Back–Reflection Technique) of Practice A 388/A 388M.

S2.1.1.2 In addition to the reportable conditions of the Recording Section of Practice A 388/A 388M, indications exceeding the resultant back reflection shall be recorded.

S2.1.1.3 The following conditions are subject to rejection:

Complete loss of back reflection accompanied by an indication of a discontinuity. For this purpose, a back reflection less than 5 % of full screen height shall be considered complete loss of back reflection.

An indication equal in amplitude to that of the back reflection established in an indication-free portion of the forging.

S2.1.2 *Angle Beam Test:*

S2.1.2.1 Calibration notches, calibration reference, and method of scanning shall be in accordance with the Procedure Section (the paragraph regarding Angle–Beam Examination) of Practice A 388/A 388M.

S2.1.2.2 A forging that contains a discontinuity which results in an indication exceeding the amplitude of the reference line is subject to rejection.

S2.1.3 The report of the ultrasonic examination shall be in compliance with the Report Section of Practice A 388/A 388M.

S2.1.4 Additional nondestructive examination or trepanning may be employed to resolve questions of interpretation of ultrasonic indications. The manufacturer shall accept responsibility for injurious conditions that will not be removed in final machining.

S3. Magnetic Particle Examination

S3.1 Each forging shall be inspected by magnetic particle methods described in Test Method A 275/A 275M. Acceptance and rejection standards shall be mutually agreed upon by the purchaser and manufacturer.

S4. Charpy V-Notch Impact Transition Curve

S4.1 Sufficient impact tests shall be made from the forging test material to establish a temperature-absorbed energy curve. The test temperature range shall be wide enough to establish the upper and lower shelf foot pound energies, with sufficient testing at intermediate temperatures to permit plotting a reasonably smooth curve.

S5. Additional Charpy Data

S5.1 The percent shear fracture and mils or millimetres of lateral expansion, defined in Test Methods and Definitions A 370, shall be reported for each Charpy specimen tested.

S6. Charpy Impact Tests

S6.1 Charpy impact tests shall be made in accordance with the provisions of Section 6 of this specification except that the test temperature shall be lower than that specified in Table 3.

S7. Drop-Weight Test

S7.1 Drop-weight tests shall be conducted in accordance with the requirements of Test Method E 208. The fracture plane of the specimens shall coincide with the location required for other mechanical test specimens as specified by the purchaser in accordance with 6.2. However, since the drop-weight specimen can be taken in any orientation, the fracture plane of the specimen when tested to Method 2 (6.2.2) shall be a minimum distance of 7⁄16 in. [11 mm] from the nearest quenched surface, and 1½ in. [40 mm] from any second surface. The purchaser may specify either duplicate no-break performance when tested 10 deg warmer than a specified temperature or request a determination of the nil-ductility temperature.

S8. Restrictive Chemistry for Grades 4N and 5

S8.1 Phosphorus and sulfur limits for Grades 4N and 5 may be specified 0.020 %, max.

S9. Additional Vanadium

S9.1 For Grade 5 forgings 0.05 to 0.15 % vanadium may be specified.

S10. Special Steels

S10.1 Vacuum treated steel shall be specified.

S10.2 When Grades 2, 3, 4N, and 5 are vacuum carbon deoxidized, the silicon content shall be 0.10 % maximum.

S10.3 The test report shall indicate that the steel was vacuum carbon deoxidized.

S11. Rings and Hollow Cylindrically Shaped Parts

S11.1 Tests shall be removed in the tangential (circumferential) direction regardless of direction of maximum working.

S12. Restrictive Chemistry

S12.1 The following restricted phosphorus and copper limits may be specified as follows:

P 0.012 % max heat, 0.015 % max product; Cu 0.10 % max
P 0.015 % max heat, 0.018 % max product; Cu 0.15 % max

S13. Alternative Fracture Toughness Requirements

S13.1 The fracture toughness requirements (drop-weight or Charpy impact tests, or both) for materials of the ASME Boiler and Pressure Vessel Code, Section III, Article NB2300, NC2300, ND2300, NE2300, NF2300 or NG2300, as specified, shall be used instead of the Charpy impact test requirements of this specification.

S14. Alternative Test Specimen Orientation

S14.1 The longitudinal axis of all test specimens shall be oriented in a direction transverse to the direction of maximum working of the forging.

S15. Restricted Sulfur Content

S15.1 The sulfur content shall be limited to 0.015 % maximum heat and 0.018 % maximum product.

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 541/A 541M-95 (1999) that may impact the use of this standard.

(1) Revised metric units, as necessary, throughout.

Standard Specification for Steel Tires[1]

This standard is issued under the fixed designation A 551; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers seven classes of carbon steel tires for railway and rapid transit use.

1.1.1 *Class A*—For untreated driving tires for locomotives in passenger service.

1.1.2 *Class AHT*—For heat-treated driving tires for locomotives in passenger service.

1.1.3 *Class B*—For untreated driving tires for freight locomotives and tires for locomotive-truck, tender-truck, trailer and car wheels, and miscellaneous service.

1.1.4 *Class BHT*—For heat-treated driving tires for freight locomotives and tires for trailer wheels.

1.1.5 *Class C*—For untreated tires for switching locomotives.

1.1.6 *Class CHT*—For heat-treated driving tires and switching locomotives and tires for locomotive-trucks, tender-trucks, trailer and car wheels, and miscellaneous service.

1.1.7 *Class DHT*—For heat-treated driving tires for locomotives with light braking conditions, heavily loaded trailer tires, and car wheels where off-tread brakes are employed.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are provided for information purposes only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[2]

E 350 Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron[3]

E 415 Method for Optical Emission Vacuum Spectrometric Analysis of Carbon and Low-Alloy Steel[4]

NOTE 1—References to these standards are for guidance only; other methods of equivalent accuracy may be used.

3. Ordering Information

3.1 The inquiry, order or contract for material under this specification shall include the following information:

3.1.1 Quantity,

3.1.2 Class,

3.1.3 Full identification of tread and flange contour with dimensional drawings as required,

3.1.4 Inside diameter to be rough machined or finished,

3.1.5 Intended service,

3.1.6 ASTM designation and year of issue, and

3.1.7 Supplementary requirements, if any.

4. Manufacture

4.1 *Melting Process*—The steel shall be made by one or more of the following processes: open-hearth, basic-oxygen, or electric-furnace.

4.2 *Discard*—Sufficient discard shall be made from each ingot to assure freedom from piping and undue segregation.

4.3 *Cooling and Heating*:

4.3.1 All tires, immediately after being rolled, shall be slow cooled in a manner to accomplish proper transformation without damage.

4.3.2 Classes AHT, BHT, CHT, and DHT shall be heated to and held at the proper temperature for a sufficient time to effect the desired transformation and then shall be immersed in a suitable quenching medium.

4.3.3 Following quenching, the tires shall be charged into a furnace for tempering to meet the hardness requirements of 6.1.1, and then cooled under suitable conditions.

5. Chemical Requirements

5.1 *Chemical Composition*—The steel shall conform to the requirements for chemical composition specified in Table 1 or to the composition agreed upon by the manufacturer and the purchaser.

5.2 *Heat or Cast Analysis*—An analysis of each heat or cast of steel shall be made by the manufacturer to determine the percentages of the elements specified in Table 1. The analysis shall be made from a test sample taken preferably during the

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] *Annual Book of ASTM Standards,* Vol 01.03.

[3] *Annual Book of ASTM Standards,* Vol 03.05.

[4] *Annual Book of ASTM Standards,* Vol 03.06.

TABLE 1 Chemical Requirements

Element	Composition, %
Carbon	
Classes A and AHT	0.50–0.65
Classes B and BHT	0.60–0.75
Classes C, CHT and DHT	0.70–0.85
Manganese	0.60–0.90
Phosphorus, max	0.050
Sulfur, max	0.050
Silicon	0.15–0.35

pouring of the heat. The chemical composition thus determined shall be reported to the purchaser or the purchaser's representative, and shall conform to the requirements in Table 1.

5.3 *Product Analysis*—An analysis to represent each heat may be made by the purchaser from turnings taken from a tire. The chemical composition thus determined shall not vary from the requirements by more than the limits in Table 2.

6. Hardness Requirement

6.1 Classes AHT, BHT, CHT, and DHT shall be accepted on the basis of a Brinell hardness test on the front face of 10 % of the tires from each heat at a location approximately 1 in. (25 mm) below the tread.

6.1.1 The tires shall conform to the following limits:

Class	AHT	BHT	CHT	DHT
Brinell hardness	223 to 277	255 to 302	285 to 331	321 to 363

6.1.2 Where continuous heat-treating furnaces are used, should any of the tested tires fail to meet the hardness requirements of 6.1.1, the manufacturer may offer for individual hardness measurements, all of the tires of that heat in the lot for inspection. Those meeting the hardness requirements of 6.1.1 shall be accepted.

6.1.3 Where batch heat-treating furnaces are used, should any of the tires fail to meet the requirements of 6.1.1, the manufacturer may offer all of the tires in the heat treatment lot for individual hardness measurement. Those meeting the hardness requirements of 6.1.1 shall be accepted.

7. Retreatments

7.1 Any tires failing to meet the specified hardness may be retreated and tested in accordance with Section 6.

8. Mating

8.1 The tires shall be grouped according to outside diameter and shipped in sets.

8.2 The variation in outside diameters in each set shall not exceed 1⁄16 in. (1.6 mm) for tires 33 in. (838 mm) or under in outside diameter, nor exceed 3⁄32 in. (2.4 mm) for tires over 33 in. (838 mm) in outside diameter.

TABLE 2 Product Analysis Requirements

Element	Over Maximum Limit, %	Under Minimum Limit, %
Carbon	0.03	0.02
Manganese	0.04	...
Phosphorus	0.010	...
Sulfur	0.010	...

9. Permissible Variations in Dimensions

9.1 Tires may be furnished with all surfaces as-rolled, and shall conform to the dimensions specified, subject to the following variations:

9.1.1 *Height of Flange*—The flange height shall not be less, but may be 1⁄16 in. (1.6 mm) more, than that specified.

9.1.2 *Thickness of Flange*—The flange thickness shall not vary more than 1⁄16 in. (1.6 mm) from that specified.

9.1.3 *Radius of Throat*—The throat radius shall not vary more than 1⁄8 in. (3.2 mm) over, nor more than 1⁄16 in. (1.6 mm) under, that specified.

9.1.4 *Width of Tires*—The tire width shall not be less, but may be 1⁄16 in. (4.8 mm) more, than that specified.

9.1.5 *Inside Diameter*—The rough inside diameter shall not be more, but may be 1⁄4 in. (6.4 mm) less, than that specified. When the finished inside diameter only is specified, the rough diameter shall be from 3⁄16 to 7⁄16 in. (4.8 to 11.1 mm) less than this diameter.

9.1.6 *Outside Diameter*—Unless otherwise specified, the outside diameter, when 54 in. (1370 mm) or under, shall not be less, but may be 1⁄2 in. (12.7 mm) more than that specified; and when over 54 in. (1370 mm), shall not vary more than 1⁄8 in. (3.2 mm) under, nor more than 3⁄8 in. (9.5 mm) over that specified.

9.1.7 *Rotundity*—Tires shall not be out-of-round more than 1⁄16 in. (1.6 mm) for tires 33 in. (838 mm) or under in outside diameter, nor more than 3⁄32 in. (2.4 mm) for tires over 33 in. (838 mm) in outside diameter.

10. Workmanship, Finish, and Appearance

10.1 The tire shall be free of injurious imperfections and shall have a good, workmanlike appearance.

11. Marking

11.1 The name of the manufacturer or brand, the serial number, heat number, date of manufacture, and class shall be legibly stamped on each tire close to the inside edge where they will not be removed by the last turning.

11.2 In addition to the above required markings, bar code tags may be applied to the axles. If these are applied, it is recommended that bar code 39 be used. The size and location of the tags, as well as the information to be included, shall be agreed upon by the purchaser and manufacturer.

12. Inspection

12.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy that the material is being produced and furnished in accordance with this specification. Mill inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspections shall be made at the place of manufacture, unless otherwise agreed to.

13. Rejection

13.1 Unless otherwise specified, any rejection based on tests made in accordance with this specification shall be reported to the manufacturer within five working days from the receipt of samples by the purchaser.

13.2 Material that shows injurious imperfections subsequent to its acceptance at the manufacturer's works will be rejected and the manufacturer shall be notified.

14. Rehearing

14.1 Tires tested in accordance with this specification that represent rejected material shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may request a rehearing within that time.

15. Certification and Report of Testing

15.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the test results shall be furnished at the time of shipment. The specification year of issue and revision letter, if any, shall be included in the certification.

16. Keywords

16.1 rail applications; wheel tires

SUPPLEMENTARY REQUIREMENTS

S1. Incidental Alloying Elements

S1.1 The purchaser may specify maximum amounts of incidental alloying elements according to Table S1.1.

S1.2 Analysis for residual elements shall conform to procedures specified in 5.1.

S2. Classes AHT, BHT, CHT, and DHT

S2.1 In addition to hardness testing, the purchaser may specify that one tension test be made from one tire per heat.

S2.2 The tension test shall conform to the requirements of Table S1.2.

S2.3 When a tension test specimen is cut from a tire, it shall be prepared from the position indicated in Fig. S1.1.

TABLE S1.1 Incidental Alloying Elements

Element	Composition, max, %
Chromium	0.15
Nickel	0.25
Molybdenum	0.06

TABLE S1.2 Tension Tests

Class	Tensile Strength, min		Elongation in 2 in. or 50 mm, min, %	Reduction of Area, min, %
	ksi	MPa		
AHT	110	760	16.0	32.0
BHT	125	860	14.0	28.0
CHT	140	965	12.0	24.0
DHT	155	1070	10.0	20.0

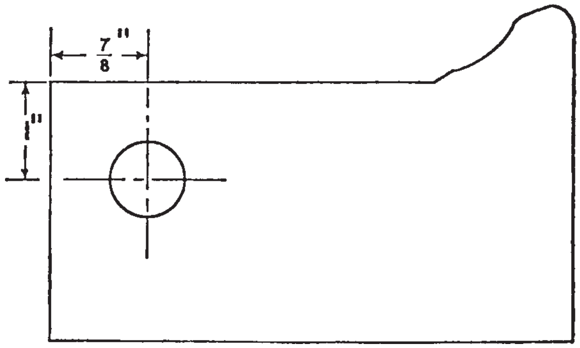

FIG. S1.1 Location in Tire of Tension Test Specimen

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

Designation: A 561 – 71 (Reapproved 1999)

Standard Practice for Macroetch Testing of Tool Steel Bars[1]

This standard is issued under the fixed designation A 561; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice for macroetch testing has been found to be a useful and reliable method for evaluating the quality of tool steel bars. It is used as a quality control and inspection test to reveal by deep acid etching the macrostructure in specimens cut from bars and to show the presence of such conditions as pipe, cracks, porosity, segregation, or foreign material. The etched surface is generally examined visually, but magnification up to about 10× is occasionally employed.

2. Apparatus

2.1 *Etching Containers*—Macroetching may be performed in a vessel of borosilicate glass, porcelain, corrosion-resistant metals, or some other acid-resisting material.

3. Reagent

3.1 *Etching Reagent*—A solution of equal volumes of concentrated hydrochloric acid (HCl, sp gr 1.19) and water is commonly used for macroetching tool steels. This solution must be used under a ventilating hood because HCl is volatile and the fumes are corrosive and irritating, although nontoxic. The solution may be reused within limits. With use, the concentration of dissolved iron and other metals increases and the acidity of the solution decreases retarding the etching action. Spent solution shall be replaced with fresh solution, not replenished with concentrated acid.

4. Sampling

4.1 The selection of specimens for macroetch testing must be done with care for interpretations to be of value.

4.1.1 Specimens are usually cut from hot-rolled annealed bars, but may be cut from machined or ground bars if the bars are to be finish machined or ground.

4.1.2 The specimen should be located at a sufficient distance from the end of the bar to avoid end effects.

4.1.3 For ease in handling, use specimens ¼ to ½ in. (6.35 to 12.7 mm) thick.

4.1.4 Cut specimens to expose a transverse section of the bar; however, the test is occasionally performed on a longitudinal section.

4.1.5 Specimens may be taken from one or both ends of a bar. Each bar may be sampled, or a few typical specimens may be tested as representative of a large number of bars.

5. Specimen Preparation

5.1 In all cutting and grinding operations on the specimen, care must be excercised to avoid heating the surface to an excessively high temperature. Specimens are cut from bars by sawing, machining, abrasive wheel cutting, or other means. Cutting should be controlled to prevent smearing the cut face and masking the structure.

5.1.1 The "as-cut" surface of a specimen may be sufficiently smooth to reveal the defects for which the examination is conducted. No additional surface preparation may then be necessary.

5.1.2 Additional surface preparation may be required to remove cutting marks and to allow details to be revealed by etching. In such circumstances, machining, grinding, or polishing may be necessary. Generally, the degree of surface smoothness required is greater the finer the detail that must be resolved. When the action of the etchant is drastic, a coarser surface finish may be used.

5.1.3 The surface must be free of adhering grease and oil. There should be no scale or oxide on the surface which will be examined after etching.

6. Procedure

6.1 *Temperature for Macroetching*—Etching characteristics are influenced markedly by the temperature of the etchant. Thus, the reagent temperature should be controlled for macroetching if comparative results are desired. Tool steels are generally macroetched at about 160°F (71°C). At this temperature, the etching reaction is vigorous and solution losses through evaporation are not excessive. The solution may be heated on a gas or electric hot plate, by an acid-proof immersion heater, or by steam.

6.2 *Etching Time*—The etching time should be sufficiently long to completely reveal the structure in the specimen, yet should not be so long as to develop artifacts such as etch pits or to obscure or obliterate the structure. Generally, etching

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[1] This practice is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.29 on Tool Steel.

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times under 10 min or over 40 min are avoided with tool steels. The time of etching is best adjusted by trial to develop the degree of etching desired. Where recovery of temperature of the solution is slow after immersion of cold specimens, reproducibility is enhanced by preheating the specimens in hot water prior to immersing in the etchant.

6.3 *Macroetching Technique*:

6.3.1 After preparation as described above, clean the specimen of dirt and grease with a solvent, if necessary. Then place directly into the etching solution already heated to the proper temperature, or preheat in water as in 6.2 and then transfer to the hot etching bath. The purpose of preheating the specimen is to obtain better control of the etching conditions where close reproducibility of degree of development is desired. The specimen must be completely immersed.

6.3.2 Moderate agitation (stirring) of the solution during macroetching promotes uniform development by eliminating temperature and composition gradients. Provision for agitating the etchant may be desirable where the volume of solution is relatively small.

6.3.3 At the end of the etching period, remove the specimen from the hot acid and rinse immediately in a stream of water. Flush off the sludge which forms on the surfaces of the specimen during etching with the aid of a stiff brush. Then dry the specimen with alcohol, a clean air blast, or live steam.

6.3.4 After drying, protect the etched surface from rusting by an application of oil, grease, glycerine, or transparent lacquer.

7. Interpretation of Results

7.1 Examine the etched surface visually or at up to 10× magnification to determine its structure. Note the presence, absence, and severity of the following conditions:

7.1.1 *Internal*:

7.1.1.1 Pipe,

7.1.1.2 Bursts,

7.1.1.3 Carbide (see Note 1) or alloy segregation,

7.1.1.4 Concentrations of nonmetallic inclusions,

7.1.1.5 Porosity, and

7.1.1.6 Internal cracks or thermal flakes.

NOTE 1—Carbide segregation is better determined by examination of a polished surface after etching in 4 % nital solution.

7.1.2 *Surface and Subsurface*:

7.1.2.1 Seams, laps, cracks, etc.,

7.1.2.2 Ingot corner segregation or cracks, and

7.1.2.3 Pinholes,

7.1.3 *Miscellaneous*:

7.1.3.1 Entrapped metallic or nonmetallic material, and

7.1.3.2 Ingot pattern (dendritic segregation, columnar grain structure, etc.).

7.2 Twelve photomacrographs[2] provide a numerical rating of severity levels of porosity (7.1.1.5) and ingot pattern (7.1.3.2) that may be present in tool steel bars.

7.2.1 These conditions identified in general as porosity and ingot pattern are described as follows:

7.2.1.1 *Center Porosity*—A center concentration of minute voids related to etched out carbides, or nonmetallic inclusions, etc.

7.2.1.2 *Ring Ingot Pattern*—One or more concentric rings characterized by differential etching associated with a minor gradient in chemical composition or ingot solidification.

7.2.2 Ratings for the conditions can be determined by comparing macroetched disks with these photographs.

7.2.3 The photographs are not intended as standards for acceptance or rejection. The numerical identity listed with each figure only refers to a degree of severity. The extent that each condition is permissible for a given application should be stated by the tool steel specification covering the application or as negotiated between the supplier and purchaser.

[2] The set of 12 photomacrographs may be obtained from ASTM Headquarters, 100 Barr Harbor Drive, W. Conshohocken, PA 19428, at a nominal cost. Request Adjunct ADJA0561.

Standard Specification for Steel Bars, Carbon, Merchant Quality, M-Grades[1]

This standard is issued under the fixed designation A 575; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers hot-wrought merchant quality carbon steel bars produced to a chemical composition. Merchant quality bars are used for structural and similar miscellaneous bar applications involving moderate cold bending, moderate hot forming, punching, and welding as used in the production of noncritical parts. Moderate cold bending involves a generous bend radius with the axis of the bend transverse to the direction of rolling.

1.2 Special quality hot-wrought carbon steel bars are covered in Specification A 576.

1.3 Some end uses may require one or more of the available designations shown under Supplementary Requirements.

1.4 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 576 Specification for Steel Bars, Carbon, Hot Wrought, Special Quality[2]

3. Ordering Information

3.1 Orders under this specification should include the following as required to describe adequately the desired material:

3.1.1 ASTM specification number and date of issue,

3.1.2 Grade designation or chemical composition (Section 7 and appropriate chemical analysis tables),

3.1.3 Supplementary Requirements or additions, if required,

3.1.4 Dimensions and quantity, and

3.1.5 End use and processing.

4. Materials and Manufacture

4.1 The steel shall be made by the open-hearth, basic-oxygen, or electric-furnace process.

5. Conditions

5.1 Merchant quality bars are available in rounds, squares, round cornered squares, hexagons, and bar size shapes under 3 in. (76.2 mm), and in flats less than 40.8 lb/ft (60.7 kg/m). Hot-wrought merchant quality carbon steel bars are produced in cut lengths and coils; the producer should be consulted regarding sections and sizes available in coils.

5.2 Merchant quality is available within a composition of 0.50 % maximum carbon, 0.60 % maximum manganese, non-resulfurized, non-leaded. The phosphorus content is 0.04 %, max, and the sulfur content is 0.05 %, max. Merchant quality grades of steel are shown in Table 1 and chemical ranges and limits in Table 2; the grade numbers are designated with the prefix "M." Merchant quality bars are not produced to any specified silicon content, grain size, or other requirement that would influence the type of steel.

TABLE 1 Grade Designations and Chemical Compositions of Hot-Wrought Merchant Quality M Series Carbon Steel Bars

Grade Designation	Carbon, %	Manganese,[A] %	Phosphorus, max, %	Sulfur, max, %
M 1008	0.10 max	0.25–0.60	0.04	0.05
M 1010	0.07–0.14	0.25–0.60	0.04	0.05
M 1012	0.09–0.16	0.25–0.60	0.04	0.05
M 1015	0.12–0.19	0.25–0.60	0.04	0.05
M 1017	0.14–0.21	0.25–0.60	0.04	0.05
M 1020	0.17–0.24	0.25–0.60	0.04	0.05
M 1023	0.19–0.27	0.25–0.60	0.04	0.05
M 1025	0.20–0.30	0.25–0.60	0.04	0.05
M 1031	0.26–0.36	0.25–0.60	0.04	0.05
M 1044	0.40–0.50	0.25–0.60	0.04	0.05

[A] Unless prohibited by the purchaser, the manganese content shall be permitted to exceed 0.60 % on heat analysis to a maximum of 0.75 %, provided that the carbon range on heat analysis has the minimum reduced by 0.01 % for each 0.05 % manganese over 0.60 %.

5.3 Merchant quality bars shall be free of visible pipe; however, they may contain pronounced chemical segregation. Internal porosity, surface seams, and other surface irregularities may be present in this quality.

6. Chemical Composition

6.1 The steel shall conform on heat analysis to the requirements of chemical composition in Table 1, or chemical compositions can be specified that conform to the ranges and

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

TABLE 2 Heat Chemical Ranges and Limits of Hot-Wrought Merchant Quality M Series Carbon Steel Bars

Element	Chemical Ranges and Limits, %		
	When Maximum of Specified Element is:	Range	Lowest Maximum
Carbon	...	...	0.10
	To 0.12 incl	...	...
	Over 0.12 to 0.24 incl	0.07	...
	Over 0.24 to 0.27 incl	0.08	...
	Over 0.27 to 0.50 incl	0.10	...
	...		
	...	...	0.35
Manganese[A]	To 0.60 incl	0.35	...
		...	...
Phosphorus	To 0.04 incl	...	0.04
Sulfur	To 0.05 incl	...	0.05
Copper	When copper is required 0.20 minimum is generally specified.	...	...

[A] Unless prohibited by the purchaser, the manganese content may exceed 0.60 % on heat analysis to a maximum of 0.75 %, provided that the carbon range on heat analysis has the minimum and maximum reduced by 0.01 % for each 0.05 % manganese over 0.60 %.

limits in Table 2. The heat analysis shall be reported to the purchaser for the elements specified.

7. General Requirements

7.1 Material furnished under this specification shall conform to the requirements of the current edition of Specification A 29/A 29M.

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply when specified by the purchaser.

S1. Special Straightness

S1.1 Bars may be specified to special straightness tolerance (see Specification A 29/A 29M).

S2. Cleaning

S2.1 The purchaser may specify that the surface of bars be descaled by pickling or blast cleaning.

S3. Coating

S3.1 The purchaser may specify oil coating on bars that have been descaled.

Designation: A 576 – 90b (Reapproved 2000)

Standard Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality[1]

This standard is issued under the fixed designation A 576; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers hot-wrought special quality carbon steel bars. Special quality bar applications include forging, heat treating, cold drawing, machining, and many structural uses. A guide for the selection of steel bars is contained in Practice A 400.

1.2 The bars shall be furnished in the grades specified in Table 1. Sections and sizes of bar steel available are covered in Specification A 29/A 29M. Hot-wrought special quality carbon steel bars are produced in cut lengths and coils; the manufacturer should be consulted regarding sections and sizes available in coils, produced to a chemical composition.

1.3 Merchant quality hot-wrought carbon steel bars are covered in Specification A 575.

1.4 Some end uses may require superior surface quality, or special chemical restrictions, metallurgical characteristics, heat treatment, or surface finishes which the purchaser may obtain by designating one or more of the available Supplementary Requirements.

1.5 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 400 Practice for Steel Bars, Selection Guide, Composition and Mechanical Properties[2]

A 575 Specification for Steel Bars, Carbon, Merchant Quality, M-Grades[2]

E 45 Practice for Determining the Inclusion Content of Steel[3]

E 527 Practice for Numbering Metals and Alloys (UNS)[4]

2.2 *SAE Standard:*

SAE J 1086 Recommended Practice for Numbering Metals and Alloys (UNS)[5]

3. Ordering Information

3.1 Orders under this specification should include the following, as required, to describe adequately the desired material:

3.1.1 Quantity (weight or number of bars),

3.1.2 Name of material (hot-wrought carbon steel bars),

3.1.3 Dimensions,

3.1.4 ASTM specification number and date of issue,

3.1.5 Deoxidation practice (see 4.2.1),

3.1.6 Grade designation or chemical composition limits (see 5.1 and Table 1),

3.1.7 Coarse or fine grain steel (4.2.2),

3.1.8 Test reports, if required (Section 7),

3.1.9 Additions to the specification and Supplementary Requirements, if required, and

3.1.10 End use.

NOTE 1—A typical ordering description is as follows: 10 000 lb, carbon steel bars, hot rolled 1 000 in. diameter by 10 ft, ASTM A 576 dated ___, killed steel, Grade 1018, test reports required, coarse grain Supplementary Requirement S10, welded industrial fan hubs and shafts.

4. Materials and Manufacture

4.1 *Melting Practice*—The steel shall be made by one or more of the following primary processes: open-hearth, basic-oxygen, or electric-furnace. The primary melting may incorporate separate degassing or refining and may be followed by secondary melting using electroslag remelting or vacuum arc remelting. Where secondary melting is employed, the heat shall be defined as all of the ingots remelted from a single primary heat.

4.2 *Deoxidation*:

4.2.1 Unless otherwise specified, the steel shall be rimmed, capped, semi-killed, or killed at the manufacturer's option.

4.2.2 If killed steel is specified, the purchaser may designate that the steel be made to coarse or fine austenitic grain size (see S10 or S11).

NOTE 2—Assured coarse grain size is not always possible since certain

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys, and is the direct responsibility of Subcommittee A01.15 on Bars.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] *Annual Book of ASTM Standards*, Vol 01.01.

[5] Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

elements or combination of elements or certain quantities of elements such as manganese, sulfur, and lead tend to produce grain refinement.

4.3 *Quality*—The bars shall be special quality.

4.4 *Hot Forming*—The bars shall be hot wrought, as wrought.

TABLE 1 Grade Designations and Chemical Requirements of Hot-Wrought Carbon Steel Bars

NOTE—Grade designations and compositions correspond to the respective AISI designations and compositions.

UNS Designation[A]	Grade	Heat Chemical Ranges and Limits, %			
		Carbon	Manganese	Phosphorus, max	Sulfur, max[B]
		Nonresulfurized Carbon Steels[C,D,E,F,G] Low Manganese 1.00 % max or less			
G10080	1008	0.10 max	0.30–0.50	0.040	0.050
G10100	1010	0.08–0.13	0.30–0.60	0.040	0.050
G10120	1012	0.10–0.15	0.30–0.60	0.040	0.050
G10150	1015	0.13–0.18	0.30–0.60	0.040	0.050
G10160	1016	0.13–0.18	0.60–0.90	0.040	0.050
G10170	1017	0.15–0.20	0.30–0.60	0.040	0.050
G10180	1018	0.15–0.20	0.60–0.90	0.040	0.050
G10190	1019	0.15–0.20	0.70–1.00	0.040	0.050
G10200	1020	0.18–0.23	0.30–0.60	0.040	0.050
G10210	1021	0.18–0.23	0.60–0.90	0.040	0.050
G10220	1022	0.18–0.23	0.70–1.00	0.040	0.050
G10230	1023	0.20–0.25	0.30–0.60	0.040	0.050
G10250	1025	0.22–0.28	0.30–0.60	0.040	0.050
G10260	1026	0.22–0.28	0.60–0.90	0.040	0.050
G10290	1029	0.25–0.31	0.60–0.90	0.040	0.050
G10300	1030	0.28–0.34	0.60–0.90	0.040	0.050
G10350	1035	0.32–0.38	0.60–0.90	0.040	0.050
G10370	1037	0.32–0.38	0.70–1.00	0.040	0.050
G10380	1038	0.35–0.42	0.60–0.90	0.040	0.050
G10390	1039	0.37–0.44	0.70–1.00	0.040	0.050
G10400	1040	0.37–0.44	0.60–0.90	0.040	0.050
G10420	1042	0.40–0.47	0.60–0.90	0.040	0.050
G10430	1043	0.40–0.47	0.70–1.00	0.040	0.050
G10440	1044	0.43–0.50	0.30–0.60	0.040	0.050
G10450	1045	0.43–0.50	0.60–0.90	0.040	0.050
G10460	1046	0.43–0.50	0.70–1.00	0.040	0.050
G10490	1049	0.46–0.53	0.60–0.90	0.040	0.050
G10500	1050	0.48–0.55	0.60–0.90	0.040	0.050
G10530	1053	0.48–0.55	0.70–1.00	0.040	0.050
G10550	1055	0.50–0.60	0.60–0.90	0.040	0.050
G10600	1060	0.55–0.65	0.60–0.90	0.040	0.050
G10700	1070	0.65–0.75	0.60–0.90	0.040	0.050
G10780	1078	0.72–0.85	0.30–0.60	0.040	0.050
G10800	1080	0.75–0.88	0.60–0.90	0.040	0.050
G10840	1084	0.80–0.93	0.60–0.90	0.040	0.050
G10900	1090	0.85–0.98	0.60–0.90	0.040	0.050
G10950	1095	0.90–1.03	0.30–0.50	0.040	0.050
G15130	1513	0.10–0.16	1.10–1.40	0.040	0.050
G15180	1518	0.15–0.21	1.10–1.40	0.040	0.050
G15220	1522	0.18–0.24	1.10–1.40	0.040	0.050
G15240	1524	0.19–0.25	1.35–1.65	0.040	0.050
G15250	1525	0.23–0.29	0.80–1.10	0.040	0.050
G15260	1526	0.22–0.29	1.10–1.40	0.040	0.050
G15270	1527	0.22–0.29	1.20–1.50	0.040	0.050
G15360	1536	0.30–0.37	1.20–1.50	0.040	0.050
G15410	1541	0.36–0.44	1.35–1.65	0.040	0.050
G15470	1547	0.43–0.51	1.35–1.65	0.040	0.050
G15480	1548	0.44–0.52	1.10–1.40	0.040	0.050
G15510	1551	0.45–0.56	0.85–1.15	0.040	0.050
G15520	1552	0.47–0.55	1.20–1.50	0.040	0.050
G15610	1561	0.55–0.65	0.75–1.05	0.040	0.050
G15660	1566	0.60–0.71	0.85–1.15	0.040	0.050
G15720	1572	0.65–0.76	1.00–1.30	0.040	0.050
		Resulfurized Carbon Steels[C,E,G]			
G11090	1109	0.08–0.13	0.60–0.90	0.040	0.08–0.13
G11100	1110	0.08–0.13	0.30–0.60	0.040	0.08–0.13
G11160	1116	0.14–0.20	1.10–1.40	0.040	0.16–0.23
G11170	1117	0.14–0.20	1.00–1.30	0.040	0.08–0.13
G11180	1118	0.14–0.20	1.30–1.60	0.040	0.08–0.13
G11190	1119	0.14–0.20	1.00–1.30	0.040	0.24–0.33
G11320	1132	0.27–0.34	1.35–1.65	0.040	0.08–0.13

TABLE 1 *Continued*

UNS Designation[A]	Grade	Heat Chemical Ranges and Limits, %			
		Carbon	Manganese	Phosphorus, max	Sulfur, max[B]
G11370	1137	0.32–0.39	1.35–1.65	0.040	0.08–0.13
G11390	1139	0.35–0.43	1.35–1.65	0.040	0.13–0.20
G11400	1140	0.37–0.44	0.70–1.00	0.040	0.08–0.13
G11410	1141	0.37–0.45	1.35–1.65	0.040	0.08–0.13
G11440	1144	0.40–0.48	1.35–1.65	0.040	0.24–0.33
G11450	1145	0.42–0.49	0.70–1.00	0.040	0.04–0.07
G11460	1146	0.42–0.49	0.70–1.00	0.040	0.08–0.13
G11510	1151	0.48–0.55	0.70–1.00	0.040	0.08–0.13

Rephosphorized and Resulfurized Carbon Steel[E,G,H]

Designation	Grade	Carbon	Manganese	Phosphorus	Sulfur	Lead
G12110	1211	0.13 max	0.60–0.90	0.07–0.12	0.10–0.15	...
G12120	1212	0.13 max	0.70–1.00	0.07–0.12	0.16–0.23	...
G12130	1213	0.13 max	0.70–1.00	0.07–0.12	0.24–0.33	...
G12150	1215	0.09 max	0.75–1.05	0.04–0.09	0.26–0.35	...
...	12L14	0.15 max	0.85–1.15	0.04–0.09	0.26–0.35	0.15–0.35

[A] New designations established in accordance with Practice E 527 and SAE J 1086.

[B] Maximum unless otherwise indicated.

[C] When silicon is required, the following ranges and limits are commonly specified: 0.10 %, max, 0.10 to 0.20 %, 0.15 to 0.35 %, or 0.20 to 0.40 %.

[D] Copper can be specified when required as 0.20 % minimum.

[E] When lead is required as an added element to a standard steel, a range of 0.15 to 0.35 % incl, is specified. Such a steel is identified by inserting the letter "L" between the second and third numerals of the grade designation, for example, 10 L 45. A cast or heat analysis is not determinable when lead is added to the ladle stream.

[F] When boron treatment is specified for killed steels, the steels can be expected to contain 0.0005 to 0.003% boron.

[G] The elements bismuth, calcium, selenium or tellurium may be added as agreed between purchaser and supplier.

[H] It is not common practice to produce these steels to specified limits for silicon because of its adverse effect on machinability.

5. Chemical Composition

5.1 The heat analysis shall conform to the requirements for chemical composition specified in Table 1 for the grade specified, or to such other limits as may be specified using the ranges and limits in Table 2.

6. Workmanship, Finish, and Appearance

6.1 *Descaling*—When descaled bars are required, S15 on Pickling or S16 on Blast Cleaning must be specified.

6.2 The bars shall be free of visible pipe and conditioned as necessary to remove injurious surface imperfections.

7. Certification and Test Reports

7.1 When specified by the purchaser, a manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the heat analysis test results for the specified elements and for copper, chromium, nickel, molybdenum, vanadium and columbium shall be furnished. When the amount of an element present is less than 0.02 %, the analysis may be reported as <0.02 %. The report shall include the name of the manufacturer, ASTM designation number and year date and revision letter, if any, type and grade, heat number, and size.

7.2 When supplementary requirements are specified, the report shall include a statement of compliance with the requirement or the results of tests when the requirement involves measured test values such as S12 on Restricted Incidental Elements.

8. General Requirements

8.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 29/A 29M, unless otherwise provided herein.

9. Keywords

9.1 carbon steel bars; hot-wrought steel bars; steel bars

TABLE 2 Heat Chemical Ranges and Limits of Hot-Wrought Carbon Steel Bars

Element	Chemical Ranges and Limits, %		
	When Maximum of Specified Element is:	Range	Lowest Maximum
Carbon[A]	...	...	0.06
	to 0.12 incl	...	...
	over 0.12–0.25 incl	0.05	...
	over 0.25–0.40 incl	0.06	...
	over 0.40–0.55 incl	0.07	...
	over 0.55–0.80 incl	0.10	...
	over 0.80	0.13	...
Manganese	...	...	0.35
	to 0.40 incl	0.15	...
	over 0.40–0.50 incl	0.20	...
	over 0.50–1.65 incl	0.30	...
Phosphorus	to 0.040 incl	...	0.040
	over 0.040–0.08 incl	0.03	...
	over 0.08–0.13 incl	0.05	...
Sulfur	to 0.050 incl	. . .	0.050
	over 0.050–0.09 incl	0.03	...
	over 0.09–0.15 incl	0.05	...
	over 0.15–0.23 incl	0.07	...
	over 0.23–0.50 incl	0.09	...
Silicon[B]	...	...	0.10
	to 0.10 incl	...	...
	over 0.10–0.15 incl	0.08	...
	over 0.15–0.20 incl	0.10	...
	over 0.20–0.30 incl	0.15	...
	over 0.30–0.60 incl	0.20	...
Copper	When copper is required 0.20 min is generally specified		
Lead[C,D]	When lead is required, a range of 0.15–0.35 is specified		
Boron		0.0005 min	
Bismuth[E]			
Calcium[E]			
Selenium[E]			
Tellurium[E]			

[A] The carbon ranges shown in the column headed "Range" apply when the specified maximum limit for manganese does not exceed 1.10 %. When the maximum manganese limit exceeds 1.10 %, add 0.01 to the carbon ranges shown above.
[B] It is not common practice to produce a rephosphorized and resulfurized carbon steel to specified limits for silicon because of its adverse effect on machinability.
[C] A heat analysis for lead is not determinable, since lead is added to the ladle stream while each ingot is poured.
[D] It is not common practice to produce these steels to specified limits for silicon because of its adverse effect on machinability.
[E] Element specification range as agreed to between purchaser and supplier.

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply when specified by the purchaser.

S1. Cold-Working Quality

S1.1 This classification encompasses bars subject to severe cold plastic deformation such as, but not limited to, upsetting, heading, forging, forward or backward extrusion.

S1.2 If the type of steel or chemical composition does not have adequate cold working characteristics, appropriate thermal treatments should be specified.

S1.3 When S1 is specified, the bars shall be produced by manufacturing practices and subjected to mill tests and inspection and freedom from injurious surface imperfections to the extent that the bars shall be suitable for the manufacture of identified parts. The quality requirements of individual application vary.

S2. Axle-Shaft Quality

S2.1 Bars shall be suitable for use in the manufacture of power-driven axle shafts of the automotive or truck type.

S3. Scrapless Nut Quality

S3.1 Bars shall be suitable for the production of scrapless nuts from round bars involving cold plastic deformation, namely piercing, upsetting, and forming, with consequent expansion in diameter.

S4. Special Surface Quality

S4.1 Special surface steels are produced with exacting control and appropriate inspection and surface preparation to minimize the frequency and degree of seams and other surface imperfections.

S5. Annealing

S5.1 The steel shall be furnished annealed.

S6. Spheroidize Annealing

S6.1 The steel shall be spheroidize annealed.

S7. Special Internal Soundness Requirement

S7.1 The steel shall be produced with special internal soundness, that is, relative freedom from segregation and porosity, as evaluated by means of a macroetch test performed on representative billet samples. The test shall consist of deep etching a cross section in a hot-acid solution and with a visual examination to evaluate soundness. An alternative method consisting of fracturing a billet section and examining the fracture surface to evaluate soundness may be used with purchaser approval.

S8. Nonmetallic Inclusion Requirement (Note S1)

S8.1 A microscopical examination of longitudinal sections to determine the nature and frequency of nonmetallic inclusions shall be made as prescribed in Practice E 45. The acceptance limits shall be specified by the purchaser.

NOTE S1—Much of the sulfur in resulfurized steels is present as sulfide inclusions. For this reason, those steels are not generally produced to inclusion rating and S9 may not be specified.

S9. Special Hardenability Requirement

S9.1 Special heat treating (hardenability) is a term used when the purchaser specifies as a requirement, the ability of a steel to heat treat to specified mechanical property values which the purchaser must meet after his heat treatment. Care should be taken so that the desired mechanical property values are compatible with the chemical composition, size, and cross section of the steel.

S10. Grain Size (Coarse)

S10.1 The steel shall conform to the coarse austenitic grain size requirement of Specification A 29/A 29M.

S11. Grain Size (Fine)

S11.1 The steel shall conform to the fine austenitic grain size requirement of Specification A 29/A 29M.

S11.1.1 When aluminum is used as a grain refining element, the fine grain size requirement shall be deemed to be fulfilled if, on heat analysis, the aluminum content is not less than 0.015 % acid soluble aluminum, or alternately, 0.020 % total aluminum. The aluminum content shall be reported. The grain size test specified in S11.1 shall be the referee test.

S11.1.2 When specified on the order, one grain size test per heat shall be made. The test result shall be reported.

S12. Restricted Incidental Elements

S12.1 The steel shall not exceed the limits for copper, nickel, chromium, molybdenum, or other elements as shown on the purchase order.

S13. Stress Relieving

S13.1 The steel shall be stress relieved by heating to a temperature specified by the purchaser or to a temperature selected by the manufacturer.

S14. Special Straightness

S14.1 The bars shall be produced with special straightness (refer to Specification A 29/A 29M for tolerances).

S15. Pickling

S15.1 The surface of the bars shall be descaled by pickling.

S16. Blast Cleaning

S16.1 The surface of the bars shall be descaled by blast cleaning.

S17. Coating

S17.1 The bars shall be oiled, limed, or phosphate-coated as specified by the purchaser. The purchaser shall also specify the method of cleaning (S15 or S16); otherwise the bars shall be descaled by pickling or blasting at the manufacturer's option.

S18. Restricted Heat Chemical Ranges

S18.1 Restricted heat chemical ranges on one or more elements may be specified by the purchaser if the manufacturer agrees to melt to the requested restriction.

Designation: A 579 – 04

Standard Specification for Superstrength Alloy Steel Forgings[1]

This standard is issued under the fixed designation A 579; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers requirements for forged steel shapes for highly stressed structural members requiring yield strengths in excess of 140 ksi [965 MPa].

1.2 This specification is not intended for applications limited by creep deformation.

1.3 Twenty-seven grades are covered by this specification. Selection will depend upon design, service conditions, and mechanical properties required.

1.4 Supplementary requirements are provided for use when additional testing or inspection is desired. These shall apply only when specified individually by the purchaser in the order.

1.5 The values stated in either inch-pound or SI (metric) units are to be regarded separately as standards. Within the text and tables, the SI units are shown in brackets. The values in each system are not exact equivalents; therefore, each system must be used independently of each other. Combining values from the two systems may result in non-conformance with the specification.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 255 Test Methods for Determining Hardenability of Steel
A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings
A 370 Test Methods and Definitions for Mechanical Testing of Steel Products
A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings
A 788 Specification for Steel Forgings, General Requirements
E 3 Methods of Preparation of Metallographic Specimens
E 21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials
E 45 Test Methods for Determining the Inclusion Content of Steel
E 112 Test Methods for Determining Average Grain Size
E 165 Test Method for Liquid Penetrant Examination

3. Ordering Information and General Requirements

3.1 In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order a detailed drawing, sketch, or written description of the forging.

3.2 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

3.3 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

4. Materials and Manufacture

4.1 The steel shall be made in accordance with the Melting Process Section of Specification A 788. A sufficient discard shall be made to secure freedom from injurious pipe and undue segregation.

4.2 The material shall be forged as close as practical to the specified shape and size.

4.3 The finished product shall be a hot-worked forging as defined by Specification A 788.

4.4 *Heat Treatment Performed by Forging Supplier*—Forgings may be furnished in one of the following conditions as specified in the inquiry and purchase order (some conditions are not applicable to all grades):

4.4.1 Stress relieved,
4.4.2 Annealed,
4.4.3 Solution treated,
4.4.4 Solution treated and aged,
4.4.5 Normalized,
4.4.6 Normalized and tempered, or
4.4.7 Quenched and tempered.

4.5 *Heat Treatment Performed by Purchaser*—When final heat treatment is to be performed by the purchaser after machining or fabrication, or both, a capability heat treatment

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

duplicating the purchaser's final heat treatment must be performed by the supplier on representative samples (see 6.3) to qualify the forgings. The results of these capability tests shall conform to the requirements of Table 1 and Table 2. See also Table 3.

5. Chemical Requirements

5.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 shall comply with Table 4.

6. Mechanical Properties

6.1 The material shall conform to the mechanical properties specified in Table 1, when ordered to 4.4.4 or 4.4.7. For the other heat treatments specified in 4.4, the provisions of 4.5 apply.

6.2 Tension tests are required for all material ordered to this specification. However, room-temperature Charpy V-notch impact tests are required only for those grades which have minimum impact strength requirements listed in Table 2.

TABLE 1 Minimum Tension Test Requirements

Grade	Yield Strength (0.2 % offset), ksi [MPa]	Tensile Strength, ksi [MPa]	Elongation[A], %	Reduction of Area[A], %
		Quench and Tempered		
13, 21, 22, 23, 12, 12a	140 [965]	150 [1035]	13	40
13, 21, 22, 23, 11	160 [1100]	175 [1210]	12	36
13, 21, 22, 23, 31	180 [1240][B]	190 [1310]	10	32
13, 21, 22, 23	200 [1380][B]	210 [1450]	9	28
22[C], 23, 32, 33	225 [1550][B]	250 [1720]	6	25
		Air Hardening		
41	200 [1380][B]	260 [1790]	9	30
41	225 [1550][B]	280 [1930]	8	25
		Martensitic Stainless		
51, 52, 53	140 [965]	175 [1210]	12	45
52	160 [1100]	220 [1520]	10	40
		No. 1 Precipitation Hardening Stainless		
61	140 [965]	165 [1140]	12	50
61	160 [1100]	180 [1240]	10	45
61	180 [1240][B]	200 [1380]	8	40
		No. 2 Precipitation Hardening Stainless		
64	140 [965]	165[(1140]	12	25
64	160 [1100]	185 [1280]	10	25
64	180 [1240][B]	210 [1450]	10	25
		No. 3 Precipitation Hardening Stainless		
62	140 [965]	165 [1140]	6	25
62, 63	160 [1100]	180 [1240]	6	25
63	180 [1240][B]	200 [1380]	6	25
63	200 [1380][B]	225 [1550]	5	25
		Maraging Steels		
74	160 [1100]	170 [1170]	15	65
75	180 [1240][B]	190 [1310]	14	60
71	200 [1380][B]	210 [1450]	12	55
72	250 [1720][B]	255 [1760]	10	45
73	275 [1890][B]	280 [1930]	9	40
		Miscellaneous		
81	180 [1240][D]	190 [1310]	13	45
82	200 [1380][D]	210 [1450]	10	30
83[D]	225 [1550][D]	260 [1790]	7	20
83[E]	250 [1720][D]	280 [1930]	4	15
84	180 [1240][D]	185 [1270]	14	45

[A] See Note in Table 3.
[B] Vacuum melting normally required to achieve list properties.
[C] By agreement.
[D] Bainitic.
[E] Martensitic.

TABLE 2 Minimum Room-Temperature Charpy V-Notch Energy Absorption[A] for Respective Yield Strength Classes, ft·lbf [J]

Grade	Yield Strength Class, ksi [MPa]						
	140 [965]	160 [1100]	180[B] [1240]	200[B] [1380]	225[B] [1550]	250[B] [1720]	275[B] [1900]
11	. . .	45 [60]	. . .	. . .	. . .	. . .	. . .
12, 12a	50 [70]	. . .	. . .	. . .	. . .	. . .	. . .
13	20 [25]	10 [15]	[C]	. . .	. . .	. . .	. . .
21	35 [45]	30 [40]	20 [25]	15 [20]	. . .	. . .	. . .
22	30 [40]	25 [35]	20 [25]	15 [20]	. . .	. . .	. . .
23	35 [45]	25 [35]	20 [25]	15 [20]	10 [15]	. . .	. . .
31	. . .	. . .	25 [35]	. . .	. . .	. . .	. . .
32	. . .	. . .	. . .	. . .	12 [17]	. . .	. . .
33	. . .	. . .	. . .	. . .	15 [20]	. . .	. . .
41	. . .	. . .	. . .	15 [20]	[C]	. . .	. . .
51	15 [20]	. . .	. . .	. . .	. . .	. . .	. . .
52	[C]	[C]	. . .	. . .	. . .	. . .	. . .
53	[C]	. . .	. . .	. . .	. . .	. . .	. . .
61	25 [35]	. . .	[C]	. . .	. . .	. . .	. . .
62	[C]	[C]	. . .	. . .	. . .	. . .	. . .
63	[C]	[C]	[C]	. . .	. . .	. . .	. . .
64	25 [35]	15 [20]	15 [20]	. . .	. . .	. . .	. . .
71	. . .	. . .	. . .	35 [45]	. . .	. . .	. . .
72	. . .	. . .	. . .	. . .	. . .	20 [25]	. . .
73	. . .	. . .	. . .	. . .	. . .	. . .	15 [20]
74	. . .	60 [80]	50 [70]	. . .	. . .	. . .	. . .
81	. . .	. . .	25 [35]	. . .	. . .	. . .	. . .
82	. . .	. . .	. . .	20 [25]	. . .	. . .	. . .
83	. . .	. . .	. . .	. . .	15 [20]	10 [15]	. . .
84	. . .	. . .	25 [35]	. . .	. . .	. . .	. . .

[A] See Note in Table 3.
[B] Vacuum melting may be required to achieve listed properties.
[C] By agreement.

TABLE 3 Material, Maximum Annealed Hardness (HB), and Section Size Capability in Inches [mm] for Respective Yield Strength Classes

NOTE—Tables 1-3 show grades and maximum section sizes in which the indicated yield strength levels can usually be achieved at a 1/4 thickness depth in the direction of maximum working. Because of variations in forging configuration and processing it does not follow that the ductility and impact strengths listed in Table 1 and Table 2 can always be obtained at these depths. The properties listed are minimums, unless otherwise agreed by purchaser and manufacturer.

Grade	Maximum Annealed Hardness (HB)	Yield Strength Class, ksi [MPa]						
		140 [965]	160 [1100]	180 [1240]	200 [1380]	225 [1550]	250 [1720]	275 [1900]
11	321	. . .	6.5 [165]	. . .	. . .	. . .	. . .	. . .
12, 12a	. . .	4.0 [100]	. . .	. . .	. . .	. . .	. . .	. . .
13	229	1.0 [25]	1.0 [25]	1.0 [25]	. . .	. . .	. . .	. . .
21	285	4.5 [115]	4.5 [115]	4.0 [100]	4.0 [100]	. . .	. . .	. . .
22	302	4.5 [115]	4.5 [115]	4.0 [100]	4.0 [100]	3.5 [90]	. . .	. . .
23	302	8.0 [200]	8.0 [200]	8.0 [200]	8.0 [200]	8.0 [200]	. . .	. . .
31	262	. . .	. . .	3.0 [75]	. . .	. . .	. . .	. . .
32	302	. . .	. . .	. . .	. . .	5.5 [140]	. . .	. . .
33	302	. . .	. . .	. . .	. . .	2.0 [50]	. . .	. . .
41	235	. . .	. . .	. . .	6.0 [150]	6.0 [150]	. . .	. . .
51	197	2.0 [50]	. . .	. . .	. . .	. . .	. . .	. . .
52	255	2.0 [50]	2.0 [50]	. . .	. . .	. . .	. . .	. . .
53	285	4.0 [100]	. . .	. . .	. . .	. . .	. . .	. . .
61	375	8.0 [200]	8.0 [200]	1.0 [25]	. . .	. . .	. . .	. . .
62	207	6.0 [150]	6.0 [150]	. . .	. . .	. . .	. . .	. . .
63	241	. . .	6.0 [150]	6.0 [150]	6.0 [150]	. . .	. . .	. . .
64	321	6.0 [150]	6.0 [150]	6.0 [150]	. . .	. . .	. . .	. . .
71	321	. . .	. . .	. . .	12.0 [300]	. . .	. . .	. . .
72	321	. . .	. . .	. . .	. . .	. . .	12.0 [300]	. . .
73	321	. . .	. . .	. . .	. . .	. . .	. . .	12.0 [300]
74	321	. . .	12.0 [300]	. . .	. . .	. . .	. . .	. . .
75	321	. . .	. . .	12.0 [300]	. . .	. . .	. . .	. . .
81	341	. . .	. . .	6.0 [150]	. . .	. . .	. . .	. . .
82	341	. . .	. . .	. . .	5.0 [125]	. . .	. . .	. . .
83	341	. . .	. . .	. . .	. . .	3.0 [75]	3.0 [75]	. . .
84	341	. . .	. . .	6.0 [150]	. . .	. . .	. . .	. . .

TABLE 4 Chemical Requirements

Elements	Composition, %													
	min	max	min	max	min	max	min	max	min	max	min	max	min	max
Grade	11		12		12a		13		21		22		23	
Carbon	0.23	0.28	. . .	0.12	. . .	0.20	0.27	0.33	0.31	0.38	0.38	0.43	0.45	0.50
Manganese	. . .	0.20	0.60	0.90	0.60	0.90	0.40	0.60	0.60	0.90	0.60	0.90	0.60	0.90
Phosphorus	. . .	0.01	. . .	0.010	. . .	0.015	. . .	0.025	. . .	0.025	. . .	0.025	. . .	0.015
Sulfur	. . .	0.01	. . .	0.010	. . .	0.015	. . .	0.025	. . .	0.025	. . .	0.025	. . .	0.015
Silicon	. . .	0.10	0.20	0.35	0.20	0.35	0.20	0.35	0.20	0.35	0.20	0.35	0.15	0.30
Nickel	2.75	3.25	4.75	5.25	4.75	5.25	. . .	. . .	1.65	2.00	1.65	2.00	0.40	0.70
Chromium	1.40	1.65	0.40	0.70	0.40	0.70	0.80	1.10	0.65	0.90	0.70	0.90	0.90	1.20
Molybdenum	0.8	1.0	0.30	0.65	0.30	0.65	0.15	0.25	0.30	0.60	0.30	0.60	0.90	1.10
Vanadium	. . .	. . .	0.05	0.10	0.05	0.10	0.05	0.10	0.17	0.23	0.05	0.10	0.08	0.15
Columbium	0.03	0.07	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Grade	31		32		33		41		51		52		53[A]	
Carbon	0.23	0.28	0.40	0.45	0.41	0.46	0.38	0.43	. . .	0.15	0.20	0.25	. . .	0.20
Manganese	1.20	1.50	0.65	0.90	0.75	1.00	0.20	0.40	. . .	1.00	0.50	1.00	. . .	1.00
Phosphorus	. . .	0.025	. . .	0.025	. . .	0.025	. . .	0.015	. . .	0.025	. . .	0.025	. . .	0.025
Sulfur	. . .	0.025	. . .	0.025	. . .	0.025	. . .	0.015	. . .	0.025	. . .	0.025	. . .	0.025
Silicon	1.30	1.70	1.45	1.80	1.40	1.75	0.80	1.00	. . .	1.00	. . .	0.50	. . .	1.00
Nickel	1.65	2.00	1.65	2.00	. . .	. . .	. . .	. . .	. . .	0.75	0.50	1.00	1.25	2.50
Chromium	0.20	0.40	0.65	0.90	1.90	2.25	4.75	5.25	11.5	13.5	11.0	12.5	15.0	17.0
Molybdenum	0.35	0.45	0.30	0.45	0.45	0.60	1.20	1.40	. . .	0.50	0.90	1.25	. . .	. . .
Copper	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.50	. . .	. . .	. . .	. . .
Titanium	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.05	. . .	. . .
Vanadium	. . .	. . .	. . .	. . .	0.03	0.08	0.40	0.60	. . .	. . .	0.20	0.30	. . .	. . .
Cobalt	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.25	. . .	. . .
Aluminum	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.05	. . .	0.05	. . .	. . .
Tungsten	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.90	1.25	. . .	. . .
Tin	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.05	. . .	0.04	. . .	. . .
Grade	61[A,B]		62[A,B]		63[A,B]		64[A,B]		71[A,B]		72[A,B]		73[A,B]	
Carbon	. . .	0.07	. . .	0.09	. . .	0.09	0.10	0.15	. . .	0.03	. . .	0.03	. . .	0.03
Manganese	. . .	1.00	. . .	1.00	. . .	1.00	0.50	1.25	. . .	0.10	. . .	0.10	. . .	0.10
Phosphorus	. . .	0.025	. . .	0.025	. . .	0.025	. . .	0.025	. . .	0.01	. . .	0.01	. . .	0.01
Sulfur	. . .	0.025	. . .	0.025	. . .	0.025	. . .	0.025	. . .	0.01	. . .	0.01	. . .	0.01
Silicon	. . .	1.00	. . .	1.00	. . .	0.50	. . .	0.50	. . .	0.10	. . .	0.10	. . .	0.10
Nickel	3.0	5.0	6.5	7.75	6.5	7.75	4.0	5.0	17.0	19.0	17.0	19.0	18.0	19.0
Chromium	15.5	17.5	16.0	18.0	14.0	15.25	15.0	16.0	. . .	. . .	. . .	. . .	. . .	. . .
Molybdenum	. . .	. . .	. . .	. . .	2.0	2.75	2.50	3.25	3.0	3.5	4.6	5.2	4.6	5.2
Copper	3.0	5.0	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Titanium	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.15	0.25	0.30	0.50	0.50	0.80
Columbium	0.15	0.45	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Cobalt	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	8.0	9.0	7.0	8.5	8.5	9.5
Aluminum	. . .	. . .	0.75	1.50	0.75	1.25	. . .	. . .	0.05	0.15	0.05	0.15	0.05	0.15
Nitrogen	. . .	. . .	. . .	. . .	. . .	. . .	0.07	0.13	. . .	. . .	. . .	. . .	. . .	. . .
Grade	74[A,B]		75[A,B]		81[A,B]		82[A,B]		83[A,B]		84[A,B]			
Carbon	. . .	0.03	. . .	0.03	0.24	0.30	0.28	0.34	0.42	0.47	0.16	0.23		
Manganese	. . .	0.10	. . .	0.10	0.10	0.35	0.10	0.35	0.10	0.35	0.20	0.40		
Phosphorus	. . .	0.01	. . .	0.01	. . .	0.01	. . .	0.01	. . .	0.01	. . .	0.010		
Sulfur	. . .	0.01	. . .	0.01	. . .	0.01	. . .	0.01	. . .	0.01	. . .	0.005		
Silicon	. . .	0.12	. . .	0.12	. . .	0.10	. . .	0.10	. . .	0.10	. . .	0.20		
Nickel	11.5	12.5	11.5	12.5	7.0	9.0	7.0	8.5	7.0	8.5	8.5	9.5		
Chromium	4.75	5.25	4.75	5.25	0.35	0.60	0.90	1.10	0.20	0.35	0.65	0.85		
Molybdenum	2.75	3.25	2.75	3.25	0.35	0.60	0.90	1.10	0.20	0.35	0.95	1.10		
Titanium	0.05	0.15	0.10	0.25	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .		
Vanadium	. . .	. . .	. . .	. . .	0.06	0.12	0.06	0.12	0.06	0.12	0.06	0.15		
Cobalt	. . .	. . .	. . .	. . .	3.5	4.5	4.0	5.0	3.5	4.5	4.25	4.75		
Aluminum	0.25	0.40	0.35	0.50	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.020		

[A] Product analysis of sulfur and phosphorus shall conform to the requirements of Table 4.
[B] 0.06 calcium, 0.003 boron, and 0.02 zirconium may be added.

6.3 Tests shall be conducted in accordance with the latest issue of Test Methods and Definitions A 370. The largest obtainable tension test specimen as specified in Test Methods and Definitions A 370 shall be used. Impact specimens shall be the standard size, Charpy V-notch, as shown in the figure for the Charpy (Simple-Beam) Impact Test of Test Methods and Definitions A 370. The use of subsize impact specimens requires prior purchaser approval.

6.4 The longitudinal axis of the specimens shall be parallel to the direction of major working of the forging. For upset-disc forgings, the longitudinal axis of the test specimen shall be in the tangential direction.

6.4.1 The longitudinal axis of the specimen shall be located midway between the parallel surfaces of the test extension if added to the periphery of disks or midway between the center and surface of solid forgings. For hollow forgings, the longitudinal axis of the specimens shall be located midway between the center and outer surfaces of the wall. When separately forged test blocks are employed as defined in 6.4.3, the tension test specimens shall be taken from a location which represents the midwall of the heaviest section of the production forgings. When specimens are required from opposite ends, they shall be taken from the diagonal corners of an axial plane.

6.4.2 Except as specified herein, tests for acceptance shall be made after heat treatment has been completed.

6.4.3 When mutually agreed upon between manufacturer and purchaser, test specimens may be machined from a specially forged block suitably worked and heat treated with the production forgings. Such a special block shall be obtained from an ingot, slab, or billet from the same heat used to make the forgings it represents. This block shall receive essentially the same type of hot working and forging reduction as the production forgings; however, a longitudinally forged bar with dimensions not less than *T* by *T* by 3*T* may be used to represent a ring forging. The dimension *T* shall be representative of the heaviest effective cross section of the forging. For quenched and tempered forgings for which tests are required at both ends by 6.5.2.3 and 6.5.2.4, separately forged test blocks are not allowed.

NOTE 1—In using separately forged test blocks, attention is drawn to the effect of mass differences between the production forgings and the test blocks.

6.5 *Specific Requirements*—The number and location of tests are based on forging length, weight, and heat treatment, and shall be as prescribed below. The length and weight to be used for this purpose shall be the shipped length and weight of forgings produced individually or the aggregate shipped length and weight of all pieces cut from a multiple forging.

6.5.1 *Stress Relieved, Annealed Solution, Treated, Solution Treated and Aged, Normal or Normalized, and Tempered Forgings*:

6.5.1.1 For forgings weighing 5000 lb [2250 kg] or less at the time of heat treatment, one tension test shall be taken from one forging per heat in each heat-treatment charge. When heat treatment is performed in continuous-type furnaces with suitable temperature controls and equipped with recording pyrometers so that complete heat-treatment records are available, a tempering charge may be considered as any continuous run not exceeding an 8-h period.

6.5.1.2 For forgings and forged bars weighing over 5000 lb [2250 kg] at the time of heat treatment, one tension test shall be taken from each forging.

6.5.2 *Quenched and Tempered Forgings*:

6.5.2.1 For quenched and tempered forgings weighing 5000 lb [2250 kg] or less at the time of heat treatment, but not exceeding 12 ft [3.7 m] in length, one tension test shall be taken from one forging per heat in each heat-treatment charge. When heat treatment is performed in continuous-type furnaces with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a tempering charge may be considered as any continuous run not exceeding an 8-h period.

6.5.2.2 For quenched and tempered forgings and forged bars weighing over 5000 lb [2250 kg] to 10 000 lb [4500 kg] at the time of heat treatment, but not exceeding 12 ft [3.7 m] in length, one tension test shall be taken from each forging.

6.5.2.3 For quenched and tempered forgings and forged bars that exceed 12 ft [3.7 m] in length, one tension test shall be taken from each end of each forging.

6.5.2.4 For quenched and tempered forgings and forged bars weighing more than 10 000 lb [4500 kg] at the time of heat treatment, two tension tests shall be taken from each forging. These shall be offset 180° from each other except that when the length, excluding test prolongations, exceeds three times the diameter or equivalent thickness, one test shall be taken from each end of the forging and shall be oriented 180° apart. In the case of circular forgings, the diameter is the largest diameter of the forging, excluding flanges. For other configurations, the term equivalent thickness is the maximum diagonal or major axis of the cross-section.

7. Nondestructive Test Requirements

7.1 *General*—The forgings shall be free from cracks, seams, laps, shrinkage, and other injurious discontinuities.

7.2 *Magnetic Particle Inspection*—All ferromagnetic forgings produced to this specification shall be subject to magnetic particle inspection in accordance with Test Method A 275/A 275M by the supplier, unless otherwise specified.

7.3 *Liquid Penetrant Inspection*—All nonmagnetic forgings produced to this specification shall be subject to liquid penetrant inspection in accordance with Test Method E 165, unless otherwise specified.

7.4 *Ultrasonic Inspection*—All forgings produced to this specification shall be subject to ultrasonic inspection in accordance with Practice A 388/A 388M, unless otherwise specified.

8. Repair Welding

8.1 Repair welding of forgings is permissible only at option of the purchaser.

9. Product Marking

9.1 Unless otherwise specified, each forging shall be legibly stamped by the manufacturer with the manufacturer's name or trademark, the manufacturer's heat and serial numbers, and this specification number (A 579) followed by the appropriate grade number. The purchaser may specify additional identification marking and the location of the stamping.

9.2 When die stamping is not permitted by the purchaser, electric pencil marking or electroetching may be used.

10. Keywords

10.1 alloy steel forgings; superstrength

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, and order. Details of these supplementary requirements shall be agreed upon by the manufacturer and the purchaser.

S1. Charpy V-Notch Impact Transition Curve

S1.1 Sufficient impact tests shall be made from the forging test material to establish a transition temperature curve based upon one or several of the following criteria:

S1.1.1 Absorbed energy (ft·lbf [J]),

S1.1.2 Fracture appearance (see Supplement 5 of Test Methods A 370), or

S1.1.3 Lateral expansion.

S1.2 The purchaser shall furnish the manufacturer with details of sample location, number of specimens, heat treatments, and information to be derived from the test.

S2. Alternative Sampling, Specimen Orientation, and Mechanical Property Requirements or Section Sizes, or Both

S2.1 Alternative methods of sampling or specimen orientation and location, and alternative mechanical properties or section sizes, or both, not covered by this specification may be established by agreement between manufacturer and purchaser.

S3. Macroetch Tests

S3.1 Macroetchings shall be made from the ends of each billet representing the top and bottom of each ingot unless otherwise specified. If forgings are produced directly from ingot form, or if billet macroetchings are impractical, etchings from the top and bottom of each ingot or full section slices from those forgings representing the top and bottom of each ingot are acceptable by agreement between manufacturer and purchaser.

S3.2 The purchaser shall specify whether photomacrographs are required.

S4. Microcleanliness

S4.1 Microcleanliness testing shall be performed in accordance with Test Methods E 45. The purchaser shall furnish all necessary information relating to method of sampling and rating, along with acceptance criteria.

S5. Grain Size

S5.1 Grain size shall be determined in accordance with Test Methods E 112. The purchaser shall include all necessary information relating to procedure and required grain size limits.

S5.2 Specimen preparation shall be in accordance with Methods E 3.

S6. Decarburization

S6.1 When decarburization testing is specified, the purchaser shall include the following information:

S6.1.1 Number of samples,

S6.1.2 Sample location,

S6.1.3 Decarburization depth limits, if any, and

S6.1.4 Any special metallographic preparation, etching, or rating procedures.

S6.2. Specimens for decarburization ratings shall be prepared in accordance with Methods E 3.

S6.3 This test is usually only applicable to grades which are prone to decarburization by surface oxidation occurring either in forging to close tolerances over finish sizes or in heat treating the finish machined parts.

S7. Fracture Toughness

S7.1 The procedure for establishing fracture toughness including type and size of specimens, testing procedure, and limiting values shall be established by agreement between manufacturer and purchaser.

S8. Cryogenic and Elevated Temperature Properties

S8.1 When mechanical property testing at other than ambient temperature is specified, the details of the testing procedure, including type and size of specimens, testing temperatures, and limiting values, shall be established by agreement between manufacturer and purchaser.

S8.2 Short Time Elevated Temperature Tension Tests shall be in accordance with Test Methods E 21.

S9. Hardenability

S9.1 Hardenability testing shall be in accordance with Test Methods A 255, unless otherwise specified.

Designation: A 592/A 592M – 89 (Reapproved 1999)

Standard Specification for High-Strength Quenched and Tempered Low-Alloy Steel Forged Fittings and Parts for Pressure Vessels[1]

This standard is issued under the fixed designation A 592/A 592M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification[2] covers high-strength quenched and tempered low-alloy steel forged fittings and parts for pressure vessels. The maximum thickness of forgings under this specification shall be 1½ in. [38 mm] for Grade A, and 3 ¾ in. [95 mm] for Grades E and F (4 in. [102 mm] maximum as heat treated).

NOTE 1—These grades are similar to corresponding grades in Specification A 517/A 517M.

1.2 Welding technique is of fundamental importance and it is presupposed that welding procedures will be in accordance with approved methods for the class of material used.

1.3 The values stated in either inch-pound units or SI (metric) units are to be regarded separately as the standard; within the text and tables, the SI units are shown in [brackets]. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.4 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:*

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

A 517/A 517M Specification for Pressure Vessel Plates, Alloy Steel, High-Strength, Quenched and Tempered[4]

A 788 Specification for Steel Forgings, General Requirements[5]

E 112 Test Methods for Determining the Average Grain Size[6]

3. Ordering Information and General Requirements

3.1 In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order a detailed drawing, a sketch, or written description of the forging.

3.2 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

3.3 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

4. Materials and Manufacture

4.1 *Melting Process*—The steel shall be made in accordance with the Melting Process Section of Specification A 788.

4.2 *Grain Size*—The steel shall be fully killed, fine grained (ASTM No. 5 or finer), as determined in accordance with Test Methods E 112, Plate IV.

4.3 *Discard*—Sufficient discard shall be made from each ingot to ensure freedom from piping and excessive segregation.

4.4 The finished product shall be a hot-worked forging as defined by Specification A 788, and shall be forged as close as practicable to the finished shape and size.

5. Heat Treatment

5.1 After forging and before reheating, the forgings shall be cooled to provide substantially complete transformation of austenite. Heat treatment for properties shall consist of heating the forgings to not less than 1650°F [900°C], quenching in a liquid medium, and tempering at 1150°F [620°C] minimum, with a holding time of 1 h/in. [1 h/25 mm] minimum, but in no case less than ½ h. Forgings with sections over 2½ to 4 in. [65 to 100 mm] inclusive, shall be liquid quenched from a

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-592/SA-592M in Section II of that Code.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards*, Vol 01.04.

[5] *Annual Book of ASTM Standards*, Vol 01.05.

[6] *Annual Book of ASTM Standards*, Vol 03.01.

temperature not less than 1750°F [955°C] prior to the above treatment for properties.

6. Chemical Requirements

6.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 shall comply with Table 1.

6.2 *Product Analysis*—The purchaser may use the product analysis provision of Specification A 788 to obtain a product analysis from a forging representing each heat or multiple heat.

7. Mechanical Requirements

7.1 The forgings as represented by tension tests shall conform to the requirements prescribed in Table 2. Charpy V-notch impact specimens shall have a lateral expansion opposite the notch of not less than 0.015 in. (15 mils) [0.38 mm]. In addition the values of energy absorption in foot-pounds (or joules) and the fracture appearance in percent shear shall be recorded and reported for information.

TABLE 1 Chemical Requirements

Element	Composition, %		
	Grade A[A]	Grade E[A]	Grade F[A]
Carbon			
Heat	0.15–0.21	0.12–0.20	0.10–0.22
Product	0.13–0.23	0.10–0.22	0.08–0.22
Manganese			
Heat	0.80–1.10	0.40–0.70	0.60–1.00
Product	0.75–1.15	0.37–0.74	0.55–1.05
Phosphorus, max	0.025	0.025	0.025
Sulfur, max	0.025	0.025	0.025
Silicon			
Heat	0.40–0.80	0.20–0.35	0.15–0.35
Product	0.35–0.86	0.18–0.37	0.13–0.37
Nickel			
Heat	. . .	. . .	0.70–1.00
Product	. . .	. . .	0.67–1.03
		. . .	
Chromium			
Heat	0.50–0.80	1.40–2.00	0.40–0.65
Product	0.46–0.84	1.34–2.06	0.36–0.79
Molybdenum			
Heat	0.18–0.28	0.40–0.60	0.40–0.60
Product	0.15–0.31	0.36–0.64	0.36–0.64
Vanadium			
Heat	. . .	[B]	0.03–0.08
Product	. . .	. . .	0.02–0.09
Titanium			
Heat	. . .	0.04–0.10	. . .
Product	. . .	0.03–0.11	. . .
Zirconium			
Heat	0.05–0.15	. . .	. . .
Product	0.04–0.16	. . .	. . .
Copper			
Heat	. . .	0.20–0.40	0.15–0.50
Product	. . .	0.17–0.43	0.12–0.53
Boron	0.0025 max	0.0015–0.005	0.002–0.006

[A] Similar to Specification A 517/A 517M Grades A, E, and F, respectively.
[B] May be substituted for part or all of titanium content on a one for one basis.

TABLE 2 Tensile Requirements

	Up to 2½ in. [65 mm], incl	Over 2½ in. to 4 in. [65 to 100 mm], incl
Tensile strength, psi (MPa)	115 000 to 135 000 [795 to 930]	105 000 to 135 000 [725 to 930]
Yield strength (0.2 % offset), min, psi [MPa]	100 000 [690]	90 000 [620]
Elongation in 2 in. [50 mm], min, %	18	17
Reduction of area, min, %	45	40

7.2 *Sampling*:

7.2.1 Samples for mechanical test specimens shall be removed after the quenching and tempering heat treatment. The purchaser shall specify any additional thermal treatments that shall be given to the test specimens in addition to the heat treatment specified in 5.1. (This is intended to simulate thermal treatments which may subsequently be performed by the fabricator.)

7.2.2 Samples shall be removed so that the test specimens will have their major axes parallel to the direction of major working of the forging.

7.2.3 Test specimens may be machined from a production forging, or prolongation thereof, or from special forged blocks suitably worked and heat treated with the production forgings. Such special blocks shall be obtained from the ingot, slab, or billet and be reduced by forging in a manner similar to that for the products to be represented. The maximum reduction for a special test block shall not exceed the minimum reduction of the forgings represented, and its thickness shall not be less than the maximum thickness of the forgings represented. If a forging is tested, the tests must represent the maximum section thickness in the lot. All test specimens shall be located at the mid-plane of the thickness and at least T from any second surface of the production forging or test block. (T equals the maximum thickness of the forging.)

7.3 *Number of Tests and Retests*:

7.3.1 *Number of Tests*:

7.3.1.1 One room-temperature tension test and one set of three Charpy V-notch specimens shall be made to represent the maximum section from each heat in each heat-treatment charge. Impact tests shall be conducted at the temperature specified on the order, but no higher than 32°F [0°C].

7.3.1.2 One grain size test shall be made from each heat.

7.3.2 *Retests of Tension Specimens*—If the results of tension tests do not conform to the requirements specified, retests are permitted, as outlined in 7.3.2.1, 7.3.2.2, and 7.3.2.3.

7.3.2.1 If the percentage of elongation of a tension test specimen is less than that prescribed in Table 2, and any part of the fracture is outside the middle half of the gage length, indicated by scribe marks on the test specimens, a single retest shall be allowed.

7.3.2.2 If a test specimen fails to meet the minimum specified requirements due to a flaw, other than a rupture, crack, or flake, a single retest shall be allowed.

7.3.2.3 In the case of failure of the mechanical test specimens to conform to the minimum specified requirements, the manufacturer may reheat treat the forgings. Testing after reheat treatment shall consist of the full number of specimens taken from locations complying with the specification or order.

7.3.3 *Retests of Impact Specimens*:

7.3.3.1 If the lateral expansion value for one specimen is below 0.015 in. [0.38 mm] but not below 0.010 in. [0.25 mm] and the average equals or exceeds 0.015 in. [0.38 mm], a retest of three additional specimens may be made. Each of the three retest specimens must equal or exceed the specified minimum value of 0.015 in. [0.38 mm].

7.3.3.2 If the required lateral expansion values are not obtained in the retest, or if the values in the initial test are below the required values for retest, no further retests are permitted unless the forgings are reheat treated. After reheat treatment a set of three specimens shall be tested and each must equal or exceed the specified minimum value of 0.015 in. [0.38 mm].

7.4 *Test Methods*—Tension and impact tests shall be made in accordance with the latest issue of Test Methods and Definitions A 370. Tension specimens shall be the standard 0.500-in. [12.5-mm] round by 2-in. [50-mm] gage length (see Fig. 5 (Suggested Types of Ends for Standard Round Tension Test Specimens), Test Methods and Definitions A 370). In case of sections too small to accommodate this standard specimen, the largest practicable small size specimen shown in Fig. 4 shall be used. The impact specimens shall be the Charpy V-notch, as shown in Fig. 10 (Charpy (Simple-Beam) Impact Test) of Test Methods and Definitions A 370.

8. Repair Welding

8.1 Repair welding of forgings may be permitted but onlyat the option of the purchaser. Such repair welds shall be made in accordance with Section IX of the ASME Boiler and Pressure Vessel Code.

9. Test Reports

9.1 The certification requirements of Specification A 788 shall apply.

10. Product Marking

10.1 Each forging shall be identified in accordance with the Marking Section of Specification A 788.

11. Keywords

11.1 high-strength low-alloy steel; pipe fittings—steel; pressure vessel service; quenched and tempered steel; steel forgings—alloy

Designation: A 597 – 87 (Reapproved 1999)

Standard Specification for Cast Tool Steel[1]

This standard is issued under the fixed designation A 597; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers tool steel compositions for usable shapes cast by pouring directly into suitable molds and for master heats for remelting and casting.

NOTE 1—A master heat is defined as any single heat of steel of certified analysis which has been processed into suitable form (shot, ingot, etc.) for remelting. A uniform blend of master heats is also acceptable for remelting. This blend is defined as a master heat lot and its average chemical composition shall be certified.

1.2 Nine grades, CA-2, CD-2, CD-5, CM-2, CS-5, CS-7, CH-12, CH-13, and CO-1, are covered in this specification.

NOTE 2—The committee formulating this specification has included air- and oil-hardening grades of tool steel that have been extensively used. Other compositions will be considered for inclusion as the need arises.

2. Referenced Documents

2.1 *ASTM Standards:*

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products[2]

E 59 Practice for Sampling Steel and Iron for Determination of Chemical Composition[3]

3. Ordering Information

3.1 Purchase orders shall include the following information to describe the desired material:

3.1.1 ASTM specification number and date of issue,

3.1.2 Name of material (cast tool steel),

3.1.3 Grade (see Table 1),

3.1.4 Form (shot, ingot, or shaped castings), and

3.1.5 Special requirements.

4. Materials and Manufacture

4.1 The steel shall be made by one or more of the following processes: Electric-arc furnace or induction furnace and may be argon-oxygen decarburization (AOD) refined. The steel can be remelted in air, vacuum, or inert atmosphere.

5. Chemical Requirements

5.1 A chemical analysis of each heat of steel (see Note 1) for master heats and for usable cast shapes shall be made by the manufacturer in accordance with Test Methods A 751. Sampling shall be in accordance with Method E 59. The chemical composition thus determined shall not vary from the limits specified in Table 1.

6. Inspection

6.1 When specified in the purchase order, the inspector representing the purchaser shall have access to the material subject to inspection for the purpose of witnessing the selection of samples and performance of the analytical tests. For such tests, the inspector shall have the right to indicate the pieces from which samples will be selected. Otherwise, the manufacturer shall report to the purchaser, or his representative, the results of the chemical analysis made in accordance with this specification.

7. Rejection and Rehearing

7.1 *Rejection*—Unless otherwise specified, any rejection based on tests made in accordance with this specification shall be reported to the manufacturer within 30 days from the date of receipt of the material.

7.2 *Rehearing*—Samples tested in accordance with this specification that represent rejected material shall be preserved for three weeks from the date of the test report. In case of dissatisfaction with the results of the test, the manufacturer may make claim for a rehearing within that time.

8. Packaging and Package Marking

8.1 *Packaging*—Material shall be packed in such a manner as to ensure safe delivery when properly transported by any common carrier.

8.2 *Package Marking*—Material from each heat shall be marked with heat or lot number, specification number (ASTM A 597), type of steel, and form in order to ensure proper identification.

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.29 on Tool Steels.

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[2] *Annual Book of ASTM Standards*, Vol 01.03.

[3] *Annual Book of ASTM Standards*, Vol 03.05.

TABLE 1 Chemical Requirements

Element	Composition, %				
	CA-2	CD-2	CD-5	CS-5	CM-2
Carbon	0.95–1.05	1.40–1.60	1.35–1.60	0.50–0.65	0.78–0.88
Manganese	0.75 max	1.00 max	0.75 max	0.60–1.00	0.75 max
Silicon	1.50 max	1.50 max	1.50 max	1.75–2.25	1.00 max
Sulfur	0.03 max	0.03 max	0.03 max	0.03 max	0.03 max
Phosphorus	0.03 max	0.03 max	0.03 max	0.03 max	0.03 max
Chromium	4.75–5.50	11.00–13.00	11.00–13.00	0.35 max	3.75–4.50
Molybdenum	0.90–1.40	0.70–1.20	0.70–1.20	0.20–0.80	4.50–5.50
Vanadium	0.20–0.50[A]	0.40–1.00[A]	0.35–0.55	0.35 max	1.25–2.20
Cobalt	...	0.70–1.00[A]	2.50–3.50	...	0.25 max
Tungsten	...	...	...	...	5.50–6.75
Nickel	...	...	0.40–0.60[A]	...	0.25 max
Element	**Composition, %**				
	CS-7	CH-12	CH-13	CO-1	
Carbon	0.45–0.55	0.30–0.40	0.30–0.42	0.85–1.00	
Manganese	0.40–0.80	0.75 max	0.75 max	1.00–1.30	
Silicon	0.60–1.00	1.50 max	1.50 max	1.50 max	
Sulfur	0.03 max	0.03 max	0.03 max	0.03 max	
Phosphorus	0.03 max	0.03 max	0.03 max	0.03 max	
Chromium	3.00–3.50	4.75–5.75	4.75–5.75	0.40–1.00	
Molybdenum	1.20–1.60	1.25–1.75	1.25–1.75	...	
Vanadium	...	0.20–0.50	0.75–1.20	0.30 max	
Cobalt	...	...	...	...	
Tungsten	...	1.00–1.70	...	0.40–0.60	
Nickel	...	...	...	...	

[A] Optional element. Tool steels have found satisfactory application either with or without element present. If desired, it should be specified on the order.

Designation: A 600 – 92a (Reapproved 1999)

Standard Specification for Tool Steel High Speed[1]

This standard is issued under the fixed designation A 600; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers tungsten-type and molybdenum-type high-speed steels available as annealed, hot-rolled bars, forgings, plate, sheet, or strip, and annealed, cold-finished bars or forgings used primarily in the fabrication of tools.

1.2 Seven types of tungsten high-speed tool steels designated T1, T2, etc., seventeen types of molybdenum high-speed tool steels designated M1, M2, etc., and two intermediate high speed steels designated as M50 and M52 are covered. Selection will depend upon design, service conditions, and mechanical properties.

1.3 The term “high-speed steel” is described and its minimum requirements are covered in the Annex.

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are provided for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[2]

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings[3]

A 561 Practice for Macroetch Testing of Tool Steel Bars[3]

A 700 Practices for Packaging, Marking, and Loading Methods for Steel Products for Domestic Shipment[3]

E 3 Methods of Preparation of Metallographic Specimens[4]

E 30 Test Methods for Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron[5]

E 45 Practice for Determining the Inclusion Content of Steel[4]

E 59 Practice for Sampling Steel and Iron for Determination of Chemical Composition[5]

2.2 *Military Standard:*

MIL-STD-163 Steel Mill Products, Preparation for Shipment and Storage[6]

2.3 *Federal Standards:*

Fed. Std. No. 123 Marking for Shipment (Civil Agencies)[6]

Fed. Std. No. 183 Continuous Identification Marking of Iron and Steel Products[6]

3. Classification

3.1 Material in accordance with this specification is classified by chemical composition. Types correspond to respective AISI designations.

3.1.1 Types T1, T2, T4, T5, T6, T8, and T15 are characterized by a controlled high tungsten content along with other alloying elements.

3.1.2 Types M1, M2, M3, M4, M6, M7, M10, M30, M33, M34, M36, M41, M42, M43, M44, M46, M47, M48, and M62 are characterized by a controlled high molybdenum content along with other alloying elements.

3.1.3 Types M2, M3, and M10 are further classified according to carbon range. Type M3 is further classified according to vanadium range.

3.1.4 Types M50 and M52 are considered intermediate high speed steels in view of their lower total alloy content than the standard types. These leaner alloy grades normally are limited to less severe service conditions.

4. Ordering Information

4.1 Orders for material under this specification shall include the following information, as required to describe adequately the desired material:

4.1.1 Name of material (high-speed tool steel),

4.1.2 Type,

4.1.3 Shape (sheet, strip, plate, flat bar, round bar, square bar, hexagon bar, octagon, special shapes),

4.1.4 Dimensions (thickness, width, diameter, length). (For coils, include the minimum inside diameter or inside diameter range, the maximum outside diameter, and maximum or minimum coil weight if required. (Minimum coil weights are subject to negotiation.)),

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys , and is the direct responsibility of Subcommittee A01.29 on Tool Steel.

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[2] *Annual Book of ASTM Standards*, Vol 01.03.

[3] *Annual Book of ASTM Standards*, Vol 01.05.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] *Annual Book of ASTM Standards*, Vol 03.05.

[6] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

4.1.5 Finish (hot rolled, forged, blasted or pickled, cold drawn, rough machined, ground, precision ground and polished),

4.1.6 Condition (annealed),

4.1.7 ASTM designation and date of issue, and

4.1.8 Special or supplementary requirements.

5. Materials and Manufacture

5.1 Unless otherwise specified, material covered by this specification shall be made by an electric melting process.

6. Chemical Composition

6.1 An analysis of each heat of steel shall be made by the manufacturer to determine the percentage of the elements specified and these values shall conform to the requirements as to chemical composition specified in Table 1. If requested or required, the chemical composition shall be reported to the purchaser or his representative.

6.2 Analysis may be made by the purchaser from finished bars and forgings by machining off the entire cross section and drilling parallel to the axis of the bar or forging at any point midway between the center and surface in accordance with the latest issue of Method E 59. The chemical analysis of the drilling chips shall be made in accordance with the latest issue of Methods E 30. The chemical composition thus determined shall not vary from the limits specified in Table 1.

7. Hardness Requirements

7.1 Annealed hardness values when obtained in accordance with the latest issue of Test Methods and Definitions A 370 shall not exceed the Brinell hardness values (or equivalent Rockwell hardness values) specified in Table 2.

7.2 Specimens for determination of minimum response to hardening shall be ¼-in. (6.4-mm) thick disks cut so as to represent either the full cross-sectional area or that midway between the center and outer surface of the material. If the material form or size does not lend itself to accurate hardness determination on ¼-in. thick cross-sectional disks, then longitudinal specimens may be used for hardness testing. Examples are round bars less than ½ in. (12.7 mm) in diameter; sheet; and strip. In this case, the specimen shall be a minimum of 3 in. (76.2 mm) in length, and parallel flats shall be ground on the original mill surfaces. The specimens shall be heat treated in two furnaces, one operating as a preheat furnace and the other

TABLE 1 Chemical Requirements, %[A]

UNS Designation[B]	Type	Carbon		Manganese		Phosphorus	Sulfur[C]	Silicon		Chromium		Vanadium		Tungsten		Molybdenum		Cobalt	
		min	max	min	max	max	max	min	max	min	max	min	max	min	max	min	max	min	max
	Tungsten-Type High-Speed Steels																		
T12001	T1	0.65	0.80	0.10	0.40	0.03	0.03	0.20	0.40	3.75	4.50	0.90	1.30	17.25	18.75	. . .	. . .	. . .	. . .
T12002	T2	0.80	0.90	0.20	0.40	0.03	0.03	0.20	0.40	3.75	4.50	1.80	2.40	17.50	19.00	. . .	1.00	. . .	. . .
T12004	T4	0.70	0.80	0.10	0.40	0.03	0.03	0.20	0.40	3.75	4.50	0.80	1.20	17.50	19.00	0.40	1.00	4.25	5.75
T12005	T5	0.75	0.85	0.20	0.40	0.03	0.03	0.20	0.40	3.75	5.00	1.80	2.40	17.50	19.00	0.50	1.25	7.00	9.50
T12006	T6	0.75	0.85	0.20	0.40	0.03	0.03	0.20	0.40	4.00	4.75	1.50	2.10	18.50	21.00	0.40	1.00	11.00	13.00
T12008	T8	0.75	0.85	0.20	0.40	0.03	0.03	0.20	0.40	3.75	4.50	1.80	2.40	13.25	14.75	0.40	1.00	4.25	5.75
T12015	T15	1.50	1.60	0.15	0.40	0.03	0.03	0.15	0.40	3.75	5.00	4.50	5.25	11.75	13.00	. . .	1.00	4.75	5.25
	Molybdenum-Type High-Speed Steels																		
T11301	M1	0.78	0.88	0.15	0.40	0.03	0.03	0.20	0.50	3.50	4.00	1.00	1.35	1.40	2.10	8.20	9.20	. . .	. . .
T11302	M2 regular C	0.78	0.88	0.15	0.40	0.03	0.03	0.20	0.45	3.75	4.50	1.75	2.20	5.50	6.75	4.50	5.50	. . .	. . .
	high C	0.95	1.05	0.15	0.40	0.03	0.03	0.20	0.45	3.75	4.50	1.75	2.20	5.50	6.75	4.50	5.50	. . .	. . .
T11313	M3 Class 1	1.00	1.10	0.15	0.40	0.03	0.03	0.20	0.45	3.75	4.50	2.25	2.75	5.00	6.75	4.75	6.50	. . .	. . .
T11323	Class 2	1.15	1.25	0.15	0.40	0.03	0.03	0.20	0.45	3.75	4.50	2.75	3.25	5.00	6.75	4.75	6.50	. . .	. . .
T11304	M4	1.25	1.40	0.15	0.40	0.03	0.03	0.20	0.45	3.75	4.75	3.75	4.50	5.25	6.50	4.25	5.50	. . .	. . .
T11306	M6	0.75	0.85	0.15	0.40	0.03	0.03	0.20	0.45	3.75	4.50	1.30	1.70	3.75	4.75	4.50	5.50	11.00	13.00
T11307	M7	0.97	1.05	0.15	0.40	0.03	0.03	0.20	0.55	3.50	4.00	1.75	2.25	1.40	2.10	8.20	9.20	. . .	. . .
T11310	M10 regular C	0.84	0.94	0.10	0.40	0.03	0.03	0.20	0.45	3.75	4.50	1.80	2.20	. . .	. . .	7.75	8.50	. . .	. . .
	high C	0.95	1.05	0.10	0.40	0.03	0.03	0.20	0.45	3.75	4.50	1.80	2.20	. . .	. . .	7.75	8.50	. . .	. . .
T11330	M30	0.75	0.85	0.15	0.40	0.03	0.03	0.20	0.45	3.50	4.25	1.00	1.40	1.30	2.30	7.75	9.00	4.50	5.50
T11333	M33	0.85	0.92	0.15	0.40	0.03	0.03	0.15	0.50	3.50	4.00	1.00	1.35	1.30	2.10	9.00	10.00	7.75	8.75
T11334	M34	0.85	0.92	0.15	0.40	0.03	0.03	0.20	0.45	3.50	4.00	1.90	2.30	1.40	2.10	7.75	9.20	7.75	8.75
T11336	M36	0.80	0.90	0.15	0.40	0.03	0.03	0.20	0.45	3.75	4.50	1.75	2.25	5.50	6.50	4.50	5.50	7.75	8.75
T11341	M41	1.05	1.15	0.20	0.60	0.03	0.03	0.15	0.50	3.75	4.50	1.75	2.25	6.25	7.00	3.25	4.25	4.75	5.75
T11342	M42	1.05	1.15	0.15	0.40	0.03	0.03	0.15	0.65	3.50	4.25	0.95	1.35	1.15	1.85	9.00	10.00	7.75	8.75
T11343	M43	1.15	1.25	0.20	0.40	0.03	0.03	0.15	0.65	3.50	4.25	1.50	1.75	2.25	3.00	7.50	8.50	7.75	8.75
T11344	M44	1.10	1.20	0.20	0.40	0.03	0.03	0.30	0.55	4.00	4.75	1.85	2.20	5.00	5.75	6.00	7.00	11.00	12.25
T11346	M46	1.22	1.30	0.20	0.40	0.03	0.03	0.40	0.65	3.70	4.20	3.00	3.30	1.90	2.20	8.00	8.50	7.80	8.80
T11347	M47	1.05	1.15	0.15	0.40	0.03	0.03	0.20	0.45	3.50	4.00	1.15	1.35	1.30	1.80	9.25	10.00	4.75	5.25
. . .	M48	1.42	1.52	0.15	0.40	0.03	0.07	0.15	0.40	3.50	4.00	2.75	3.25	9.50	10.50	4.75	5.50	8.00	10.00
. . .	M62	1.25	1.35	0.15	0.40	0.03	0.07	0.15	0.40	3.50	4.00	1.80	2.10	5.75	6.50	10.00	11.00	. . .	. . .
	Intermediate High Speed Steels																		
T11350	M50	0.78	0.88	0.15	0.45	0.03	0.03	0.20	0.60	3.75	4.50	0.80	1.25	. . .	. . .	3.90	4.75	. . .	. . .
T11352	M52	0.85	0.95	0.15	0.45	0.03	0.03	0.20	0.60	3.50	4.30	1.65	2.25	0.75	1.50	4.00	4.90	. . .	. . .

[A] Chemistry limits include product analysis tolerances. Unless otherwise specified, nickel plus copper equals 0.75 % max for all types.

[B] New designation established in accordance with Practice E 527 and SAE J 1086.

[C] Where specified, sulfur may be 0.06 to 0.15 % to improve machinability.

TABLE 2 Maximum Brinell Hardness in Annealed or Cold Drawn Condition

Type	Annealed BHN	Cold Drawn Annealed BHN	Cold Drawn BHN
M1	248	255	262
M2 (regular C)	248	255	262
M2 (high C)	255	262	269
M3, Class 1 and Class 2	255	262	269
M4	255	262	269
M6	277	285	293
M7	255	262	269
M10 (regular C)	248	255	262
M10 (high C)	255	262	269
M30	269	277	285
M33	269	277	285
M34	269	277	285
M36	269	277	285
M41	269	277	285
M42	269	277	285
M43	269	297	285
M44	285	293	302
M46	269	277	285
M47	269	277	285
M48	311	321	331
M50	248	255	262
M52	248	255	262
M62	285	293	302
T1	255	262	269
T2	255	262	269
T4	269	277	285
T5	285	293	302
T6	302	311	321
T8	255	262	269
T15	277	285	293

as a high-heat furnace. The furnaces may be either controlled atmosphere or molten-salt bath. The austenitizing temperature ranges stipulated in Table 3 cover both furnace types.

7.2.1 After being austenitized for the proper time, the samples may be oil quenched or quenched in molten salt plus air cooling. When a salt quench is employed, its temperature shall be 1050 to 1175°F (566 to 635°C) except for M3, M4, M41, , M42,M43 , M46, M47, M48, M62, and T15, when it shall be 1000 to 1075°F (538 to 579°C). All samples shall be double tempered at 1025°F (552°C) for 2 h each cycle except for M0 and M52 which shall be given two tempering cycles of 2 h each at 1000°F and M41, M42, M43, M44, M46, M47, M48, M62, and T15, which shall be given three tempering cycles of 2 h each at 1000°F.

7.2.2 The hardness of the specimen after the specified heat treatment shall meet the minimum hardness value for the particular type of steel shown in Table 3. Rockwell C tests should be used where possible but light-load tests may be necessary on thin specimens. These tests should be specified by agreement between seller and purchaser. The hardness value shall be obtained in accordance with the latest issue of Test Methods and Definitions A 370 and shall be the average of at least five readings taken in an area midway between the center and surface of the largest dimension of the cross-sectional specimen or along the parallel surfaces of the longitudinal specimen. The surface to be tested shall be ground sufficiently to remove any surface condition, scale, carburization, or decarburization which might affect readings.

8. Macrostructure

8.1 The macrostructure of a specimen representing the entire cross-sectional area in the annealed condition and prepared in accordance with the latest issue of Practice A 561 shall exhibit a structure free of excessive porosity, slag, dirt, or other nonmetallic inclusions, pipes, checks, cracks and other injurious defects.

8.2 Macroetch severity levels for center porosity and ingot pattern, illustrated photographically in Practice A 561, shall not exceed the ratings specified in Table 4 for the appropriate material size and composition.

9. Decarburization

9.1 Decarburization shall be determined on a specimen representing a cross section of the material and prepared in accordance with the latest issue of Methods E 3. When examined at 20× or greater magnification, it shall not exceed the values given in Tables 5-8 for the appropriate size and shape of the material.

9.2 Material ordered as drill rod, ground and polished, centerless ground, ground finished, or machine finished flats and squares shall be free of scale and decarburization.

10. Permissible Variations in Dimensions

10.1 Permissible variations in dimensions shall not exceed the applicable limits stated in Tables 8-22, incl. Where out-of-round or square requirements are shown, they shall be determined as follows:

10.1.1 *Out-of-Round*—Difference between high and low readings as determined by micrometers or other suitable measuring instruments.

10.1.2 *Out-of-Square*—The amount required to be removed from each edge in order to square the edge with the face as determined with a square and suitable measuring instruments.

11. Workmanship, Finish, and Appearance

11.1 High-speed tool steel shall be free of heavy scale, deep pitting, laps, porosity, injurious segregations, excessive non-metallic inclusions, seams, cracks, checks, slivers, scale marks, dents, soft and hard spots, pipes, or any defects that would detrimentally affect the suitability of the material, after removal of the recommended stock allowance. (See Tables 5-8)

11.2 Visual examination shall be made to ensure compliance with the requirements for workmanship, finish, dimensions and tolerances, identification marking, and packaging.

12. Sampling

12.1 Unless otherwise specified, a lot shall consist of all material submitted for inspection at the same time, of the same heat, type, finish, and size, and must conform to the provisions of this specification.

13. Inspection

13.1 Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. The supplier may utilize his own facilities or any other acceptable to the purchaser.

TABLE 3 Heat-Treating Requirements

NOTE—The austenitizing temperatures are stipulated for the response to hardening test only. Other combinations of austenitizing and tempering temperatures may be used for particular applications.

Class	Preheat Temperature °F (°C)	Austenitizing Temperature, °F (°C)[A]		Tempering Temperature, °F (°C)[B]	Minimum Hardness, Rockwell C
		Salt Bath	Controlled Atmosphere Furnace		
M1	1350–1550 (732–843)	2185 (1196)	2205 (1207)	1025 (552)	64
M2 (regular C)	1350–1550 (732–843)	2220 (1216)	2240 (1227)	1025 (552)	64
M2 (high C)	1350–1550 (732–843)	2200 (1204)	2220 (1216)	1025 (552)	65
M3, Class 1	1350–1550 (732–843)	2200 (1204)	2220 (1216)	1025 (552)	64
M3, Class 2	1350–1550 (732–843)	2200 (1204)	2220 (1216)	1025 (552)	64
M4	1350–1550 (732–843)	2200 (1204)	2220 (1216)	1025 (552)	64
M6	1350–1550 (732–843)	2170 (1188)	2190 (1199)	1025 (552)	64
M7	1350–1550 (732–843)	2200 (1204)	2220 (1216)	1025 (552)	65
M10 (regular C)	1350–1550 (732–843)	2185 (1196)	2205 (1207)	1025 (552)	63
M10 (high C)	1350–1550 (732–843)	2185 (1196)	2205 (1207)	1025 (552)	64
M30	1350–1550 (732–843)	2200 (1204)	2220 (1216)	1025 (552)	64
M33	1350–1550 (732–843)	2200 (1204)	2220 (1216)	1025 (552)	65
M34	1350–1550 (732–843)	2200 (1204)	2220 (1216)	1025 (552)	64
M36	1350–1550 (732–843)	2200 (1204)	2220 (1216)	1025 (552)	64
M41	1350–1550 (732–843)	2175 (1190)	2195 (1202)	1000 (538)	66
M42	1350–1550 (732–843)	2150 (1177)	2170 (1188)	1000 (538)	66
M43	1350–1550 (732–843)	2150 (1177)	2170 (1188)	1000 (538)	66
M44	1350–1550 (732–843)	2170 (1188)	2190 (1199)	1000 (538)	66
M46	1350–1550 (732–843)	2200 (1204)	2220 (1216)	1000 (538)	66
M47	1350–1550 (732–843)	2175 (1190)	2195 (1202)	1000 (538)	66
M48	1350–1550 (732–843)	2175 (1190)	2195 (1202)	1000 (538)	66
M50	1350–1550 (732–843)	2020 (1104)	2040 (1116)	1000 (538)	61
M52	1350–1550 (732–843)	2125 (1163)	2145 (1174)	1000 (538)	63
M62	1350–1550 (732–843)	2175 (1190)	2195 (1202)	1000 (538)	66
T1	1500–1600 (816–871)	2330 (1277)	2350 (1288)	1025 (552)	63
T2	1500–1600 (816–871)	2330 (1277)	2350 (1288)	1025 (552)	63
T4	1500–1600 (816–871)	2330 (1277)	2350 (1288)	1025 (552)	63
T5	1500–1600 (816–871)	2330 (1277)	2350 (1288)	1025 (552)	63
T6	1500–1600 (816–871)	2330 (1277)	2350 (1288)	1025 (552)	63
T8	1500–1600 (816–871)	2330 (1277)	2350 (1288)	1025 (552)	63
T15	1500–1600 (816–871)	2240 (1227)	2260 (1238)	1000 (538)	65

[A] Temperature limit shall be ±10°F (±5°C). If samples are austenitized in salt, the sample shall be immersed in the austenitizing salt bath for 5 min minimum. If austenitized in a controlled atmosphere furnace, the sample shall be at the austenitizing temperature for 5 to 15 min. The time at temperature is the time after the sample reaches the austenitizing temperature. This range in time is given because of the difficulty in determining when the sample reaches the austenitizing temperature in some types of controlled atmosphere furnaces.

Quenching may be done in oil or molten salt.

[B] Tempers at 1025°F (552°C) are for 2 + 2 h. Tempers at 1000°F (538°C) are for 2 + 2 + 2 h.

TABLE 4 Macroetch Standards
Maximum Allowable Rating[A]

Bar Size, in. (mm)	T Classification Steels[B]		M Classification Steels[C]	
	Porosity	Ingot Pattern	Porosity	Ingot Pattern
Up to 2 (50.8), incl	3½	5	3	5
Over 2 to 3 (50.8 to 76), incl	4	5	3½	5
Over 3 to 4 (76 to 102), incl	4½	5	4	5
Over 4 to 5 (102 to 127), incl	5	5	4	5
Over 5 to 6 (127 to 152), incl	5	5	4½	5
Over 6 (152)	As negotiated between supplier and purchaser			

[A] Refer to macroetch photographs in Practice A 561.

[B] Types T1, T2, T4, T5, T6, T8, and T15.

[C] Types M1, M2, M3, M4, M6, M7, M10, M30, M33, M34, M36, M41, M42, M43, M44, M46, M47, M48, M50, M52, and M62.

TABLE 5 Maximum Decarburization Limits Rounds[A]

NOTE—The recommended minimum allowance for machining prior to heat treatment is 25 % greater than the maximum decarburization allowed.

Specified Diameter, in. (mm)	Decarburization Limits per Side, in. (mm), Drawn Finish
Up to ½ (12.7), incl	0.013 (0.33)
Over ½ to 1 (12.7 to 25.4), incl	0.025 (0.64)
Over 1 to 2 (25.4 to 50.8), incl	0.038 (0.96)
Over 2 to 3 (50.8 to 76), incl	0.050 (1.27)
Over 3 to 4 (76 to 102), incl	0.070 (1.78)

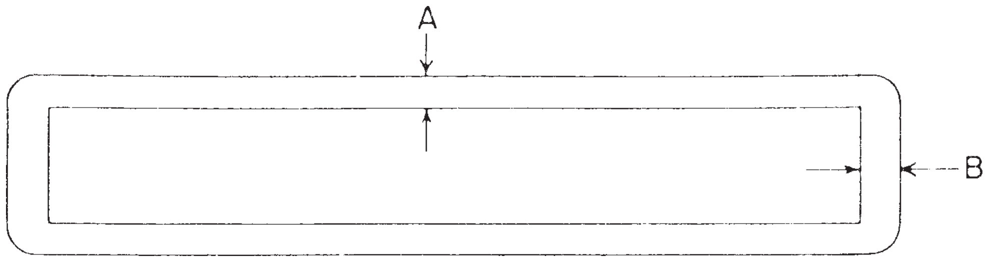
[A] Rounds to be free of decarburization except drawn finish. Maximum decarburization of drawn finish rounds to be in accordance with the table above.

13.2 When specified in the purchase order, the inspector representing the purchaser shall have access to the material subject to inspection for the purpose of witnessing the selection of samples, preparation of test pieces, and performance of the tests. For such tests, the inspector shall have the right to indicate the pieces from which samples will be selected. Otherwise the seller shall report to the purchaser, or his representative, the results of the chemical analysis and the physical property tests made in accordance with this specification.

13.3 The purchaser may perform any of the inspections set forth in the specification on the as-received material where such inspections are deemed necessary to assure that supplies and services conform to the prescribed requirements.

TABLE 6 Maximum Decarburization Limits
Hot Rolled Square and Flat Bars
Maximum Limit Per Side

NOTE—The recommended minimum allowance for machining prior to heat treatment is 25 % greater than the maximum decarburization allowed.



Specified Thickness, in. (mm)		Specified Widths, in. (mm): 0 to ½ (0 to 12.7) incl.	Over ½ to 1 (12.7 to 25.4), incl	Over 1 to 2 (25.4 to 50.8), incl	Over 2 to 3 (50.8 to 76), incl	Over 3 to 4 (76 to 102), incl	Over 4 to 5 (102 to 127), incl	Over 5 to 6 (127 to 152), incl	Over 6 to 7 (152 to 178), incl	Over 7 to 8 (178 to 203), incl	Over 8 to 9 (203 to 229), incl	Over 9 to 12 (229 to 304), incl
0 to ½ (0 to 12.7), incl	A	0.020 (0.51)	0.020 (0.51)	0.024 (0.61)	0.028 (0.71)	0.032 (0.81)	0.036 (0.91)	0.040 (1.02)	0.044 (1.12)	0.048 (1.22)	0.048 (1.22)	0.048 (1.22)
	B	0.020 (0.51)	0.026 (0.66)	0.032 (0.81)	0.038 (0.97)	0.044 (1.12)	0.054 (1.37)	0.062 (1.57)	0.066 (1.68)	0.078 (1.98)	0.082 (2.08)	0.096 (2.44)
Over ½ to 1 (12.7 to 25.4), incl	A	...	0.036 (0.91)	0.036 (0.91)	0.036 (0.91)	0.040 (1.02)	0.044 (1.12)	0.052 (1.32)	0.056 (1.42)	0.060 (1.52)	0.060 (1.52)	0.060 (1.52)
	B	...	0.036 (0.91)	0.042 (1.07)	0.046 (1.17)	0.056 (1.42)	0.064 (1.63)	0.082 (2.08)	0.090 (2.29)	0.098 (2.49)	0.102 (2.59)	0.108 (2.74)
Over 1 to 2 (25.4 to 50.8), incl	A	...	...	0.052 (1.32)	0.052 (1.32)	0.056 (1.42)	0.056 (1.42)	0.060 (1.52)	0.060 (1.52)	0.064 (1.63)	0.068 (1.73)	0.072 (1.83)
	B	...	...	0.052 (1.32)	0.056 (1.42)	0.060 (1.52)	0.072 (1.83)	0.086 (2.18)	0.098 (2.49)	0.112 (2.84)	0.118 (3.00)	0.122 (3.10)
Over 2 to 3 (50.8 to 76), incl	A	...	...	...	0.064 (1.63)	0.064 (1.63)	0.068 (1.73)	0.068 (1.73)	0.072 (1.83)	0.072 (1.83)	0.080 (2.03)	0.080 (2.03)
	B	...	...	...	0.064 (1.63)	0.072 (1.83)	0.082 (2.08)	0.094 (2.39)	0.110 (2.79)	0.122 (3.10)	0.130 (3.30)	0.136 (3.45)
Over 3 to 4 (76 to to 102), incl	A	...	...	...	...	0.080 (2.03)	0.080 (2.03)	0.086 (2.18)	0.092 (2.34)	0.094 (2.39)	0.100 (2.54)	0.100 (2.54)
	B	...	...	...	...	0.080 (2.03)	0.090 (2.29)	0.100 (2.54)	0.120 (3.05)	0.132 (3.35)	0.132 (3.35)	0.150 (3.81)

14. Rejection

14.1 Unless otherwise specified, any rejection based on tests made in accordance with this specification should be reported to the seller within 30 days from the date of receipt of the material.

14.2 Material that shows injurious defects subsequent to its acceptance by the purchaser shall be rejected and the seller notified.

15. Rehearing

15.1 Samples tested in accordance with this specification that represent rejected material shall be preserved for three weeks from the date of the test report. In case of dissatisfaction with the results of the test, the seller may make claim for a rehearing within that time.

16. Packaging, Loading, and Package Marking

16.1 *Packaging and Loading*:

16.1.1 Unless otherwise specified, shipments shall be packaged and loaded in accordance with Practices A 700.

16.1.2 When specified in the contract or order, and for direct procurement by or direct shipment to the government, when Level A is specified, preservation, packaging, and loading shall be in accordance with the Level A requirements of MIL-STD-163.

16.2 *Package Marking*:

16.2.1 Shipments shall be properly marked with the name or brand of manufacturer, purchaser's name and order number, specification number (ASTM A 600), heat number, grade or type, and where appropriate, the size, length, and weight. Unless otherwise specified, method of marking is at the option of the manufacturer.

16.2.2 When specified in the contract or order, and for direct procurement by or direct shipment to the government, marking for shipment, in addition to any requirements specified in the contract or order, shall be in accordance with MIL-STD-163 for military agencies, and in accordance with Fed. Std. No. 123 for civil agencies.

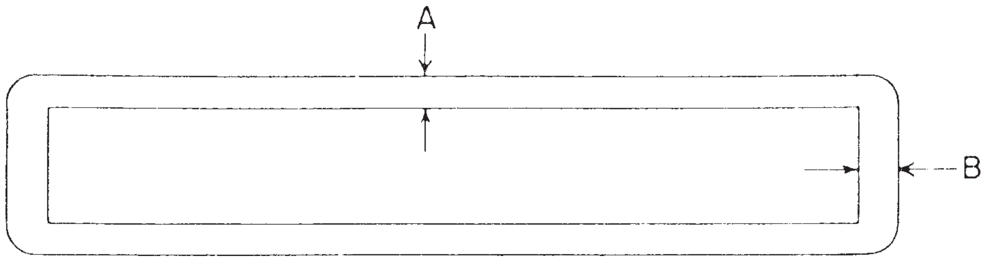
16.2.3 For government procurement by the Defense Supply Agency, steel shall be continuously marked for identification in accordance with Fed. Std. No. 183.

17. Keywords

17.1 high speed; tool steel

TABLE 7 Maximum Decarburization Limits
Forged Square and Flat Bars
Maximum Limit Per Side

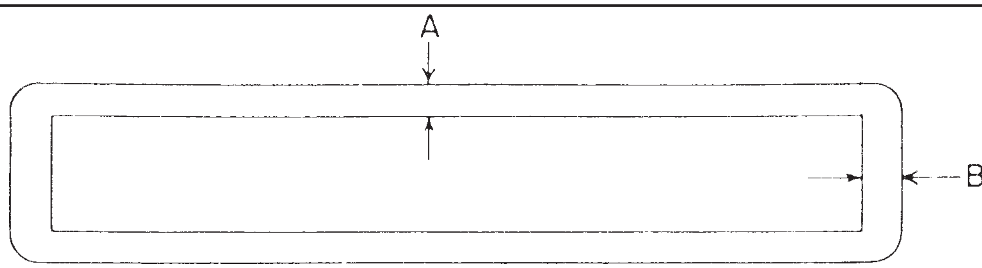
NOTE—The recommended minimum allowance for machining prior to heat treatment is 25 % greater than the maximum decarburization allowed.



Specified Thickness, in. (mm)		Specified Width, Inches (mm)								
		Over 1 to 2 (25.4 to 50.8), incl	Over 2 to 3 (50.8 to 76), incl	Over 3 to 4 (76 to 102), incl	Over 4 to 5 (102 to 127), incl	Over 5 to 6 (127 to 152), incl	Over 6 to 7 (152 to 178), incl	Over 7 to 8 (178 to 203), incl	Over 8 to 9 (203 to 229), incl	Over 9 to 12 (229 to 305), incl
Over ½ to 1, (12.7 to	A	0.038 (0.97)	0.042 (1.07)	0.048 (1.22)	0.052 (1.32)	0.056 (1.42)	0.062 (1.57)	0.066 (1.68)	0.072 (1.83)	0.080 (2.03)
25.4), incl	B	0.048 (1.22)	0.056 (1.42)	0.070 (1.78)	0.080 (2.03)	0.094 (2.39)	0.110 (2.79)	0.132 (3.35)	0.132 (3.35)	0.132 (3.35)
Over 1 to 2, (25.4 to	A	0.058 (1.47)	0.062 (1.57)	0.066 (1.68)	0.070 (1.78)	0.074 (1.88)	0.080 (2.03)	0.084 (2.13)	0.094 (2.39)	0.106 (2.69)
50.8), incl	B	0.058 (1.47)	0.066 (1.68)	0.078 (1.98)	0.086 (2.18)	0.100 (2.54)	0.114 (2.90)	0.132 (3.35)	0.132 (3.35)	0.132 (3.35)
Over 2 to 3 (50.8 to	A	...	0.080 (2.03)	0.084 (2.13)	0.088 (2.24)	0.092 (2.34)	0.098 (2.49)	0.106 (2.69)	0.114 (2.90)	0.126 (3.20)
76), incl	B	...	0.080 (2.03)	0.092 (2.34)	0.098 (2.49)	0.106 (2.69)	0.118 (3.00)	0.136 (3.45)	0.136 (3.45)	0.136 (3.45)
Over 3 to 4 (76 to	A	...	...	0.102 (2.59)	0.106 (2.69)	0.112 (2.84)	0.120 (3.05)	0.132 (3.35)	0.140 (3.56)	0.158 (4.01)
102), incl	B	...	...	0.102 (2.59)	0.106 (2.69)	0.112 (2.84)	0.120 (3.05)	0.132 (3.35)	0.140 (3.56)	0.158 (4.01)
127), incl	B	...	...	...	0.126 (3.20)	0.130 (3.30)	0.138 (3.51)	0.146 (3.71)	0.156 (3.96)	0.170 (4.32)
Over 5 to 6 (127 to	A	...	...	...	...	0.150 (3.81)	0.158 (4.01)	0.166 (4.22)	0.176 (4.47)	0.188 (4.78)
152), incl	B	...	...	...	...	0.150 (3.81)	0.158 (4.01)	0.166 (4.22)	0.176 (4.47)	0.188 (4.78)
Over 6 to 7 (152 to	A	...	...	...	...	...	0.176 (4.47)	0.186 (4.72)	0.186 (4.72)	0.198 (5.03)
178), incl	B	...	...	...	...	...	0.176 (4.47)	0.186 (4.72)	0.186 (4.72)	0.198 (5.03)

TABLE 8 Maximum Decarburization Limits
Cold Drawn Square and Flat Bars
Maximum Limits Per Side

NOTE—The recommended minimum allowance for machining prior to heat treatment is 25 % greater than the maximum decarburization allowed.



Specified Thickness, in. (mm)		Specified Width, in. (mm)					
		0 to ½ (0 to 12.7), incl	Over ½ to 1 (12.7 to 25.4), incl	Over 1 to 2 (25.4 to 50.8), incl	Over 2 to 3 (50.8 to 76), incl	Over 3 to 4 (76 to 102), incl	Over 4 to 5 (102 to 127), incl
0 to ½ (0 to 12.7), incl	A	0.020 (0.51)	0.020 (0.51)	0.024 (0.61)	0.028 (0.71)	0.032 (0.81)	0.036 (0.91)
	B	0.020 (0.51)	0.026 (0.66)	0.032 (0.81)	0.038 (0.97)	0.044 (1.12)	0.054 (1.37)
Over ½ to 1 (12.7 to 25.4), incl	A	...	0.036 (0.91)	0.036 (0.91)	0.036 (0.91)	0.040 (1.02)	0.044 (1.12)
	B	...	0.036 (0.91)	0.042 (1.07)	0.046 (1.17)	0.056 (1.42)	0.064 (1.63)
Over 1 to 2 (25.4 to 50.8), incl	A	...	...	0.052 (1.32)	0.052 (1.32)	0.056 (1.42)	...
	B	...	...	0.052 (1.32)	0.056 (1.42)	0.060 (1.52)	...

TABLE 9 Size Tolerances for Hot-Rolled Bars
Rounds,[A] Squares, Octagons, Quarter Octagons, Hexagons
Size Tolerances

NOTE—Out-of-round or square to be ¾ of total tolerance maximum.

Specified Sizes, in. (mm)	Size Tolerances, in. (mm)	
	Minus	Plus
To ½ (12.7), incl	0.005 (0.13)	0.012 (0.30)
Over ½ to 1 (12.7 to 25.4), incl	0.005 (0.13)	0.016 (0.41)
Over 1 to 1½ (25.4 to 38.1), incl	0.006 (0.15)	0.020 (0.51)
Over 1½ to 2 (38.1 to 50.8), incl	0.008 (0.20)	0.025 (0.64)
Over 2 to 2½ (50.8 to 63.5), incl	0.010 (0.25)	0.030 (0.76)
Over 2½ to 3 (63.5 to 76.2), incl	0.010 (0.25)	0.040 (1.02)
Over 3 to 4 (76.2 to 101.6), incl	0.012 (0.30)	0.050 (1.27)
Over 4 to 5½ (101.6 to 139.7), incl	0.015 (0.38)	0.060† (1.52)
Over 5½ to 6½ (139.7 to 165.1), incl	0.018 (0.46)	0.100 (2.54)
Over 6½ to 8 (165.1 to 203.2), incl	0.020 (0.51)	0.150 (3.81)

[A] For high-speed steel rounds free of scale and decarburization, see Table 10.
† Editorially corrected.

TABLE 10 Diameter Tolerances for Round Bars, High-Speed Steels (Free of Scale and Decarburization)

NOTE—Out-of-round to be ½ of total tolerance maximum.

Specified Diameter, in. (mm)	Diameter Tolerances, in. (mm)	
	Under	Over
¼ to ⅝ (6.4 to 15.8), excl	0.0015 (0.038)	0.0015 (0.038)
⅝ to 3¹⁄₁₆ (15.8 to 77.6), excl	0.000	0.004 (0.10)
3¹⁄₁₆ to 4¹⁄₁₆ (77.6 to 103), excl	0.000	0.006 (0.15)
4¹⁄₁₆ to 7⅛ (103 to 181), excl	0.000	0.031 (0.78)
7⅛ to 8⅛ (181 to 206.2), excl	0.000	0.062 (1.6)
8⅛ to 10⅛ (206.2 to 257), excl	0.000	0.093 (2.4)
10⅛ to 12⅛ (257 to 307.7), excl	0.000	0.125 (3.2)
12⅛ and over (307.7 and over), excl	0.000	0.187 (4.7)

TABLE 11 Hot-Rolled Flat Bars
Width and Thickness Tolerances
Width Tolerances[A]

Specified Widths, in. (mm)	Width Tolerances, in. (mm)	
	Under	Over
To 1 (25.4), incl	0.016 (0.41)	0.031 (0.79)
Over 1 to 3 (25.4 to 76), incl	0.031 (0.79)	0.047 (1.19)
Over 3 to 5 (76 to 127), incl	0.047 (1.19)	0.063 (1.60)
Over 5 to 6 (127 to 152), incl	0.063 (1.60)	0.094 (2.39)
Over 7 to 10 (178 to 254), incl	0.078 (1.98)	0.125 (3.18)
Over 10 to 12 (254 to 305), incl	0.094 (2.39)	0.156 (3.96)

Thickness Tolerances

Specified Widths, in. (mm)	Thickness Tolerances for Specified Thicknesses, in. (mm)											
	To ¼ (6.4), incl		Over ¼ to ½ (6.4 to 12.7), incl		Over ½ to 1 (12.7 to 25.4), incl		Over 1 to 2 (25.4 to 50.8), incl		Over 2 to 3 (50.8 to 76), incl		Over 3 to 4 (76 to 102), incl	
	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over
To 1 (25.4), incl	0.006(0.15)	0.010(0.25)	0.008(0.20)	0.012(0.30)	0.010(0.25)	0.016(0.41)	...	...	...	...	...	...
Over 1 to 2 (25.4 to 50.8), incl	0.006(0.15)	0.014(0.36)	0.008(0.20)	0.016(0.41)	0.010(0.25)	0.020(0.51)	0.020(0.51)	0.024(0.61)	...	...	...	...
Over 2 to 3 (50.8 to 76), incl	0.006(0.15)	0.018(0.46)	0.008(0.20)	0.020(0.51)	0.010(0.25)	0.024(0.61)	0.020(0.51)	0.027(0.69)	0.026(0.66)	0.034(0.86)	...	...
Over 3 to 4 (76 to 102), incl	0.008(0.20)	0.020(0.51)	0.010(0.25)	0.022(0.56)	0.013(0.33)	0.024(0.61)	0.024(0.61)	0.030(0.76)	0.032(0.81)	0.042(1.07)	0.040(1.02)	0.048(1.22)
Over 4 to 5 (102 to 127), incl	0.010(0.25)	0.020(0.51)	0.012(0.30)	0.024(0.61)	0.015(0.38)	0.030(0.76)	0.027(0.69)	0.035(0.89)	0.032(0.81)	0.042(1.07)	0.042(1.07)	0.050(1.27)
Over 5 to 6 (127 to 152), incl	0.012(0.30)	0.020(0.51)	0.014(0.36)	0.030(0.76)	0.018(0.46)	0.030(0.76)	0.030(0.76)	0.035(0.89)	0.036(0.91)	0.046(1.17)	0.044(1.12)	0.054(1.37)
Over 6 to 7 (152 to 178), incl	0.014(0.36)	0.027(0.69)	0.016(0.41)	0.032(0.81)	0.018(0.46)	0.035(0.89)	0.030(0.76)	0.040(1.02)	0.036(0.91)	0.048(1.22)	0.046(1.17)	0.056(1.42)
Over 7 to 10 (178 to 254), incl	0.018(0.46)	0.030(0.76)	0.020(0.51)	0.035(0.89)	0.024(0.61)	0.040(1.02)	0.035(0.89)	0.045(1.14)	0.040(1.02)	0.054(1.37)	0.052(1.32)	0.064(1.62)
Over 10 to 12 (254 to 305), incl	0.020(0.51)	0.035(0.89)	0.025(0.64)	0.040(1.02)	0.030(0.76)	0.045(1.14)	0.040(1.02)	0.050(1.27)	0.046(1.17)	0.060(1.52)	0.056(1.42)	0.072(1.83)

[A] Out-of-square to be ¾ of total width tolerance maximum.

TABLE 12 Forged Bars
Rounds,[A] Squares, Octagons, Hexagons
Size Tolerances

NOTE—Out-of-round or square to be ¾ of total tolerance maximum.

Specified Sizes, in. (mm)	Size Tolerances, in. (mm)	
	Minus	Plus
Over 1 to 2 (25.4 to 50.8), incl	0.030 (0.76)	0.060 (1.52)
Over 2 to 3 (50.8 to 76), incl	0.030 (0.76)	0.080 (2.03)
Over 3 to 5 (76 to 127), incl	0.060 (1.52)	0.125 (3.18)
Over 5 to 7 (127 to 177.8), incl	0.125 (3.18)	0.187 (4.75)
Over 7 to 9 (178 to 229), incl	0.187 (4.75)	0.312 (7.92)

[A] Refer to Table 10 for diameter tolerances on rounds of high-speed steels free of scale and decarburization.

TABLE 13 Forged Flat Bars
Width Tolerances

Specified Widths, in. (mm)	Width Tolerances, in. (mm)[A] Minus	Plus
Over 1 to 3 (25.4 to 76), incl	0.031 (0.79)	0.078 (1.98)
Over 3 to 5 (76 to 127), incl	0.062 (1.57)	0.125 (3.18)
Over 5 to 7 (127 to 178), incl	0.125 (3.18)	0.187 (4.75)
Over 7 to 9 (178 to 229), incl	0.187 (4.75)	0.312 (7.92)

Thickness Tolerances

Specified Widths, in. (mm)	Thickness Tolerances for Specified Thicknesses, in. (mm)									
	To 1 (25.4), incl		Over 1 to 3 (25.4 to 76), incl		Over 3 to 5 (76 to 127), incl		Over 5 to 7 (127 to 178), incl		Over 7 to 9 (178 to 229), incl	
	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus
Over 1 to 3 (25.4 to 76), incl	0.016 (0.41)	0.031 (0.79)	0.031 (0.79)	0.078 (1.98)	. . .	. . .	. . .	. . .	. . .	. . .
Over 3 to 5 (76 to 127), incl	0.031 (0.79)	0.062 (1.57)	0.047 (1.19)	0.094 (2.39)	0.062 (1.57)	0.125 (3.18)	. . .	. . .	. . .	. . .
Over 5 to 7 (127 to 178), incl	0.047 (1.19)	0.094 (2.39)	0.062 (1.57)	0.125 (3.18)	0.078 (1.98)	0.156 (3.96)	0.125 (3.18)	0.187 (4.75)	. . .	. . .
Over 7 to 9 (178 to 229), incl	0.062 (1.57)	0.125 (3.18)	0.078 (1.98)	0.156 (3.96)	0.094 (2.39)	0.187 (4.75)	0.156 (3.96)	0.219 (5.56)	0.187 (4.75)	0.312 (7.92)

[A] Out-of-square to be ¾ of total width tolerance maximum.

TABLE 14 Straightened Hot Rolled Annealed Bars or Cold Finished Bars
Straightness Tolerances

This table does not apply to flat bars having a width to thickness ratio of 6 to 1 or greater. Measurement is taken on the concave side of the bar with a straightedge. Bars are furnished to the following straightedge tolerances: Hot rolled bars:

$$\tfrac{1}{8}\text{ in. in any 5 ft, but may not exceed } 1/8\text{ in.} \times (\text{no. of ft in length}/5)$$

The foregoing formula applies also to bars under 5 ft in length, (3.2 mm in any 1.54 m, but may not exceed 3.2 mm × (no. of m in length/1.54). The foregoing formula applies also to bars under 1.54 m in length.)

$$\tfrac{1}{16}\text{ in. in any 5 ft, but may not exceed } 1/16\text{ in.} \times (\text{no. of ft in length}/5)$$

The foregoing formula applies also to bars under 5 ft in length, (1.6 mm in any 1.54 m, but may not exceed 1.6 mm × (no. of m in length/1.54). The foregoing formula applies also to bars under 1.54 m in length.)

TABLE 15 Hot Rolled or Forged Bars and Billets
Tolerances for Machine Cut Lengths

Specified Sizes Apply to Rounds, Squares, Hexagons, Octagons, and Width of Flats, in. (mm)	Tolerances for Specified Lengths, 14 ft (4.27 m) max, in. (mm)	
	Minus	Plus
To 9 (229), incl	0	⅜ (9.5)
Over 9 to 12 (229 to 305), incl	0	½ (12.7)
Over 12 to 18 (305 to 457), incl	0	¾ (19.1)
Over 18 (457)	0	1 (25.4)

TABLE 16 Drill Rod, Rounds, Polished or Ground
Size Tolerances

NOTE—Out-of-round to be ½ of total tolerance maximum.

Specified Size, in. (mm)	Standard Manufacturing Tolerance, in. (mm), plus and minus	Precision Tolerance, in. (mm), plus and minus
Up to 0.124 (3.15), incl	0.0003 (0.008)	0.0002 (0.005)
0.125 to 0.499 (3.18 to 12.7), incl	0.0005 (0.013)	0.00025 (0.006)
0.500 to 1.500 (12.7 to 38.1), incl	0.001 (0.025)	0.0005 (0.013)

TABLE 17 Drill Rod, Shapes Other than Rounds, Cold Drawn
Size Tolerances

Specified Size, in. (mm)	Tolerances, in. (mm), plus and minus
Up to ¼ (6.4), excl	0.0005 (0.013)
¼ to ¾ (6.4 to 19.0), excl	0.001 (0.025)
¾ to 1 (19.0 to 25.4), incl	0.0015 (0.038)

TABLE 18 Cold Drawn Bars
Rounds, Octagons, Quarter Octagons and Hexagons
Size Tolerances

NOTE—Out-of-round to be ½ of total tolerance maximum.

Specified Size, in. (mm)	Tolerance, in. (mm), plus and minus
¼ to ½ (6.4 to 12.7), excl	0.002 (0.05)
½ to 1 (12.7 to 25.4), excl	0.0025 (0.06)
1 to 2¾ (25.4 to 69.8), incl	0.003 (0.08)

TABLE 19 Cold Drawn Square and Flat Bars
Size Tolerances

NOTE—Out-of-square to be ½ of total tolerance maximum.

Specified Size, in. (mm)	Tolerance, in. (mm), plus and minus
¼ to ¾ (6.4 to 19.1), incl	0.002 (0.05)
Over ¾ to 1½ (19.1 to 38.1), incl	0.003 (0.08)
Over 1½ (38.1)	0.004 (0.10)

TABLE 20 Forgings, Disks, Rings and Rectangular Blocks

NOTE 1— Unmachined tool steel forgings are furnished to size and surface allowances for machining and tolerances over allowances. Experience indicates that the allowances and tolerances in the tabulation below are satisfactory for many applications. When width and thickness differ, each dimension carries its individual allowance and tolerance in accordance with the tabulation: also, the ID and OD take their respective allowances and tolerances.

NOTE 2—When forgings are ordered, the purchaser should state whether the sizes are the forged or the finished sizes. The minimum sizes ordered for forgings should be the finished sizes plus allowances for machining; and the ordered forged sizes are subject to applicable tolerances.

Finish Size, Diameter or Distance Between Parallel Faces or Both, in. (mm)	Allowances for Machining Over Finished Size[A], in. (mm)	Tolerances Over the Allowance[A], in. (mm)	
		Minus	Plus
Up to 3 (76), incl	⅛ (3.2)	0	⅛ (3.2)
Over 3 to 5 (76 to 127), incl	3⁄16 (4.8)	0	3⁄16 (4.8)
Over 5 to 7 (127 to 178), incl	5⁄16 (7.9)	0	5⁄16 (7.9)
Over 7 to 12 (178 to 305), incl	⅜ (9.5)	0	⅜ (9.5)
Over 12 to 17 (305 to 432), incl	½ (12.7)	0	½ (12.7)

[A] Ring forgings: For the outside diameter, use the same allowances and tolerances shown in the above tabulation; for the inside diameter, double the tolerances shown in the above tabulation.

TABLE 21 Hot Rolled Plates and Sheets
Tolerances for Width and Thickness

Specified Thickness, in. (mm)	Specified Width, in. (mm)			
	Up to 15 (381)		Over 15 (381)	
	All tolerances, over specified width and specified thickness, in. (mm), all plus			
	Width	Thickness	Width	Thickness
Up to 0.025, (0.64), incl	⅛ (3.2)	0.006 (0.15)	3⁄16 (4.8)	0.006 (0.15)
Over 0.025 to 0.065, (0.64 to 1.65), incl	⅛ (3.2)	0.008 (0.20)	3⁄16 (4.8)	0.008 (0.20)
Over 0.065 to 0.120, (1.65 to 3.05), incl	⅛ (3.2)	0.010 (0.25)	3⁄16 (4.8)	0.010 (0.25)
Over 0.120 to 0.1875, (3.05 to 4.76), incl	3⁄16 (4.8)	0.016 (0.41)	¼ (6.4)	0.016 (0.41)
Over 0.1875 to 0.250, (4.76 to 6.35), incl	3⁄16 (4.8)	0.018 (0.46)	¼ (6.4)	0.018 (0.46)

Specified Thickness, in. (mm)	Specified Width, in. (mm)	
	Over 12 (305)	
	All tolerances, over specified width and specified thickness, in. (mm), all plus	
	Width	Thickness
¼ to ½ (6.4 to 12.7), incl	¼ (6.4)	1⁄16 (1.6)
Over ½ to 2 (12.7 to 50.8), incl	¼ (6.4)	⅛ (3.2)
Over 2 (50.8)	¼ (6.4)	¼ (6.4)

TABLE 22 Machined Square and Flat Bars
Size, Straightness and Squareness Tolerances

NOTE—For closer tolerances and improved surface finish, bars with machined surfaces in standard bar lengths may be available. The bars are free of surface imperfections and decarburization. Surface finish in 125 µin. (3.18 µm) rms maximum. These bars are furnished oversize to allow for finishing after heat treating.

Size Tolerances			
Dimension	Oversize, in. (mm)	Tolerance on Oversized Dimension, in. (mm)	
		Minus	Plus
Thickness	0.015 (0.38)	0	0.020 (0.51)
Width	0.015 (0.38)	0	0.020 (0.51)

Straightness Tolerances

⅛ in. in any 5 ft, but may not exceed $1/6$ in. × (no. of ft in length/5)

The foregoing formula applies also to bars under 5 ft in length, (1.6 mm in any 1.54 m, but may not exceed 1.6 mm × (no. of m in length/1.54). The foregoing formula applies also to bars under 1.54 m in length.)

Squareness Tolerances

The width and thickness dimensions specified must be attainable when surfaces are subsequently made to be parallel and square. Closer limits of squareness may be agreed upon between seller and purchaser.

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, and order. Details of these supplementary requirements shall be agreed upon by the seller and the purchaser.

S1. Ultrasonic Quality

S1.1 Material shall be ultrasonically tested at appropriate stages of the manufacture to ensure the quality, when and as agreed upon between seller and purchaser. When required, it shall be performed in accordance with the latest issue of Practice A 388/A 388M.

S2. Cleanliness

S2.1 In special situations, such as where the surface finish of the part requires optimum polishing characteristics, the cleanliness of the steel shall be ascertained in accordance with the latest issue of Practice E 45. The permissible limits shall be agreed upon between seller and purchaser.

ANNEX

(Mandatory Information)

A1. MINIMUM REQUIREMENTS FOR HIGH-SPEED STEELS

A1.1 General

A1.1.1 High-speed steels are so named primarily because of their ability to machine materials at high cutting speeds. They are complex iron base alloys of carbon, chromium, vanadium, molybdenum or tungsten, or combinations thereof and in some cases substantial amounts of cobalt. The carbon and alloy contents are balanced at levels to give high attainable hardening response, high wear resistance, high resistance to the softening effect of heat, and good toughness for effective use in industrial cutting operations. Commercial practice has developed two groups of cutting materials: the recognized standard high-speed steel which serves almost all applications under mild to severe metal cutting conditions, and a smaller group of intermediate steels which are satisfactory for limited applications under mild to moderate metal-cutting conditions.

A1.2 Requirements

A1.2.1 The minimum requirements that must be met to be classed as a standard high-speed steel, and those for an intermediate high-speed steel, are listed in Table A1.1. To be acceptable for either group, an alloy must meet all of the requirements shown for that group.

TABLE A1.1 Requirements for High-Speed Steels

	Standard	Intermediate
Chemical Requirements:		
Minimum alloy content by major elements:		
Carbon	0.65	0.70
Chromium	3.50	3.25
Vanadium	0.80	0.80
Tungsten + 1.8 molybdenum	11.75	6.50
Minimum total alloy content based on tungsten equivalents (1/3 Cr + 6.2 V + W + 1.8 Mo):		
Grades containing less than 5 % cobalt	22.50	13.00
Grades containing 5 % or more cobalt	21.00	12.00
Hardening Response Requirements:		
Ability to be austenitized, and tempered at a temperature not less than 950°F with a fine grain structure (Snyder-Graff grain size 8 minimum) to	63 HRC	61 HRC

Designation: A 604 – 93 (Reapproved 2003)

Standard Test Method for Macroetch Testing of Consumable Electrode Remelted Steel Bars and Billets[1]

This standard is issued under the fixed designation A 604; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method[2] covers testing and inspection and is applicable to bars, billets, and blooms of carbon, alloy, and stainless steel which have been consumable electrode remelted.

1.2 For the purpose of this test method, the consumable electrode remelting process is defined as a steel refining method wherein single or multiple electrodes are remelted into a crucible producing an ingot which is superior to the original electrode by virtue of improved cleanliness or lower gas content or reduced chemical or nonmetallic segregation. See Appendix X1 and Appendix X2 for descriptions of applicable remelting processes.

1.3 This test method and the accompanying comparison macrographs[3] are generally applicable to steel bar and billet sizes up to 225 in.^{2} in transverse cross section.

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings[4]

2.2 *ASTM Adjuncts:*

ADJA0604

Adjunct to A604 Test Method for Macroetch Testing of Consumable Electrode Remelted Steel Bars and Billet[3]

3. Description of Macroetch Testing

3.1 Macroetch testing, as described herein, is a method for examining and rating transverse sections of bars and billets to describe certain conditions of macro segregation which are often characteristic of consumable electrode remelted materials. This test method is not intended to define major defects such as those described by Method E 381.

3.2 This test method employs the action of an acid or other corrosive agent to develop the characteristics of a suitably prepared specimen. After etching, the sections are compared visually, or at a very low magnification, if necessary for clarification of conditions, to standard plates describing the various conditions which may be found. Materials react differently to etching reagents because of variations in chemical composition, method of manufacture, heat treatment, and many other variables.

4. Application

4.1 When material is furnished subject to macroetch testing and inspection under this test method, the manufacturer and purchaser should be in agreement concerning the following:

4.1.1 The stage of manufacture at which the test shall be conducted,

4.1.2 The number and location of the sections to be tested,

4.1.3 The condition and preparation of the surface to be macroetched,

4.1.4 The etching reagent, temperature and time of etching, or degree of etching including any special techniques which must be used, and

4.1.5 The type and degree of conditions or combinations thereof that shall be considered acceptable or subject to metallurgical review.

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[1] This test method is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved April 10, 2003. Published July 2003. Originally approved in 1970. Last previous edition approved in 1998 as A 604 – 93(1998).

[2] ASTM Committee A01 gratefully acknowledges the help of the AISI Committee on General Metallurgy in preparing the appendix, assembling the macroetch photographs, and assisting with the text of this test method.

[3] A complete set of the 20 macrographs on glossy paper is available at nominal cost from ASTM Headquarters, 100 Barr Harbor Drive, W. Conshohocken, PA 19428. Request Adjunct ADJA0604.

[4] *Annual Book of ASTM Standards,* Vol 03.01.

5. Sample Preparation

5.1 Unless otherwise specified, the test shall be performed on specimens, usually ¼ to 1 in. thick, cut to reveal a transverse surface.

5.2 Disks for macroetch inspection may be removed from billets by a variety of methods including torch cutting, sawing, machining, or high-speed abrasive wheels. Adequate preparation of the surface for macroetching must completely remove the effects of torch cutting or high-speed abrasive wheels.

5.3 Due to the nature of the conditions to be detected, further surface preparation is usually required.

5.4 When such further preparation is performed, grinding, machining, or sanding should be carried out in such a manner as not to mask the structure.

5.5 The surface of the disk to be etched must be free of dirt, grease, or other foreign material which might impair the result of the test.

6. Etching Reagents

6.1 The etching response and appearance is dependent upon the type and temperature of the etching reagent and the time of immersion. These details must be established by agreement between manufacturer and purchaser.

6.2 For illustrative purposes some of the commonly used etching reagents are as follows:

6.2.1 *Hydrochloric Acid*—A solution of 1 part commercial concentrated hydrochloric acid (HCl, sp gr 1.19) and 1 part water is more generally used than any other macroetching reagent. This solution may be heated without significant change in concentration, and may be reused if it has not become excessively contaminated or weakened. Etching is generally done with the solution at a temperature of approximately 160°F.

6.2.2 *Hydrochloric Acid-Sulfuric Acid Mixture*—A mixture containing 50 % water, 38 % commercial concentrated HCl, and 12 % commercial concentrated sulfuric acid (H_2SO_4, sp gr 1.84) is sometimes used in place of the previously mentioned 50 % HCl solution. The statements in the previous paragraph regarding reuse and temperature of etchant are applicable to this reagent.

6.2.3 *Aqua Regia*—A solution consisting of 1 part concentrated nitric acid (HNO_3, sp gr 1.42) and 2 parts concentrated HCl is used on corrosion and heat-resistant materials of the 18 % chromium, 8 % nickel type and higher alloy types. This reagent is used at room temperature.

NOTE 1—The reagents in 6.2.1, 6.2.2, and 6.2.3 should be used under ventilating hoods or with some provision to remove the corrosive fumes.

6.2.4 *Nitric Acid*—This etchant consists of 5 % HNO_3 solution in alcohol or water, and is generally used at room temperature. When this reagent is used, the etch disk must have a smooth surface.

7. Etching Containers

7.1 Macroetching must be done in containers that are resistant to attack from the etching reagents. Caution must be exerted to prevent the occurrence of electrolytic couples which can cause uneven attacks and misleading results.

8. Preparation of Etched Surface and Examination

8.1 Upon completion of etching, surfaces of disks should be cleaned by either chemical or mechanical methods that do not affect the macroetch quality. Care should be taken to prevent rusting of the etched surface.

9. Interpretation of Conditions Found by Macroetching

9.1 Four distinct classes of conditions are defined and described under this method:

9.1.1 *Class 1: Freckles*—Circular or near-circular dark etching areas generally enriched with carbides and carbide-forming elements.

9.1.2 *Class 2: White Spots*—Light etching areas, having no definitive configuration or orientation which are generally reduced in carbide or carbide-forming elements.

9.1.3 *Class 3: Radial Segregation*—Radially or spirally oriented dark etching elongated areas occurring most frequently at mid-radius which are generally carbide enriched. This condition may be easily confused with freckles in some materials.

9.1.4 *Class 4: Ring Pattern*—One or more concentric rings evidenced by a differential in etch texture associated with minor composition gradients and ingot solidification.

9.2 Macroetch photographs show examples of each of the conditions revealed by macroetch testing, with five degrees of severity, identified as A, B, C, D, and E for each condition. Degree A exhibits the minimum occurrence of each condition detectable by visual examination of the etched surface, while degrees B, C, D, and E represent increasing severity of occurrence.

9.3 For each condition, or combination of conditions, ratings shall be obtained by comparing each macroetched section with the standard photographs. Bar or billet sections to 225 in.^{2} cross-sectional area may be rated against these standards. Larger sizes may be rated by agreement between manufacturer and purchaser, but caution must be exercised in interpretation of such results. Figs. 1-20 have been reduced 44 % in area from the standard photographs.

9.4 If the appearance of a given condition does not exactly match one of the five standard photographs, it shall be assigned the rating of the standard that it most nearly matches.

9.5 No standards for acceptance are stated or implied in these illustrations. The extent to which each condition may be permissible varies with the intended application, and such standards should be stated in the applicable product specification, or may be the subject of negotiation between manufacturer and purchaser.

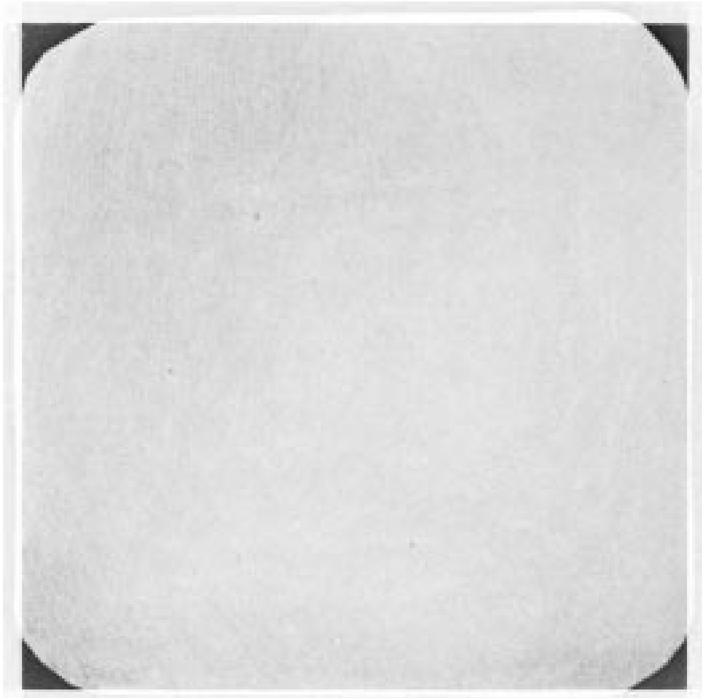

FIG. 1 Class 1—Freckles—Severity A

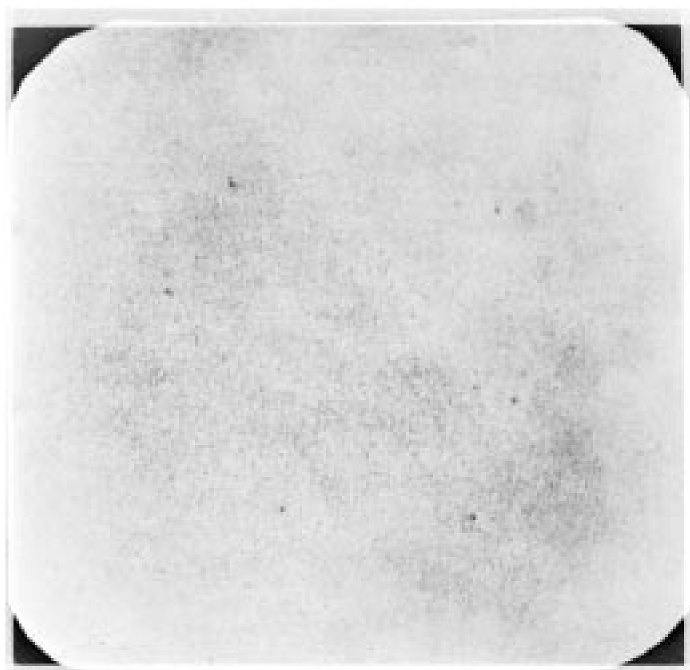

FIG. 2 Class 1—Freckles—Severity B

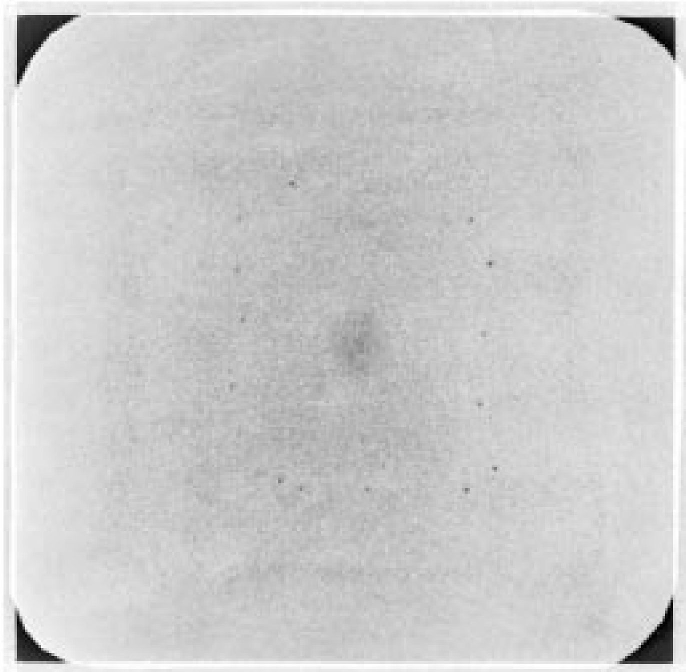

FIG. 3 Class 1—Freckles—Severity C

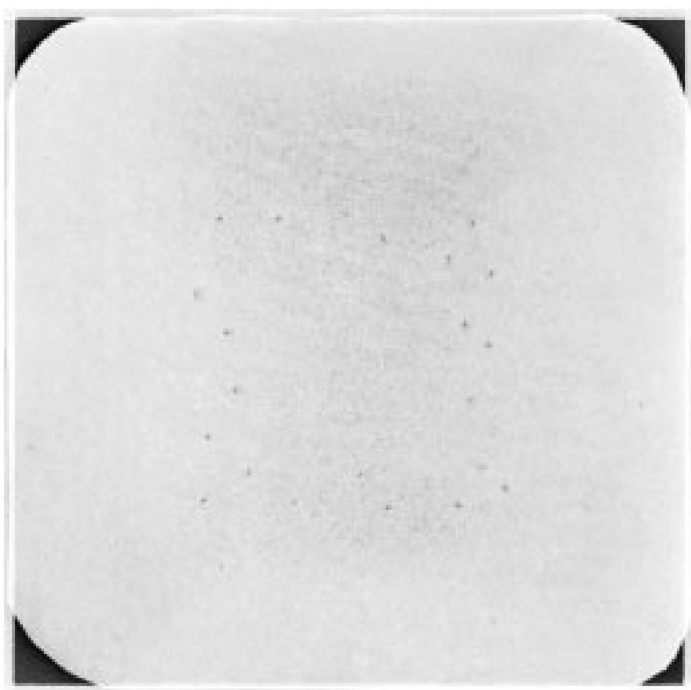

FIG. 4 Class 1—Freckles—Severity D

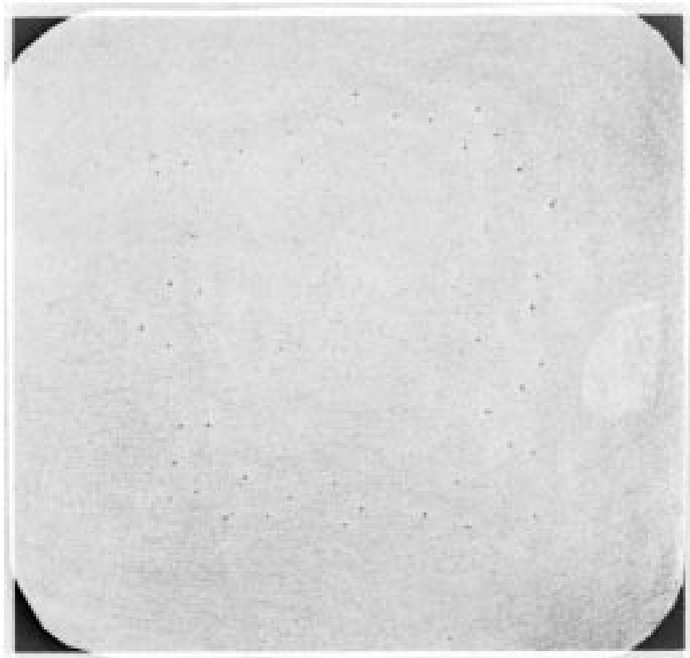

FIG. 5 Class 1—Freckles—Severity E

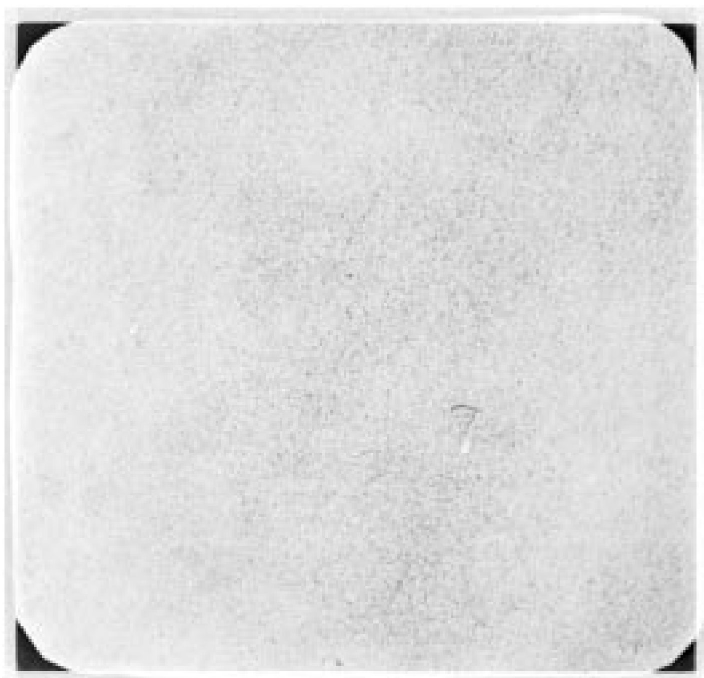

FIG. 6 Class 2—White Spots—Severity A

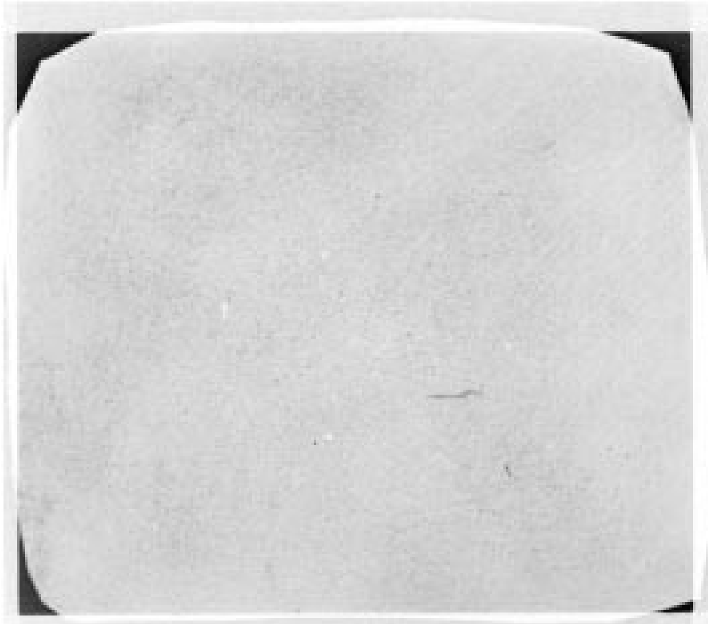

FIG. 7 Class 2—White Spots—Severity B

FIG. 8 Class 2—White Spots—Severity C

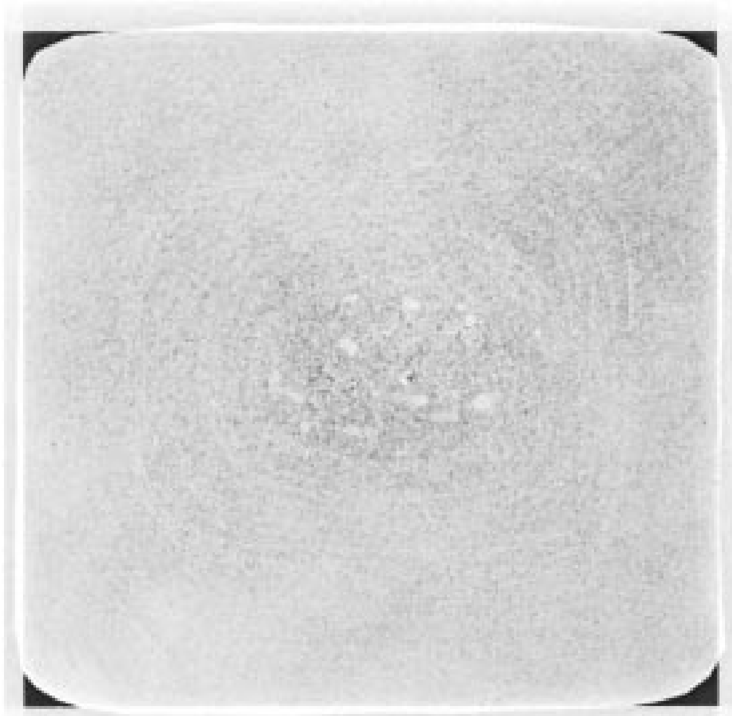

FIG. 9 Class 2—White Spots—Severity D

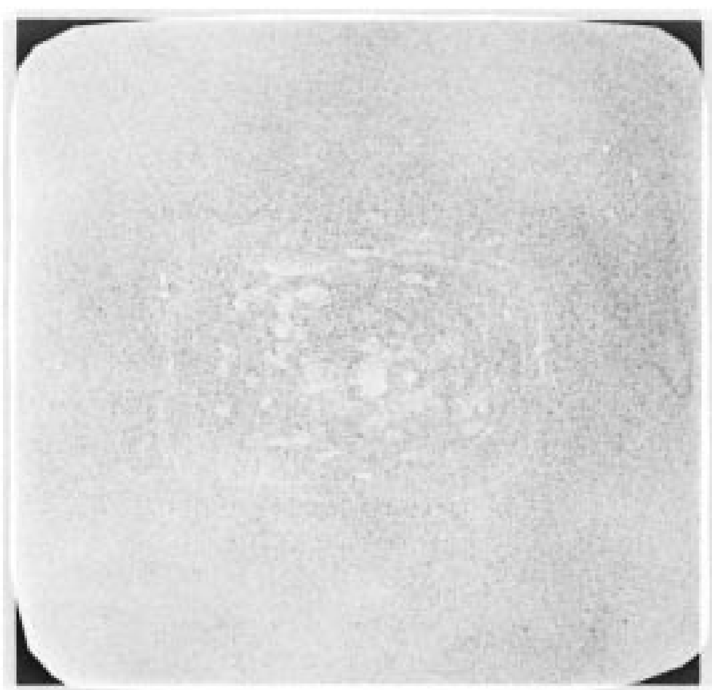

FIG. 10 Class 2—White Spots—Severity E

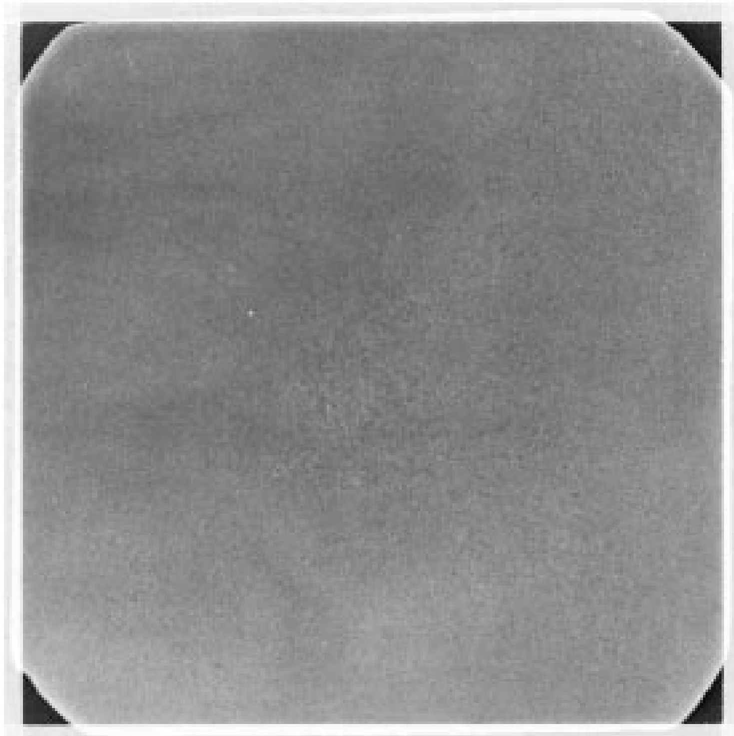

FIG. 11 Class 3—Radial Segregation—Severity A

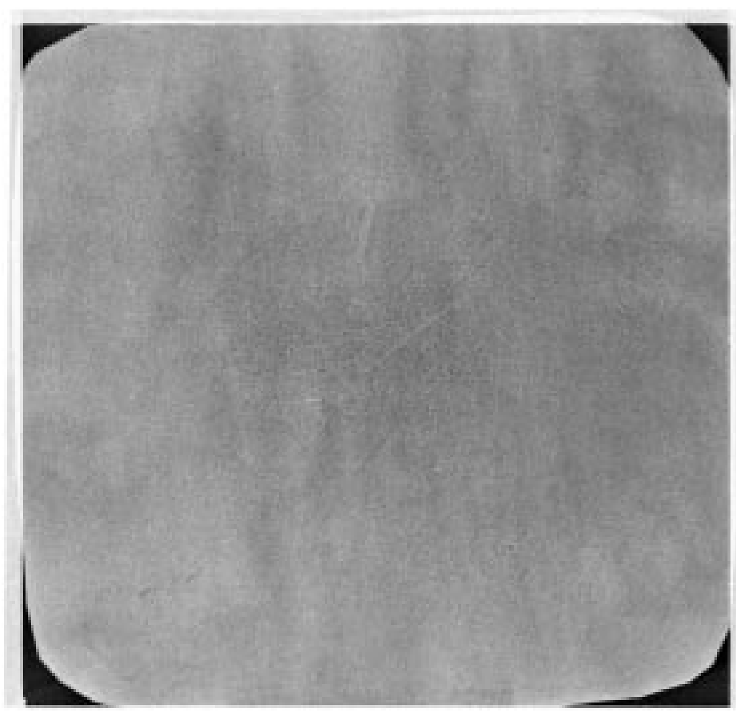

FIG. 12 Class 3—Radial Segregation—Severity B

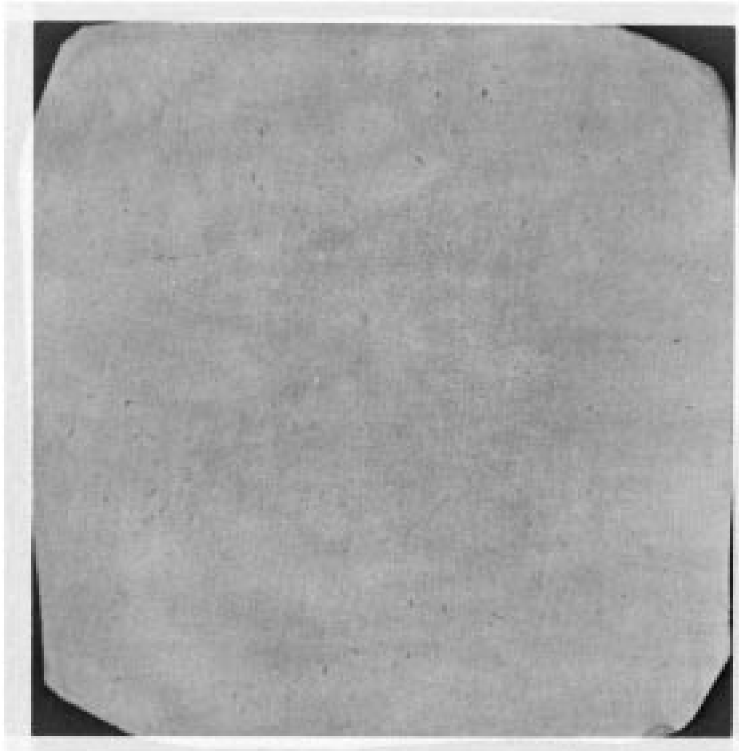

FIG. 13 Class 3—Radial Segregation—Severity C

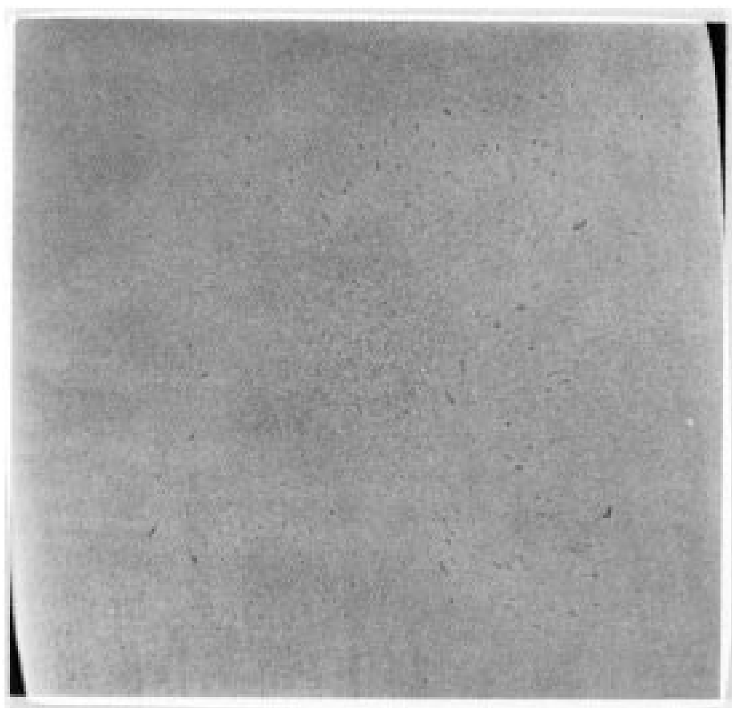

FIG. 14 Class 3—Radial Segregation—Severity D

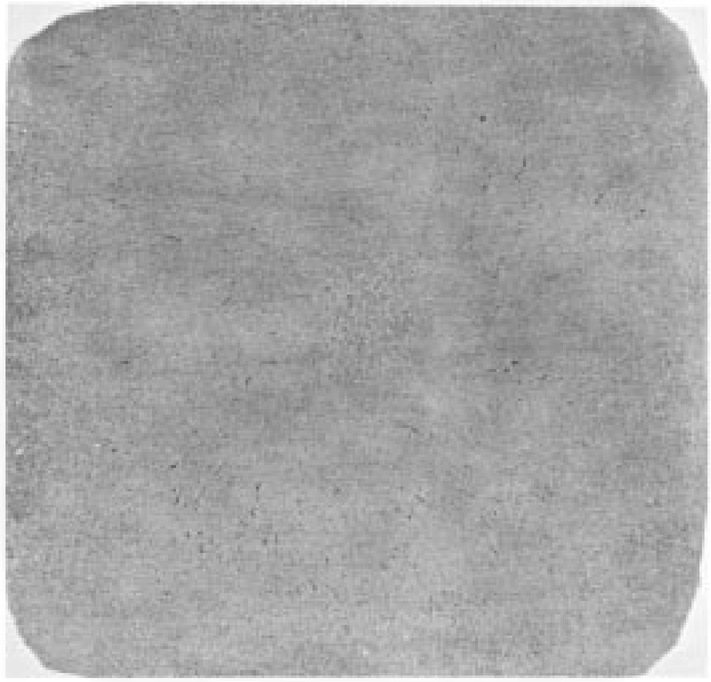

FIG. 15 Class 3—Radial Segregation—Severity E

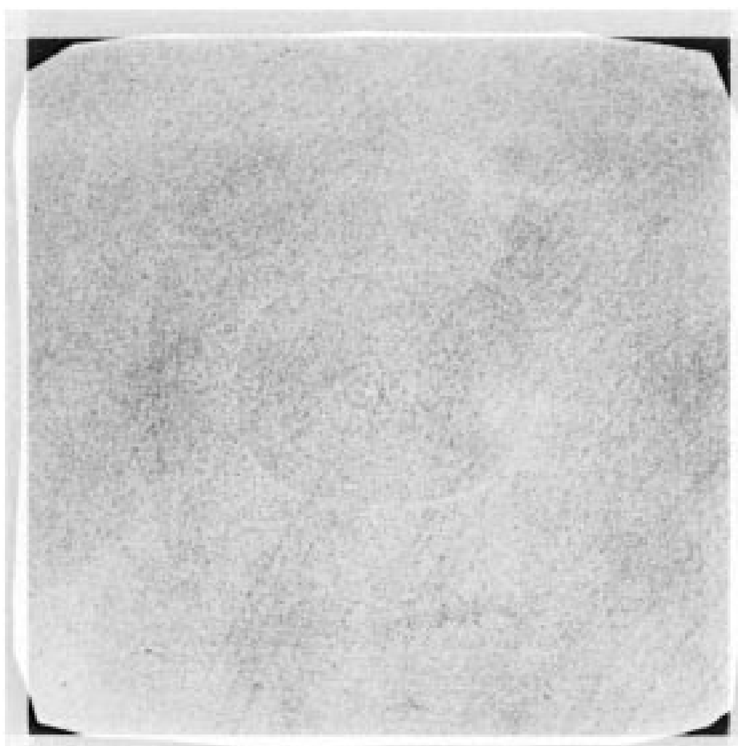

FIG. 16 Class 4—Ring Pattern—Severity A

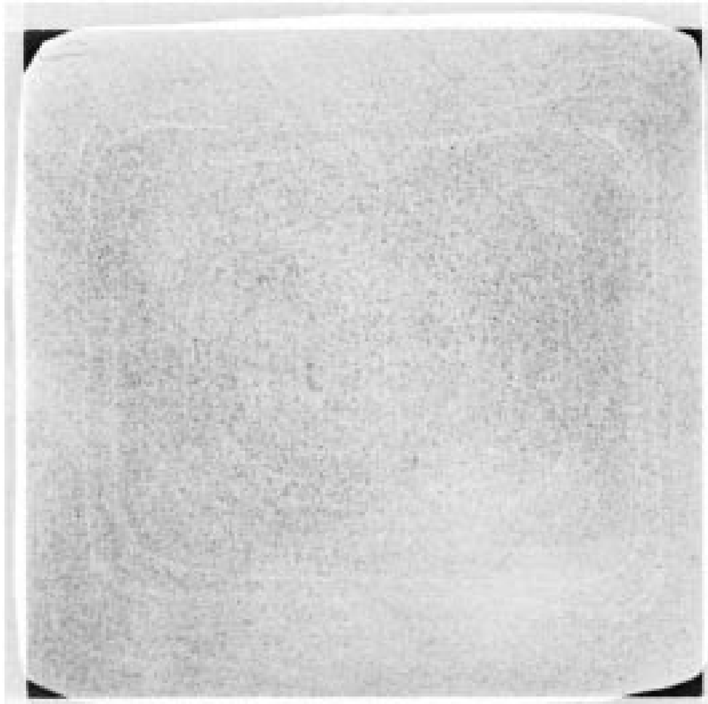

FIG. 17 Class 4—Ring Pattern—Severity B

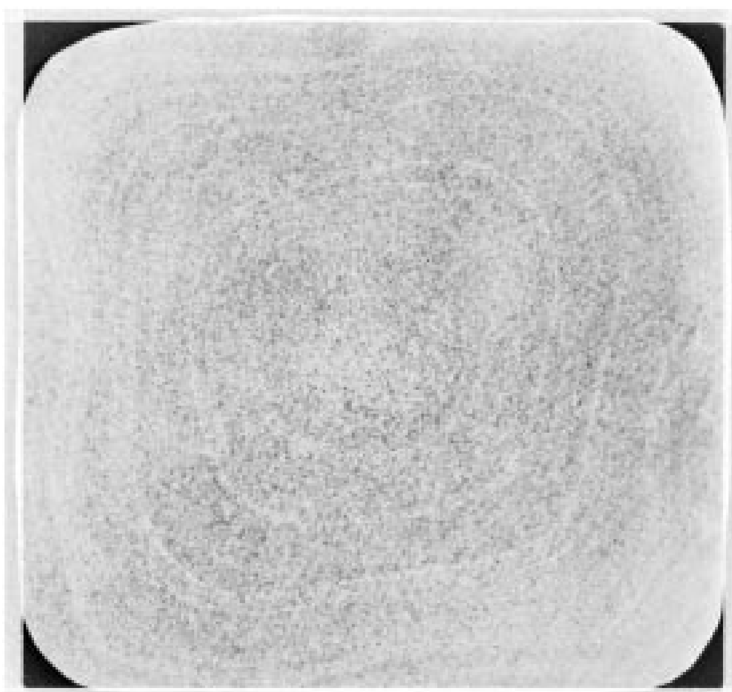

FIG. 18 Class 4—Ring Pattern—Severity C

FIG. 19 Class 4—Ring Pattern—Severity D

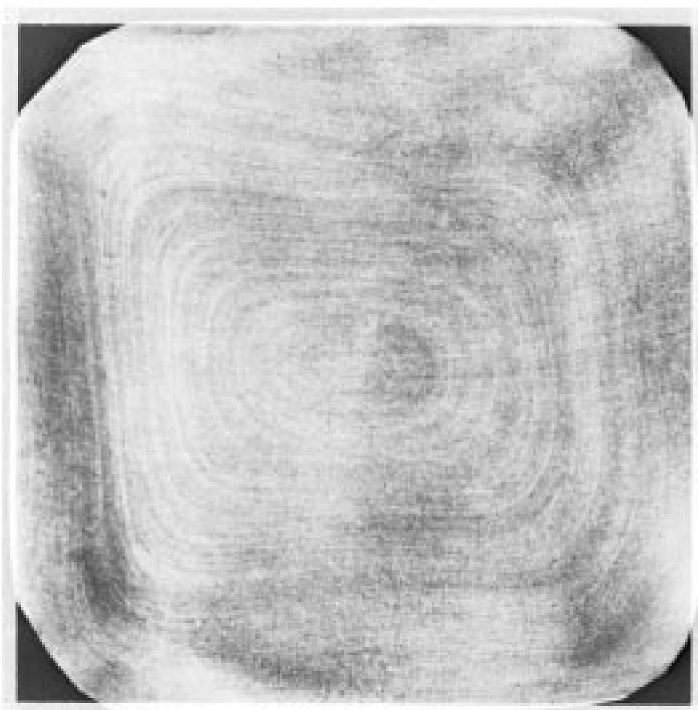

FIG. 20 Class 4—Ring Pattern—Severity E

APPENDIXES

(Nonmandatory Information)

X1. CONSUMABLE ELECTRODE VACUUM MELTING

X1.1 Process Description

X1.1.1 Consumable electrode vacuum melting (CEVM) of steel has grown from a laboratory process to a major production operation capable of producing ingots in certain grades up to 60 in. in diameter, weighing 50 tons. The available ingot sizes and weights vary from grade to grade, depending upon their complexity and alloy content. Currently, a significant proportion of the ultra-high-strength steels for aircraft and missiles, bearing steels for aircraft engines, and other speciality alloys are being consumable electrode vacuum melted.

X1.1.2 The consumable electrode vacuum melting process is diagramed in Fig. X1.1. To start the melting operation, an electrode produced from conventional air-melted or vacuum-processed steel is suspended in the consumable electrode vacuum melting furnace. The system is evacuated and an arc is struck to a bottom starting pad. Molten metal is transferred across the arc from the electrode to the solidifying ingot contained within the water-cooled copper crucible. As melting proceeds and the ingot solidifies progressively upward, the electrode is fed downward to maintain the proper arc length. As the metal droplets pass through the arc, they are exposed to this vacuum at extremely high arc temperatures, producing extensive degassification, as well as some breakdown and dispersion of inclusions. Due to the rapid cooling provided by the copper crucible, only a portion of the ingot is molten at a time and solidification proceeds in a continuously progressive manner.

X1.2 Product Characteristics

X1.2.1 Essentially, the CEVM operation changes the properties of steel in three ways:

X1.2.1.1 By reducing gas content.

X1.2.1.2 By improving microcleanliness. The nonmetallic inclusion content is rated in a manner similar to that used for air melt except that the level is generally lower and a different chart is used.

X1.2.1.3 By changing the mode of solidification from that of the traditional static-cast ingot to a progressive solidification process, involving high heat input from an arc and rapid heat extraction by the water-cooled copper crucible.

X1.2.2 Depending upon the grade of steel and the application under consideration, consumable electrode vacuum melting is reported to significantly improve one or more of the following properties: transverse ductility in aircraft forging billets, fatigue strength or endurance limit, notched tensile strength or fracture toughness, Charpy V-notch impact strength, stress rupture, and creep strength. Furthermore, hot workability and yield of some grades are significantly improved. The CEVM process has also made possible the

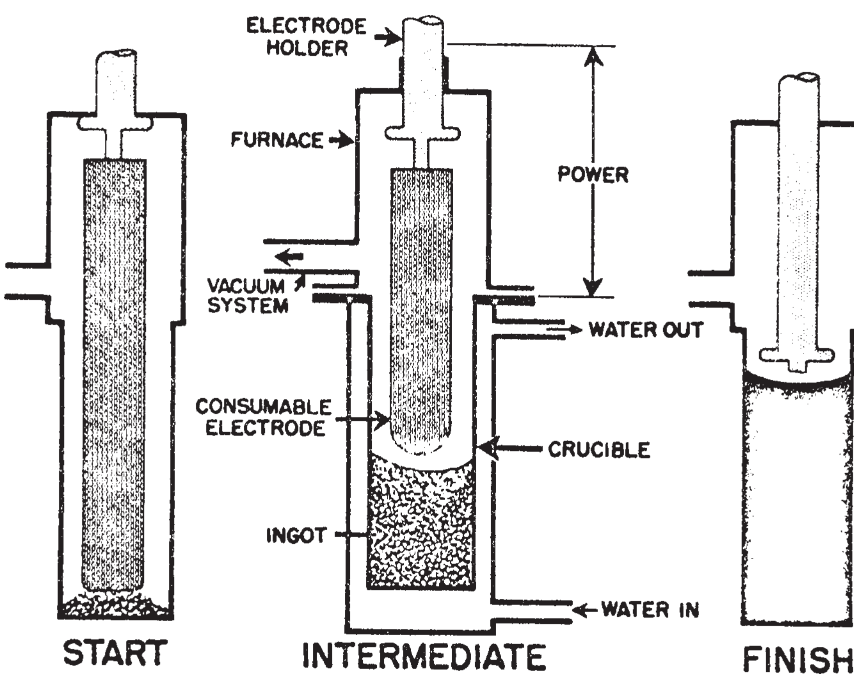

FIG. X1.1 Consumable Electrode Vacuum Melting Furnace development of new alloys for extremely high-strength or high-temperature applications that did not exhibit satisfactory properties when melted by other methods.

X1.3 Macrotech Characteristics

X1.3.1 Consumable electrode vacuum-melted steels and alloys may contain discontinuities peculiar to this process which are disclosed upon macroetch examination.

X2. ELECTROSLAG REMELTING

X2.1 Process Description

X2.1.1 Electroslag remelting (ESR) was first introduced in an American patent by Hopkins, but most of the published work has been done by Russian engineers. The process has been shown to reduce inclusions, similar to vacuum-arc remelting, with the additional benefit of reducing sulfur content in critical alloys for aerospace and nuclear applications. Many variations of processing parameters, equipment design, ingot sizes and shapes are used.

X2.1.2 The ESR process consists of remelting a consumable electrode through a bath of molten slag using the electrical resistance of the slag to provide the required heat input. The slag composition will vary with the type of alloy and the processor's objectives. Single or three-phase ac or dc current may be applied. Water-cooled ingot molds may be square, round, or designed to produce rough tube rounds. Stationary molds or molds that can be raised as the ingot solidifies are used. Starting the process may be done with cold slag and starter chips or molten slag prepared in a small arc furnace. A diagram of this process is shown in Fig. X2.1.

X2.2 Product Characteristics

X2.2.1 The ingot surface is protected by a film of slag that solidifies on the ingot as it cools, providing an improved surface.

X2.2.2 Sulfur content may be reduced substantially to improve workability.

X2.2.3 A significant drop in oxide inclusions may be obtained.

X2.2.4 Improved uniformity occurs due to the solidification process.

X2.2.5 Little, if any, loss in alloying elements occurs with appropriate processing parameters.

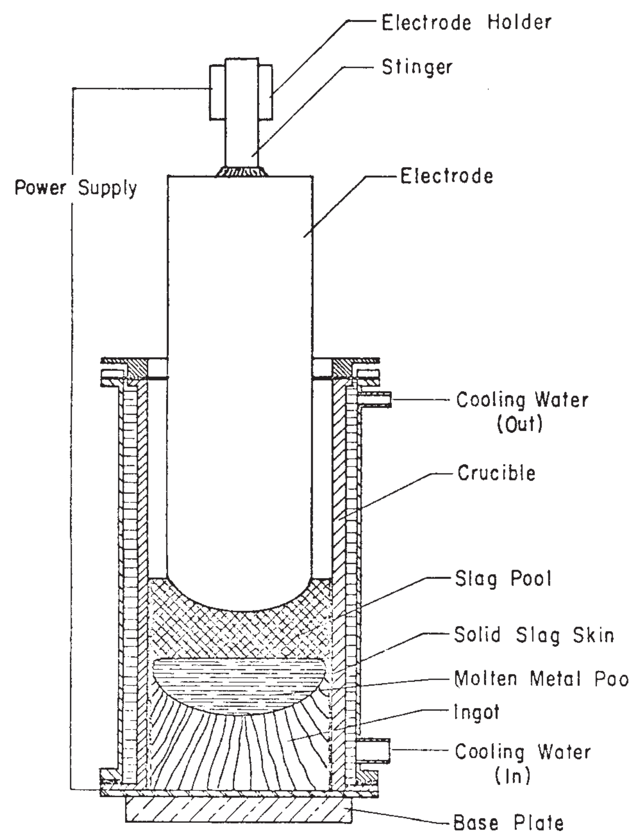

FIG. X2.1 Schematic of ESR Melting Process

X2.3 Macrotech Characteristics

X2.3.1 ESR steels and alloys may contain discontinuities peculiar to this process which are disclosed upon macroetch examination

Designation: A 646 – 95 (Reapproved 1999)

Standard Specification for Premium Quality Alloy Steel Blooms and Billets for Aircraft and Aerospace Forgings[1]

This standard is issued under the fixed designation A 646; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers premium quality alloy steel semifinished rolled or forged blooms and billets for reforging into critical parts such as aircraft landing-gear forgings.

1.2 Blooms and billets, hereinafter referred to as blooms, are semifinished steel products, hot rolled or forged to approximate cross-sectional dimensions. Blooms may be square, round, hexagonal, octagonal, or rectangular in section. For the purposes of this specification, minimum bloom section size will be 16 in.^{2} (103 cm^2).

1.3 This specification covers two basic classifications of steel:

1.3.1 *Class I*—Vacuum-induction melted or consumable-electrode vacuum melted, or other suitable processes which will satisfy the quality requirements of this specification.

1.3.2 *Class II*—Air-melted vacuum degassed.

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 255 Test Method of End-Quench Test for Hardenability of Steel[2]

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings[2]

A 604 Test Method for Macroetch Testing of Consumable Electrode Remelted Steel Bars and Billets[2]

E 30 Test Methods for Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron and Wrought Iron[3]

E 45 Test Methods for Determining the Inclusion Content of Steel[4]

E 114 Practice for Ultrasonic Pulse-Echo Straight-Beam Testing by the Contact Method[5]

E 127 Practice for Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks[5]

E 214 Practice for Immersed Ultrasonic Examination by the Reflection Method Using Pulsed Longitudinal Waves[5]

E 350 Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron[3]

E 381 Method for Macroetch Testing, Inspection, and Rating Steel Products, Comprising Bars, Billets, Blooms, and Forgings[4]

2.2 *AMS Standards:*[6]

AMS 2300 Premium Quality Steel Cleanliness, Magnetic Particle, and

AMS 2301 Aircraft Quality Steel Cleanliness.

2.3 *Government Standard:*[7]

MIL-STD-430A Macrograph Standards for Steel Bars, Billets, and Blooms

3. Terminology

3.1 *Definitions:*

3.1.1 *air-melted vacuum-degassed steel*—arc- or induction-furnace-melted steel that is vacuum treated immediately prior to or during the operation of pouring the ingot.

3.1.2 *consumable-electrode vacuum-remelted steel*—metal that has been remelted into a crucible in vacuum from single or multiple electrodes.

3.1.3 *electroslag-melted steel*—metal that has been remelted into a crucible from single or multiple electrodes utilizing an electrical discharge through molten slag as a source of heat.

3.1.4 *heat*—for the purpose of this specification, if consumable electrode remelting is employed, all of the remelted ingots produced one parent arc- or induction-melted heat.

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 03.05.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] *Annual Book of ASTM Standards*, Vol 03.03.

[6] Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

[7] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

3.1.5 *vacuum induction melted steel*—metal that has been melted, refined, and poured from a furnace operating in vacuum.

4. Ordering Information

4.1 When this specification is to be applied to an inquiry, contract, or order, the purchaser shall so state, and shall also furnish the following information:

4.1.1 Class designation (see 1.3),

4.1.2 Quality level (Table 1), grade designation (Table 2), or detailed chemistry (Table 3) for nonstandard grades,

4.1.3 Desired billet or bloom size,

4.1.4 Weight or quantity and length,

4.1.5 Minimum forging reduction required if ordered size exceeds 225 in.^{2} (1450 cm^2) (see 5.2.2),

4.1.6 Annealing, if required (see 5.3.2),

4.1.7 Macroetch standards of acceptance (see 7.1),

4.1.8 Microcleanliness standards of acceptance (see 7.2),

4.1.9 Ultrasonic quality level required (see 7.3.7.1),

4.1.9.1 Also any further restrictions on ultrasonic, such as transducer type and size, whether contact or immersion preferred, level of reportable discontinuities and any special surface finish requirements.

4.1.10 Hardenability standards of acceptance (see 8.1), and

4.1.11 Any supplementary requirements desired.

5. Manufacture

5.1 *Melting Practice*:

5.1.1 Class I material shall be manufactured by the vacuum-induction-melting process or by the consumably-electrode vacuum-melting process. By agreement other processes such as electroslag or electron-beam melting may be considered acceptable.

5.1.2 Class II material shall be manufactured by an electric-furnace vacuum-degassed process.

5.2 *Hot-Working Procedure*:

5.2.1 Blooms may be either hot rolled or forged.

5.2.2 Blooms having cross-sectional areas ranging from 16 to 225 in.^{2} (103 to 1450 cm^2) when made from air-melt ingots shall have at least 2 to 1 reduction of area from ingot to bloom. On blooms exceeding 225 in.^{2}, forging reduction requirements shall be by agreement. Ingot-to-final forging reduction is not included in this requirement.

5.3 *Heat Treatment*:

5.3.1 Unless otherwise specified all material purchased to this specification will be furnished in the untreated condition. In this condition some grades may not be soft enough for cold sawing.

TABLE 1 Maximum Permissible Discontinuities

NOTE 1—See 7.3.

Quality Level	Response, in. (mm)		Stringers, Length in. (mm)
	Single Discontinuities	Multiple Discontinuities	
AA	3⁄64 (1.2)	2⁄64 (0.8)	2⁄64 –1⁄2 (0.8–12.7)
A	5⁄64 (2.0)	3⁄64 (1.2)	3⁄64 –1 (1.2–25.4)
B	8⁄64 (3.2)	5⁄64 (2.0)	5⁄64 –1 (2.0–25.4)
C	12⁄64 (4.8)	8⁄64 (3.2)	8⁄64 –1 (3.2–25.4)

5.3.2 When specified, the material may be ordered annealed or normalized and tempered to a maximum Brinell Hardness, as specified in Table 2 or by agreement.

5.3.3 Material shall be furnished in condition to withstand, for an indefinite time, exposure to all climatic conditions without developing any external or internal cracks. The method of cooling or of treatment before shipment shall be optional with the manufacturer, but he shall be responsible (in the same manner as for discontinuities disclosed after delivery) for cracks which may develop before material is subjected to reheating. When any other specific treatment or conditioning of material is specified by the purchaser, the manufacturer shall be responsible only for carrying out those specific operations.

6. Chemical Requirements

6.1 *General Requirements*:

6.1.1 Table 2 lists 21 standard grades of alloy steel which are currently produced in premium quality; however, it is not the intent of this specification to restrict application only to the materials listed in Table 2.

6.1.2 When a standard grade is ordered, the analysis shall conform to the requirements as to chemical composition prescribed in Table 2 for the respective grades.

6.1.3 The steel when ordered to other than standard analysis shall conform to the requirements as to chemical ranges and limits prescribed in Table 3.

6.1.4 Small quantities of certain elements are present in alloy steels which are neither specified nor required. These elements are residual and may be present up to the following amounts: copper, 0.35 %; nickel, 0.25 %; chromium, 0.20 %; and molybdenum, 0.06 %.

6.2 *Heat Analysis*:

6.2.1 Each heat of steel shall be analyzed by the manufacturer to determine the percentage of elements prescribed in Table 2. This analysis shall be made on a sample taken during the pouring of the heat, except that in the event mechanical difficulties prevent obtaining samples from the ladle, that may be obtained from suitable portions of the ingots or product.

6.2.2 If consumable-electrode remelting is employed, the analysis of each resulting ingot shall conform to the requirements of Table 2. Samples for these analyses shall be removed from the top end of the ingot after adequate discard at any area midway between the center and surface of the ingot or bloom. One complete analysis from the master heat or from one remelt ingot plus carbon and manganese analysis from each remelt ingot are required.

6.3 *Product Analysis*:

6.3.1 Analysis may be made by the purchaser from material representing each heat or lot. The chemical composition thus determined shall not vary from the ranges or limits as specified in Table 2 or Table 3 by more than the amount specified in Table 4, unless otherwise agreed.

6.3.2 Samples for product analyses shall be taken from a location midway between center and surface of the bloom.

6.4 *Method of Analysis*—Test Methods E 30 and E 350 shall be used for referee purposes.

TABLE 2 Chemical and Hardness Requirements

AISI or Proprietary Name Grade	Grade No.	Composition, % Carbon	Manganese	Phosphorus	Sulfur	Silicon	Nickel	Chromium	Molybdenum	Vanadium	Others	Maximum Annealed Brinell Hardness
3310	1	0.08–0.13	0.45–0.60	0.025 max	0.025 max	0.20–0.35	3.25–3.75	1.40–1.75	. . .	. . .	. . .	262
9310	2	0.08–0.13	0.45–0.65	0.025 max	0.025 max	0.20–0.35	3.00–3.50	1.00–1.40	0.08–0.15	. . .	. . .	262
4620	3	0.17–0.22	0.45–0.65	0.025 max	0.025 max	0.20–0.35	1.65–2.00	. . .	0.20–0.30	. . .	. . .	229
8620	4	0.18–0.23	0.70–0.90	0.025 max	0.025 max	0.20–0.35	0.40–0.70	0.40–0.60	0.15–0.25	. . .	. . .	229
4330 Mod.	5	0.28–0.33	0.75–1.00	0.025 max	0.025 max	0.20–0.35	1.65–2.00	0.70–0.95	0.35–0.50	0.05–0.10	. . .	285
4335 Mod.	6	0.33–0.38	0.60–0.90	0.025 max	0.025 max	0.40–0.60	1.65–2.00	0.65–0.90	0.30–0.40	0.17–0.23	. . .	285
4340	7	0.38–0.43	0.65–0.85	0.025 max	0.025 max	0.20–0.35	1.65–2.00	0.70–0.90	0.20–0.30	. . .	. . .	285
300 M	8	0.38–0.43	0.65–0.90	0.012 max	0.012 max	1.45–1.80	1.65–2.00	0.70–0.95	0.35–0.45	0.05–0.10	. . .	285
D6AC	9	0.45–0.50	0.60–0.90	0.010 max	0.010 max	0.15–0.30	0.40–0.70	0.90–1.20	0.90–1.10	0.08–0.15	. . .	285
H-11	10	0.38–0.43	0.20–0.40	0.015 max	0.015 max	0.80–1.00	. . .	4.75–5.25	1.20–1.40	0.40–0.60	. . .	235
4130	11	0.28–0.33	0.40–0.60	0.025 max	0.025 max	0.20–0.35	. . .	0.80–1.10	0.15–0.25	. . .	. . .	229
4140	12	0.38–0.43	0.75–1.00	0.025 max	0.025 max	0.20–0.35	. . .	0.80–1.10	0.15–0.25	. . .	. . .	235
98BV40	13	0.40–0.46	0.75–1.00	0.025 max	0.025 max	0.50–0.80	0.60–0.90	0.80–1.05	0.45–0.60	0.01–0.06	0.0005 min, Boron	285
6150	14	0.48–0.53	0.70–0.90	0.025 max	0.025 max	0.20–0.35	. . .	0.80–1.10	. . .	0.15 min	. . .	235
52100	15	0.98–1.10	0.25–0.45	0.025 max	0.010 max	0.20–0.35	. . .	1.30–1.60	. . .	. . .	. . .	302
HP 9-4-20	16	0.17–0.23	0.20–0.40	0.010 max	0.010 max	0.10 max	8.5–9.5	0.65–0.85	0.90–1.10	0.06–0.12	Co 4.25–4.75	341
HP 9-4-30	17	0.29–0.34	0.10–0.35	0.010 max	0.010 max	0.10 max	7.0–8.0	0.90–1.10	0.90–1.10	0.06–0.12	Co 4.25–4.75	341
Marage 200	18	0.03 max	0.10 max	0.010 max	0.010 max	0.10 max	17.0–19.0	. . .	3.0–3.50	. . .	Co 8.0–9.0; Ti 0.10–0.25; A1 0.05–0.105; B, Zr, Ca added	321
Marage 250	19	0.03 max	0.10 max	0.010 max	0.010 max	0.10 max	17.0–19.0	. . .	4.6–5.2	. . .	Co 7.0–8.5; Ti 0.30–0.50; A1 0.05–0.15; B, Zr, Ca added	321
Marage 300	20	0.03 max	0.10 max	0.010 max	0.010 max	0.10 max	18.0–19.0	. . .	4.7–5.2	. . .	Co 8.5–9.5; Ti 0.50–0.80; A1 0.05–0.15; B, Zr, Ca added	321
Nit. 135	21	0.38–0.43	0.50–0.70	0.025 max	0.025 max	0.20–0.40	. . .	1.40–1.80	0.30–0.40	. . .	A1 0.95–1.30	285

7. Quality Evaluation Tests

7.1 *Macroetch*—Macroetch inspection shall be required for all material furnished to this specification. Samples representing the top and bottom of each ingot shall be examined. Macroetching shall be performed in accordance with Method E 381 and Test Method A 604, as applicable. Standards of acceptance shall be by agreement.

7.2 *Microcleanliness*—All material furnished to this specification shall be inspected for microcleanliness. At least one sample shall be removed from a location midway between the center and outside surface representing the top and bottom of the first and last ingots of each heat. The specimens shall be prepared and rated by the procedure described in Method A of Test Methods E 45. The polished face shall be longitudinal to the direction of maximum working. All specimens shall be prepared and rated in accordance with Test Methods E 45, using Method D (Modified JK Chart) for Class I steel and Method A (JK Chart) for Class II steel. Standards of acceptance shall be by agreement.

7.3 *Nondestructive Testing, Ultrasonic Inspection*:

7.3.1 *General*:

7.3.1.1 All material ordered to this specification shall be ultrasonic inspected unless otherwise specified. Inspection may be performed by either the immersion or the contact method providing that the manufacturer can ensure adequate resolution of the applicable reference standards with the chosen method.

7.3.1.2 The usage of reference blocks containing flat-bottomed holes for calibration is the preferred method for evaluation of discontinunity size up to billet cross-sectional dimensions of approximately 12 in. (305 mm). With larger sizes, it is recognized that reference block fabrication becomes difficult and in general a back reflection method of calibration can be used as an alternative as referenced in 7.3.8.3.

7.3.2 *Apparatus*—An ultrasonic, pulsed, reflection type of instrument shall be used for this inspection. The system shall have a minimum capability for testing at frequencies of 1 to 5 MHz, and shall provide linear presentation, within ±5 % up to at least 75 % of full screen height.

7.3.2.1 *Voltage Regulation*—The response of equipment to line voltage variations shall be such that no change occurs in signal amplitude for normal line voltage variations.

7.3.3 *Immersion Inspection Procedure*— This method is recommended for material where the cross-sectional dimension to be inspected is less than approximately 8 in. (203 mm). Material inspected by the immersion method shall be performed in accordance with the procedure outlined in Practice E 214.

TABLE 3 Chemical Ranges and Limits for Alloy Steels Other Than Standard

Element	When Maximum of Specified Range is, percent:	Range, percent	
Carbon	To 0.25, incl	0.05[A]	0.08[B]
	Over 0.25 to 0.40, incl	0.06[A]	0.09[B]
	Over 0.40 to 0.55, incl	0.07[A]	0.09[B]
	Over 0.55 to 0.70, incl	0.09[A]	0.11[B]
	Over 0.70 to 0.95, incl	0.11[A]	0.14[B]
	Over 0.95 to 1.35, incl	0.14[A]	0.17[B]
Manganese	To 0.45, incl	0.15	
	Over 0.45 to 0.80, incl	0.20	
	Over 0.80 to 1.15, incl	0.25	
	Over 1.15 to 1.65, incl	0.30	
	Over 1.65 to 2.10, incl	0.35	
Phosphorus		0.025 max	
Sulfur		0.025 max	
Silicon	To 0.15, incl	0.08	
	Over 0.15 to 0.20, incl	0.10	
	Over 0.20 to 0.35, incl	0.15	
	Over 0.35 to 0.60, incl	0.20	
	Over 0.60 to 1.00, incl	0.30	
	Over 1.00 to 2.20, incl	0.35	
Nickel	To 0.50, incl	0.20	
	Over 0.50 to 1.50, incl	0.30	
	Over 1.50 to 2.00, incl	0.35	
	Over 2.00 to 3.00, incl	0.40	
	Over 3.00 to 5.30, incl	0.50	
	Over 5.30 to 10.00, incl	1.00	
	Over 1.75 to 3.99, incl		
Chromium	To 0.40, incl	0.15	
	Over 0.40 to 0.80, incl	0.20	
	Over 0.80 to 1.05, incl	0.25	
	Over 1.05 to 1.25, incl	0.30	
	Over 1.25 to 1.75, incl	0.40	
	Over 1.75 to 3.99, incl	0.50	
Molybdenum	To 0.10, incl	0.05	
	Over 0.10 to 0.20, incl	0.07	
	Over 0.20 to 0.50, incl	0.10	
	Over 0.50 to 0.80, incl	0.15	
	Over 0.80 to 1.15, incl	0.20	
Tungsten	To 0.50, incl	0.20	
	Over 0.50 to 1.00, incl	0.30	
	Over 1.00 to 2.00, incl	0.50	
	Over 2.00 to 4.00, incl	0.60	
Vanadium	To 0.25, incl	0.05	
	Over 0.25 to 0.50, incl	0.10	

[A] These ranges for carbon apply to steel not exceeding 200 in.^{2}(1290 cm^2) in cross-sectional area.

[B] These ranges for carbon apply to steel exceeding 200 in.^{2} in cross-sectional area.

7.3.4 *Contact Inspection Procedure*—Material inspected by the contact method shall be performed in accordance with the procedure outlined in Practice E 114 or A 388/A 388M.

7.3.5 *Scanning*—Blooms shall be inspected using the straight-beam (longitudinal-wave) technique. Blooms having parallel surfaces shall be inspected from two adjacent sides, excluding ends. Cylindrical blooms shall be inspected a minimum of 180° around the circumference, with the beam directed along the radius, noting that an axial scan from the end faces is not normally applicable.

7.3.6 *Recalibration*—Calibration standards shall be spot checked against the primary calibration to ensure that the ultrasonic system calibration is not drifting. A calibration check at the finish of a group of blooms of a size and a minimum of one check each shift is recommended.

7.3.7 *Quality Levels and Reference Standards*:

7.3.7.1 The reference blocks shall be fabricated in accordance with the procedures of Practice E 127, with the exception of surface finish. Transducer contact surfaces of the product and the reference block should be comparable roughness. Flatbottom hole sizes shall be in accord with the applicable quality level specified in Table 1.

7.3.7.2 A comparison of the back reflections between equivalent thicknesses of the reference block material and the actual material to be tested, without change in instrument setting shall not show a variation in excess of 25 %. Reference blocks which do not meet the comparison requirement shall not be used for the specific part to be inspected.

7.3.8 *Evaluation of Discontinuities*:

7.3.8.1 When inspecting material to the flat-surface standards, estimate the size of a discontinuity by comparing its response to that of a flat-surface standard of the same depth, except as follows:

Depth of Discontinuity, in. (mm)	Allowable Difference, ± in. (mm)
Less than 1 (25.4)	⅛ (3.2)
1 to 3 (76.2)	¼ (6.4)
Greater than 3	½ (12.7)
Greater than 6 (152.4)	1 (25.4)

7.3.8.2 As an alternative, a distance-amplitude correction (DAC) curve or circuitry may be used.

7.3.8.3 Material having a cross-sectional dimension exceeding 12 in. (305 mm) may be inspected by the following procedure, using the back-reflection method, instead of preparing large reference blocks by agreement between manufacturer and purchaser. A straight-beam longitudinal-wave search unit shall be placed on the material under test in a discontinuity-free area having a satisfactory surface condition to produce the desired result. The type, size and frequency of the transducer shall be mutually agreed upon as required by the specific situation. The instrument sensitivity shall be adjusted so that the height of the first back reflection occupies at least 75 %, but less than 100 %, of the full screen amplitude. The reporting levels and acceptability limits in terms of discontinuity size shall be mutually agreed upon prior to order placement.

7.3.9 *Acceptance Criteria (Table 1)*:

7.3.9.1 Any single discontinuity response that exceeds that of the single discontinuity standard for the applicable quality level shall be unacceptable.

7.3.9.2 Any multiple discontinuity, that is, any two that have an indicated distance between centers of less than 1 in. (25.4 mm) and whose responses equal or exceed that of the "multiple discontinuity" standard for the applicable quality level, shall be unacceptable.

7.3.9.3 Any stringer discontinuity whose response *and* length exceeds that of the standard for the applicable quality level shall be unacceptable.

TABLE 4 Permissible Variations in Produce Analysis

NOTE 1— Product cross-sectional area is defined as either:
(*a*) maximum cross-sectional area of rough machined forging (excluding boring),
(*b*) maximum cross-sectional area of the unmachined forging, or
(*c*) maximum cross-sectional area of the billet, bloom, or slab.
Area taken at right angles to the axis of the original ingot or billet.

Element	Unit or Maximum Specified Range, %	Permissible Variation Over the Specified Maximum Limit or Under the Specified Minimum Limit, %					
		Up to and including 100 in.^{2} (645 cm^2)	Over 100 to 200 in.^{2} (645 to 1290 cm^2), incl	Over 200 to 400 in.^{2} (1290 to 2580 cm^2), incl	Over 400 to 800 in.^{2} (2580 to 5160 cm^2), incl	Over 800 to 1600 in.^{2} (5160 to 10 320 cm^2), incl	Over 1600 in.^{2} (10 320 cm^2)
Carbon	up to and including 0.05	0.005	0.005	0.005	0.01	0.01	0.01
	0.06 to 0.10, incl	0.01	0.01	0.01	0.01	0.01	0.01
	0.11 to 0.25, incl	0.02	0.03	0.03	0.04	0.05	0.05
	0.26 to 0.55, incl	0.03	0.04	0.04	0.05	0.06	0.06
	0.56 and over	0.04	0.05	0.05	0.06	0.07	0.07
Manganese	up to and including 0.90	0.03	0.04	0.05	0.06	0.07	0.08
	0.91 and over	0.06	0.06	0.07	0.08	0.08	0.09
Phosphorus	...	0.008	0.008	0.010	0.010	0.015	0.015
Sulfur	...	0.005	0.005	0.005	0.005	0.006	0.006
Silicon	up to and including 0.35	0.02	0.03	0.04	0.04	0.05	0.06
	0.36 and over	0.05	0.06	0.06	0.07	0.07	0.08
Nickel	up to and including 1.00	0.03	0.03	0.03	0.03	0.03	0.03
	1.01 to 2.00, incl	0.05	0.05	0.05	0.05	0.05	0.05
	2.01 to 5.30, incl	0.07	0.07	0.07	0.07	0.07	0.07
	5.31 to 10.00, incl	0.10	0.10	0.10	0.10	0.10	0.10
	10.01 and over	0.15	0.15	0.15	0.15	0.15	0.15
Chromium	up to and including 0.90	0.03	0.04	0.04	0.05	0.05	0.06
	0.91 to 2.10, incl	0.05	0.06	0.06	0.07	0.07	0.08
	2.11 and over	0.10	0.10	0.12	0.14	0.15	0.16
Molybdenum	up to and including 0.20	0.01	0.02	0.02	0.02	0.03	0.03
	0.21 to 0.40, incl	0.02	0.03	0.03	0.03	0.04	0.04
	0.41 to 1.15, incl	0.03	0.04	0.05	0.06	0.07	0.08
	1.16 and over	0.05	0.06	0.08	0.10	0.12	0.12
Vanadium	up to and including 0.10	0.01	0.01	0.01	0.01	0.01	0.01
	0.11 to 0.25, incl	0.02	0.02	0.02	0.02	0.02	0.02
	0.26 to 0.50, incl	0.03	0.03	0.03	0.03	0.03	0.03
	0.51 and over	0.04	0.04	0.04	0.04	0.04	0.04
Titanium	...	0.05	0.05	0.05	0.05	0.05	0.05
Cobalt	0.26 to 5.00, incl	0.07	0.07	0.07	0.08	0.08	0.09
	5.01 and over	0.14	0.14	0.14	0.16	0.16	0.18
Aluminum	up to and including 0.05	0.01	0.01	0.02	0.02	0.03	0.03
	0.06 and over	0.02	0.02	0.02	0.03	0.03	0.03
Zirconium	...	0.01	0.01	0.01	0.01	0.01	0.01

8. Heat Treat Quality

8.1 *Hardenability*—All heats of material produced to this specification shall be tested for hardenability in accordance with Test Method A 255. The standards of acceptance shall be by agreement.

9. Permissible Variations in Weight

9.1 The permissible variation from the specified or theoretical weight of the blooms or billets shall be ±5 % for individual pieces or for lots of less than 20 tons (18100 kg). For lots of 20 tons or over, the permissible variation shall be ±2.5 % of the specified or theoretical weight of the lot.

9.2 The term "lot" is defined as all the blooms or billets of the same nominal cross-sectional dimensions and specified piece weight in a shipment.

10. Finish and Appearance

10.1 The material shall be free from rejectable discontinuities.

10.2 Conditioning, cutting, or parting of material may be done by scarfing or flame cutting when methods involved preheating and temperature control necessary to avoid any damage to flame-cut material are employed.

10.3 The surface of the bloom must be adequate for ultrasonic inspection to the applicable reference standard. In some cases, a smooth ground or milled surface may be necessary for adequate penetration and resolution.

10.4 Material may be conditioned to remove rejectable surface discontinuities, provided the depth of conditioning does not exceed 1⁄16 in. (1.6 mm) for each inch of dimension concerned, up to a maximum depth of 3⁄4 in. (19.0 mm), and provided that the width of the conditioning is at least four times its greatest depth. The maximum depth of conditioning on two parallel sides at opposite locations shall not exceed 1½ times the maximum allowed for one side.

11. Marking

11.1 Each bloom shall be legibly stamped by the manufacturer with the manufacturer's name or trademark; the manufacturer's heat number; A 646 followed by the appropriate class number, grade number, ingot number, and cut location.

12. Inspection

12.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Mill inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operation. All tests and inspections shall be made at the place of manufacture, unless otherwise agreed to.

13. Rejection

13.1 Any rejection based on tests made in accordance with 6.3 shall be reported to the manufacturer within 60 days from the receipt of the material by the purchaser.

13.2 Material that shows rejectable discontinuities prior to or subsequent to acceptance at the purchaser's plant shall be subject to rejection and the manufacturer shall be notified.

14. Certification and Reports

14.1 The manufacturer shall furnish the following information on the test report:

14.1.1 Chemical analysis,

14.1.2 Macroetch rating (if required, Test Method A 604 only),

14.1.3 Microcleanliness ratings,

14.1.4 Hardenability results,

14.1.5 Ultrasonic inspection report including statement: "Ultrasonically inspected in accordance with ASTM A _____, Class _____," and

14.1.6 Results of supplementary requirements when required.

15. Keywords

15.1 aerospace application; reforging stock; steel billets; steel blooms

SUPPLEMENTARY REQUIREMENTS

These requirements shall not apply unless specified in the order.

S1. Magnetic Particle Cleanliness

S1.1 When specified, each heat of billet or bloom material shall be inspected in accordance with either Aeronautical Material Specification AMS 2300 for Class I or AMS 2301 for Class II.

S2. Mechanical Property Capability

S2.1 When specified, mechanical property testing may be required to represent the capability of the material to respond to the final heat treatment to be performed on the end product. The purchaser must specify the details of the capability heat treatment along with minimum property levels to be achieved with the specimens after heat treatment.

Designation: A 649/A 649M – 99 (Reapproved 2003)

Standard Specification for Forged Steel Rolls Used for Corrugating Paper Machinery[1]

This standard is issued under the fixed designation A 649/A 649M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification[2] covers two kinds of rolls used in machinery for producing corrugated paperboard. Rolls are fabricated of forged bodies and trunnions. The trunnions may be bolted or shrink assembled on one or both ends of the body. A seal weld may be made at the body/trunnion interface. Roll shells are made of carbon/manganese, or low alloy steel as hereinafter described, and are heat treated prior to assembly. Pressure rolls are surface hardened. Provision is made in Supplementary Requirement S1 for the optional surface hardening of corrugating rolls.

1.2 Corrugating and pressure rolls made to this specification shall not exceed 30 in. [760 mm] in inside diameter. The wall thickness of the roll body shall not be less than $1/12$ of the inside diameter or 1 in. [25 mm], whichever is greater, but shall not exceed 4 in. [100 mm]. The wall thickness of the corrugating roll is measured at the bottom of the corrugations in the location of the trunnion fit. The maximum operating temperature of the roll is 600°F [315°C] and the maximum allowable working pressure is 250 psi [1.7 MPa]. The minimum design temperature shall be 40°F [4°C] for roll wall thicknesses up to 3 in. [75 mm]. For roll wall thicknesses over 3 in. [75 mm] to 4 in. [100 mm], the minimum design temperature shall be 120°F [50°C]. The maximum stresses on the roll bodies from the combined internal and external loading are limited to 18 750 psi [129 MPa] for the Class 2 pressure roll bodies, and 20 000 psi [138 MPa] for Class 1A, 1B, or 5 pressure or corrugating roll bodies in Grades 1 or 2. For the trunnions, the maximum stresses from the combined internal and external loading are limited to 15 000 psi [103.4 MPa] for Classes 3 or 4, or 20 000 psi [138 MPa] for Classes 1A, 1B, or 5 in Grade 2 only. The Grade 1 strength level is not permissible for trunnions.

1.3 Referring to Table 1, material to Classes 1A, 1B, or 5 shall be used for the manufacture of corrugating or pressure roll shells, and Class 2 shall be used only for pressure roll shells. Trunnions shall be made from forgings in Classes 1A, 1B, or 5 in Grade 2 strength level as restricted by Footnote B in Table 2 or in forgings in either Class 3 or 4.

1.4 The values stated in either inch-pound units or SI [metric] units are to be regarded separately as standards. Within the text and tables, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independent of the other. Combining values from the two systems may result in nonconformance with the specification.

1.5 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch-pound units.

1.6 Except as specifically required in this standard, all of the provisions of Specification A 788 apply.

2. Referenced Documents

2.1 *ASTM Standards:* [3]

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 788 Specification for Steel Forgings, General Requirements

E 165 Practice for Liquid Penetrant Examination

3. Ordering Information

3.1 Orders for material under this specification shall include the information required by Specification A 788. The purchaser should refer to Specification A 788 for other relevant information.

3.2 The additional ordering information given in Specification A 788 shall be specified as necessary to describe adequately the desired material.

4. Materials and Manufacture

4.1 *Forging Process*:

4.1.1 Roll body forgings may be made as solid forgings and subsequently bored.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved Oct. 1, 2003. Published November 2003. Originally approved in 1971. Last previous edition approved in 1999 as A 649/A 649M–99.

[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-649/SA-649M in Section II of that Code.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

TABLE 1 Chemical Requirements

	Composition, %					
	Class 1A	Class 1B	Class 2	Class 3	Class 4	Class 5
Carbon	0.45–0.60	0.40–0.60	0.55 max	0.35 max	0.35 max	0.50–0.60
Manganese	0.55–1.05	0.60–0.95	0.50–0.90	0.40–0.70	0.60–1.05	0.90–1.50
Phosphorus	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max
Sulfur	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max
Silicon[A]	0.15–0.35	0.15–0.35	0.15–0.35 max	0.15–0.35	0.15–0.35 max	0.15–0.35
Nickel	...	1.55–2.00	...	...	...	0.60 max
Chromium	0.80–1.15	0.65–0.95	...	0.80–1.15	...	0.30 max
Molybdenum	0.15–0.50	0.20–0.45	...	0.15–0.25	...	0.15 max

[A] When vacuum carbon deoxidation (VCD) is used the silicon content shall be 0.10 % maximum.

TABLE 2 Tensile Requirements

Class	Grade	Yield Strength, min[A]	Tensile Strength, min	Elongation in 2 in. or 50 mm, %, min	Reduction of Area, %, min
		ksi	ksi		
1A, 1B or 5	1	130	150	12.0	30
1A, 1B or 5	2[B]	65	100	14.0	30
2	...	37.5	75	20.0	50.0
3 or 4	...	30	60	22.0	55

[A] 0.2 % offset.
[B] For trunnion application, a maximum tensile strength of 125 ksi [860 MPa] applies for Grade 2 of Classes 1A, 1B, or 5.

4.1.2 Trunnions or gudgeons which are to be subsequently assembled to form the roll shall be made as a solid forging or where practical upset from segments cut from billets or bars.

4.2 *Heat Treatment*:

4.2.1 *Heat Treatment for Mechanical Properties (Requirements do not apply to surface treatment)*:

4.2.1.1 *Machining*—The forged roll body shall have all surfaces rough machined, including boring, prior to heat treatment for mechanical properties.

4.2.1.2 Roll bodies shall be normalized, liquid quenched, and tempered to produce the required mechanical properties, except that for Class 2 forgings, and when Grade 2 strength requirements are specified, a normalize and temper heat treatment may be applied.

4.2.1.3 The trunnions shall be normalized and tempered or annealed to produce the required mechanical properties.

4.2.2 *Surface Hardening of Pressure Roll Forgings*—The working face of pressure rolls shall be surface hardened either before or after fitting the trunnions, at the manufacturer's option.

4.3 *Assembly and Weld*—Except for integrally forged or bolted-on trunnions, the assembly shall be made by shrink fitting trunnions into the prepared body ends. If used, welding of the trunnion to the roll body is restricted to a ⅜ in. [9.5 mm] max. seal weld, made with low hydrogen materials. A minimum preheat of 400°F [205°C] and a minimum post weld heat treatment of 850°F [455°C] for 8 h shall be used. The maximum post weld heat treatment shall be not higher than t − 50°F [t − 28°C] where t is the final tempering temperature. All welds shall be machined or ground for the final magnetic particle or liquid penetrant examination.

5. Chemical Composition

5.1 The steel shall conform to the requirements for chemical composition prescribed in Table 1.

6. Mechanical Properties

6.1 *Tensile Requirements*:

6.1.1 The material shall conform to the requirements for tensile properties prescribed in Table 2 when tested in accordance with Test Methods and Definitions A 370. Tension test specimens shall be the standard round ½-in. [12.5 mm] diameter, 2-in. [50 mm] gage length. The yield strength prescribed in Table 2 shall be determined by the 0.2 % offset method.

6.1.1.1 Tests for acceptance shall be made after the heat treatment of the forgings, for mechanical properties in accordance with 4.2.1.

6.1.2 *Number, Location, and Orientation of Test Specimens*:

6.1.2.1 *Roll Body Forgings*—A full-size prolongation shall be provided on a roll body forging representing each heat of steel in each heat-treatment furnace charge. One longitudinal tension test specimen shall be taken from the prolongation and the axis of the specimen shall be located midway between the inner and outer surfaces of the wall body.

6.1.2.2 *Trunnions*—Test material shall be provided from each heat of steel in each heat-treatment furnace charge. One longitudinal tension specimen shall be taken from each test piece and the axis of the specimen shall be located at any point midway between the center and surface of the solid forging.

6.2 *Hardness*:

6.2.1 Roll body forgings shall have a Brinell hardness from 352 HB to 415 HB (Grade 1) or 207 HB to 285 HB (Grade 2). No less than three hardness determinations shall be made on each roll. The hardness readings are to be taken on the outside of the roll bodies using care to prepare locations for tests that are free of decarburization but not so deep as to affect the usefulness of the material.

6.2.2 The surface hardened pressure roll body forgings shall have a hardness of 58 HRC to 65 HRC or equivalent. No less than three hardness determinations shall be made on each roll. The hardness depth shall not exceed ¼ [6 mm].

7. Retreatment

7.1 If the results of the mechanical tests of any forging do not conform to the specified requirements, the manufacturer may retreat the forging one or more times, but not more than three additional times without approval of the purchaser.

8. Magnetic Particle Examination

8.1 The entire surface of the roll, including the seal weld area, shall be examined by either a wet continuous method in accordance with Test Method A 275/A 275M or by a liquid penetrant method in accordance with Practice E 165 after machining or grinding. The use of prods in the magnetic particle method is not permitted.

8.2 Only indications with major dimensions greater than ⅛ in [3.2 mm] are considered relevant.

8.3 *Acceptance Standards*—The following relevant indications are unacceptable:

8.3.1 Any linear indications greater than 3⁄16 in. [4.8 mm] long.

8.3.2 Rounded indications greater than 3⁄16 in. [4.8 mm].

8.3.3 Four or more indications in a line separated by 1⁄16 in. [1.6 mm] or less edge to edge.

8.3.4 Ten or more indications in any 6 in.^{2} [38.71 cm^2] of surface.

9. Hydrostatic Testing

9.1 The machined roll assembly shall be hydrostatic tested at 1½ times the maximum operating pressure. The operating pressure shall be furnished by the purchaser.

9.2 The recommended minimum hydrostatic test temperature is 70°F [21°C].

10. Package Marking, Packaging, and Loading

10.1 Packaging and loading shall be done so the forging is not damaged during shipment to the purchaser.

11. Keywords

11.1 internal pressure; machinery—corrugating; roll assembly—forged; rolls—corrugating; rolls—pressure; steel forgings—alloy; steel forgings—carbon; steel rolls; surface-hardened; trunnions—bolted; trunnions—shrink-fitted

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser on the order and agreed to by the manufacturer:

S1. Surface-Hardened Corrugating Rolls

S1.1 After all surfaces have been machined, the outer surface of the corrugating rolls may be surface-hardened to a surface hardness of Rockwell 53 HRC to 65 HRC. The depth of hardness shall not exceed ⅜ in. [9.5 mm]. A minimum of three hardness determinations shall be made on the surface. Additional hardness tests shall be made to establish the depth of hardness. The hardened surface shall be magnetic particle tested (see Section 8).

S2. Notch Toughness

S2.1 For applications where minimum notch toughness limits are required, impact testing shall be specified for both roll bodies and trunnions. The following requirements shall be specified:

S2.1.1 Type of impact specimen and test standard (for example, ASTM Test Methods and Definitions A 370 specimen Type A or B).

S2.1.2 Minimum value for absorbed energy or lateral expansion.

S2.1.3 Test temperature.

S2.1.4 Frequency of testing.

S2.2 Trunnion and pressure rolls may be liquid quenched and tempered instead of the heat treatments specified in 4.2 when impact testing is required.

Designation: A 663/A 663M – 89 (Reapproved 2000)

Standard Specification for Steel Bars, Carbon, Merchant Quality, Mechanical Properties[1]

This standard is issued under the fixed designation A 663/A 663M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers hot-wrought merchant quality carbon steel bars and bar size shapes produced to mechanical property requirements and intended for noncritical constructional applications (see 3.2).

1.2 Merchant quality hot-wrought steel bar is available in the following ranges of size and section:

1.2.1 Rounds, squares, and hexagons with diameters or distance across flats under 3 in. [75 mm].

1.2.2 Bar size shapes with maximum dimensions under 3 in. [75 mm].

1.2.3 Other bar sections with weight per foot under 40.84 lb/ft [60.78 kg/m].

1.2.4 Flats 6 in. [152 mm] or under in width, over 0.203 in. [over 5 mm in thickness up to 150 mm in width] in thickness, and under 40.84 lb/ft or 12 in.^{2} [77.4 cm^2] in cross-sectional area.

1.2.5 Flats over 6 in. to 8 in., inclusive in width, 0.230 in. and over [over 6 mm in thickness and over 50 mm through 200 mm in width] in thickness and under 40.84 lb/ft [60.78 kg/m] or 12 in.^{2} [77.4 cm^2] in cross-sectional area.

1.2.6 Hot-wrought merchant quality carbon steel bars subject to mechanical property requirements are hot wrought in straight lengths only.

1.3 Some applications may require one or more of the available designations shown under supplementary requirements.

NOTE 1—Special quality hot-wrought carbon steel bars subject to mechanical property requirements are covered in Specification A 675/A 675M.

1.4 The values stated in either inch-pound units or SI units are to be regarded separately as the standard. Within the text, the SI units are shown in brackets. The values stated in each system are not equivalents, therefore each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

A 675/A 675M Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties[2]

E 290 Test Method for Semi-Guided Bend Test for Ductility of Metallic Materials[4]

3. Ordering Information

3.1 Orders for material under this specification should include the following information:

3.1.1 Quantity (weight or number of pieces),

3.1.2 Dimensions (cross-sectional shape, size, and length),

3.1.3 Name of material (merchant quality carbon steel bars),

3.1.4 Specification number and date of issue,

3.1.5 Grade designation,

3.1.6 Copper bearing steel (if required),

3.1.7 Heat analysis or test report (request, if required),

3.1.8 Application and processing, and

3.1.9 Supplementary requirements (if required).

4. Manufacture

4.1 The steel shall be made by the open-hearth, basic-oxygen, or electric-furnace process.

5. Chemical Composition

5.1 The steel shall conform on heat analysis to the following chemical requirements:

Phosphorus, max, percent	0.04
Sulfur, max, percent	0.05
Copper, when copper steel is specified, min, percent	0.20

[1] This specification is under the jurisdiction of Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

Current edition approved Dec. 7, 1989. Published February 1990. Originally published as A 663–72 to replace A 306–64(1972). Last previous edition A 663–88$^{\epsilon 1}$.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

5.2 When tension tests are waived in accordance with 6.1.6, chemistry consistent with the mechanical properties desired shall be applied.

6. Mechanical Properties

6.1 *Tensile Requirements*:

6.1.1 The material as represented by the test specimen shall conform to the applicable requirements in Table 1.

6.1.2 Test specimens shall be prepared for testing from the material in its as-rolled condition. The tension specimen may be aged as described in Test Methods and Definitions A 370.

6.1.3 Test specimens shall be taken longitudinally and may be tested in full thickness or section, or they may be machined to the dimensions shown in Figs. 4 or 5 of Test Methods and Definitions A 370. If test specimens are selected conforming to the dimensions of Fig. 5, they shall be machined from a position midway between the center and the surface of the bar.

6.1.4 Test specimens for shapes and flats may be machined to the form and dimensions shown in Fig. 4 of Test Methods and Definitions A 370 or with both edges parallel. Test specimens for material over 1½ in. [40 mm] in thickness or diameter may be machined to a thickness or diameter of at least ¾ in. [20 mm] for a length of at least 9 in. [230 mm], or they may conform to the dimensions shown in Fig. 5 of Test Methods and Definitions A 370.

6.1.5 Tensile requirements shall be determined in accordance with Test Methods and Definitions A 370.

6.1.6 Shapes less than 1 $in.^2$ [645 mm^2] in cross section and bars (other than flats) less than ½ in. [12.5 mm] in thickness or diameter need not be subject to tension tests by the manufacturer.

6.1.7 For material over ¾ in. [19 mm] in thickness or diameter, a deduction from the percentage of elongation in 8 in. [200 mm] specified in Table 1 of 0.25 percent shall be made for each increase of 1⁄32 in. [0.8 mm] in the specified thickness or diameter above ¾ in. [19 mm].

TABLE 1 Tensile Requirements

Grade Designation	Tensile Strength, ksi [MPa]	Yield Point,[A] min, ksi [MPa]	Elongation, min, %	
			8-in. or [200-mm] Gage Length	2-in. or [50-mm] Gage Length
45 [310]	45–55 [310–380]	25.0 [175]	27	33
50 [345]	50–60 [345–415]	28.0 [195]	25	30
55 [380]	55–65 [380–450]	30.0 [210]	23	26
60 [415]	60–72 [415–495]	33.0 [230]	21	22
65 [450]	65–77 [450–530]	36.0 [250]	17	20
70 [485]	70–85 [485–585]	39.0 [270]	14	18
75 [515]	75–90 [515–620]	41.0 [285]	14	18
80 [550]	80 min [550 min]	44.0 [305]	13	17

[A] When the tension test does not show a yield point (drop of the beam, halt of the pointer or sharp-kneed stress-strain diagram), yield strength shall be determined by either 0.5 % extension-under-load or 0.2 % offset. The minimum ksi (MPa) requirement does not change. The test report, if required, shall show yield strength.

6.1.8 For material under 5⁄16 in. [8 mm] in thickness or diameter, a deduction from the percentage of elongation in 8 in. [200 mm] specified in Table 1 of 2.00 percent shall be made for each decrease of 1⁄32 in. [0.8 mm] in the specified thickness or diameter below 5⁄16 in. [8 mm].

6.1.9 For material over 2 in. [50 mm] in thickness or diameter, a deduction from the percentage of elongation in 2 in. [50 mm] specified in Table 1 of 1.00 percent shall be made for each 1 in. [25 mm] of specified thickness or diameter or fraction thereof over 2 in. [50 mm] in thickness or diameter.

6.2 *Number of Tests*:

6.2.1 Two tension tests shall be made from each heat, unless the finished material from a heat is less than 50 tons [45 Mg], when one tension test will be sufficient. However, for material 2 in. [50 mm] and under in thickness, when the material from one heat differs ⅜ in. [9.5 mm] or more in thickness, one tension test shall be made from both the thickest and the thinnest material rolled (larger than the sizes enumerated in 6.1.6), regardless of weight represented. For material over 2 in. [50 mm] thick, when the material from one heat differs 1 in. [25 mm] or more in thickness, one tension test shall be made from both the thickest and the thinnest material rolled that is more than 2 in. [50 mm] thick regardless of the weight represented.

6.3 *Test Reports*:

6.3.1 When test reports are required by the purchase order, the report shall show the results of each test required by 6.2, except that only one test need be reported when the amount of material from a heat in a shipment is less than 10 tons [9 Mg] and when the thickness variations described in 6.2 are not exceeded.

6.3.2 The thickness of the product tested may not necessarily be the same as an individual ordered thickness since it is the heat that is tested rather than each ordered item.

6.3.3 When Supplementary Requirements are specified, the report shall include a statement of compliance with the requirement or the results of tests when the requirement involves measured test values.

7. General Requirements

7.1 Material furnished under this specification shall conform to the requirements of the current edition of Specification A 29/A 29M, except as stated in 1.2 and 3.2.

7.2 Merchant quality bars shall be free from visible pipe; however, they may contain pronounced chemical segregation. Internal porosity, surface seams, and other surface irregularities may be present in this quality. Deoxidation practice and grain size are at the manufacturer's option.

7.3 Unless otherwise specified, the bars shall be furnished as rolled and not pickled, blast cleaned nor oiled.

8. Keywords

8.1 carbon steel bars; merchant quality steel bars; steel bars

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply when specified by the purchaser.

S1. Special Straightness

S1.1 Bars may be specified to special straightness tolerance (refer to Specification A 29/A 29M).

S2. Cleaning

S2.1 The purchaser may specify that the surface of bars be descaled by pickling or blast cleaning.

S3. Coating

S3.1 The purchaser may specify oil on bars which have been descaled.

S4. Bend Tests

S4.1 *Requirements:*

S4.1.1 The bend test specimen shall stand being bent at room temperature through 180° without cracking on the outside of the bent portion, to an inside diameter which shall have the relation to the thickness or diameter of the specimen as given in Table S4.1.

TABLE S4.1 Bend Requirements

Grade Designation	Ratio of Bend Diameter to Thickness of Specimen for Thickness or Diameter of Bar, in. (mm)				
	¾ [20] and Under	Over ¾ [20] to 1 [25], incl	Over 1 [25] to 1½ [40], incl	Over 1½ [40] to 2 [50], incl	Over 2 [50] to under 3 [75]
45 [310]	flat	flat	½	1	1
50 [345]	flat	½	1	1½	2½
55 [380]	½	1	1½	2	2½
60 [415]	½	1	1½	2½	3
65 [450]	1	1½	2	3	3½
70 [485]	1½	2	2½	3	3½
75 [515]	2	2	3	3½	4
80 [550]	2	2½	3	3½	4

S4.2 *Test Specimens:*

S4.2.1 Bend test specimens for material 1½ in. [40 mm] and under in diameter or thickness may be the full thickness of the section. For flat bars over 2 in. [50 mm] in width, the width may be reduced by milling to 1½ in. [40 mm].

S4.2.2 Bend test specimens for material over 1½ in. [40 mm] in diameter or thickness may be machined to a thickness or diameter of at least ¾ in. [20 mm] or to 1 in. by ½ in. [25 by 12.5 mm] in section. Machined sides of bend test specimens may have the corners rounded to a radius of not over 1⁄16 in. [1.6 mm] for material 2 in. [50 mm] and under in thickness, and not over ⅛ in. [3.2 mm] in radius for material over 2 in. [50 mm] in thickness.

S4.3 *Number of Tests:*

S4.3.1 Two bend tests shall be made from each heat unless the finished material from a heat is less than 50 tons [45 Mg] when one bend test will be sufficient. However, for material 2 in. [50 mm] and under in thickness, when the material from one heat differs ⅜ in. [9.5 mm] or more in thickness, one bend test shall be made from the thickest and the thinnest material rolled, regardless of weight represented. For material over 2 in. [50 mm] thick, when the material from one heat differs 1 in. [25 mm] or more in thickness, one bend test shall be made from both the thickest and the thinnest material rolled that is more than 2 in. [50 mm] thick regardless of the weight represented.

S4.4 *Test Methods:*

S4.4.1 Bend tests shall be made in accordance with Test Method E 290.

Standard Specification for Steel Forgings, Carbon and Alloy, for General Industrial Use[1]

This standard is issued under the fixed designation A 668/A 668M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers untreated and heat-treated carbon and alloy steel forgings for general industrial use. Other ASTM specifications for forgings are available for specific applications such as pressure vessels, railroad use, turbine generators, gearing, and others involving special temperature requirements.

1.2 Hot-rolled or cold finished bars are not within the scope of this specification.

1.3 Six classes of carbon steel and seven classes of alloy steel forgings are listed (see Section 7) , which indicates their required heat treatments, as well as mechanical properties.

1.4 Provision, with the suffix H for certification and marking, for the supply of forgings after hardness testing only.

1.5 Supplementary requirements, including those in Specification A 788, of an optional nature are provided. These shall apply only when specified by the purchaser.

1.6 Appendix X1 lists the current classes corresponding to the various classes of Specifications A 235, A 237, and A 243, which have been superseded by this specification.

1.7 The values stated in either inch-pound units or SI units are to be regarded separately as the standard; within the text and tables, the SI units are shown in brackets. The values stated in each system are not exactly equivalent; therefore; each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.8 Unless the order specifies the applicable ″M″ specification, the forgings shall be furnished to the inch-pound units

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings

A 788 Specification for Steel Forgings, General Requirements

E 381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings

3. Terminology

3.1 *The terminology section of Specification A 788 is applicable to this specification*.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *hollow cylindrical forging*—a forging whose length, as measured on its longitudinal axis is more than its diameter, shall be considered as a hollow cylinder within the scope of this specification if it has been lengthened by extrusion or forged in a manner similar to that of a ring, namely, expanded in diameter on a mandrel.

3.2.2 *ring-shaped or disk-shaped forging*—a forging whose length, as measured on its longitudinal axis, is less than its diameter or main transverse dimension is considered a ring or disk within the meaning of this specification.

4. Ordering Information and General Requirements

4.1 Material supplied to this specification shall conform to the requirements of Specification A 788 which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations and additional supplementary requirements.

4.1.1 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

4.2 When this specification is to be applied to an inquiry, contract, or order, the purchaser should furnish the following information:

4.2.1 The ordering information required by Specification A 788.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys, and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved March 1, 2004. Published April 2004. Originally approved in 1972. Last previous edition approved in 2003 as A 668 – 03.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard.**

4.2.2 The class of forging desired as listed in Section Table 1,

4.2.3 Location(s) of areas of significant loading if test specimens are to be located in accordance with 7.1.4.5.

4.2.4 The options which may be selected as found in 5.4.2, 7.6.3, and 7.7, and

4.2.5 Any applicable supplementary requirements.

5. Materials and Manufacture

5.1 *Discard*—Sufficient discard shall be made from each ingot to secure freedom from piping and undue segregation.

5.2 *Forging Process*

5.2.1 The forging shall be brought as close as practical to finished shape and size by hot mechanical work.

5.2.2 Supplementary requirements S2, S14, and S15 may be specified by the purchaser to satisfy concerns about the utility of the proposed forging.

5.3 *Heat Treatment*:

5.3.1 All forgings, other than Class A, shall be heat treated. See Section 7.

5.3.2 Where options exist within a class, the choice of heat treatment shall be left to the discretion of the manufacturer, unless the purchaser specifies one of the available options.

6. Chemical Composition

6.1 The steel shall conform to the requirements for chemical composition prescribed in Table 1.

6.2 The choice of chemical composition is left to the discretion of the manufacturer, unless otherwise specified by the purchaser. See Appendix X2.

6.3 *Heat Analysis*:

6.3.1 An analysis of each heat shall be made by the manufacturer.

6.4 *Product Analysis*—An analysis may be made by the purchaser according to the requirements of Specification A 788. If a standard grade has been used to manufacture the forging the permissible variations in composition of Specification A 788 shall apply. If a non-standard grade of steel has been used, and composition limits have not been supplied, the product analysis can be used only to confirm the type of steel supplied.

7. Mechanical Properties

7.1 *Tensile Requirements*:

7.1.1 The material shall conform to the tensile properties prescribed in Table 2.

7.1.2 *Size Classification*—The dimensions of the forging at time of heat treatment determine the size classification (see Table 2):

TABLE 1 Chemical Requirements

Elements	Composition, max, %	
	Classes A to F and AH to FH	Classes G to N and GH to NH
Manganese	1.35	...
Phosphorus	0.050	0.040
Sulfur	0.050	0.040

7.1.2.1 *Solid Forgings*—Either the as forged or rough machined diameter or thickness of solid forgings, disregarding large ends, collars, flanges, and journals, at time of heat treatment shall determine the size classification.

7.1.2.2 *Ring or Hollow Cylinder Forging*— The size classification shall be determined by its wall thickness or width, whichever is the smaller dimension of either the as forged or rough machined forging at time of heat treatment.

7.1.3 *Number of Tests*—Unless the purchaser specifies that forgings shall be furnished in accordance with the requirements of 7.3, the number of tension tests performed shall be as follows:

7.1.3.1 For all classes of heat-treated forgings with rough machined weights less than 5000 lb [2250 kg] each, one test shall be made from each size classification represented in each heat in each annealing or normalizing charge, or from each size classification in each heat in each normalizing or quenching charge represented in each tempering charge. For untreated forgings (Class A) weighing less than 5000 lb [2250 kg] each, one test from each heat shall be made.

7.1.3.2 On all classes, for forgings with rough machined weights of 5000 lb [2250 kg] or more, at least one test from each forging shall be made.

7.1.3.3 On all classes, for forgings with rough machined weights of 7000 lb [3200 kg] or more, two tests will be taken: on ring and disk forgings 180 ° apart; on shafts and long hollow cylinders (over 80 in. [2.0 m] in length excluding test material), one from each end and offset 180 °. Shafts and cylinder forgings 80 in. [2.0 m] or less in length (excluding test material) may have both tests located at one end 180 ° apart.

7.1.3.4 When forgings are made in multiple as a single forging, that is, forged as one piece and divided after heat treatment, the multiple forging shall be considered as one forging, and the number of tests required shall be as designated in 7.1.3.1, 7.1.3.2, and 7.1.3.3.

7.1.4 *Prolongations*:

7.1.4.1 A sufficient number of the forgings shall have prolongations for extracting specimens for testing. Locations of test specimens for various types of forgings shall be as shown in Fig. 1.

7.1.4.2 The nominal or principal outside rough machine diameter or thickness of the forgings, disregarding large ends, collars, flanges, and journals shall determine the size of the prolongations for test specimens; however, the prolongations on annealed, normalized, or normalized and tempered shafts may be extensions of the small diameter end of the shaft, as shown in Fig. 1.

7.1.4.3 For quenched forgings in Classes F, J, K, L, M, and N, the prolongations shall be sufficiently long so that the center of the gage length (for longitudinal specimens) or axis (for tangential specimens) of the tension test specimen shall be at the following locations:

(*1*) On solid round forgings, bars, or billets (see Fig. 1 (*a*)), at midradius and from the end, 3½ in. [90 mm] or ½ the diameter, whichever is less.

(*2*) On solid rectangular forgings, bars, or billets, at ¼ the thickness and width and from the end, 3½ in. [90 mm] or ½ the thickness, whichever is less.

TABLE 2 Tensile Requirements

Class	Size, in. [mm] Over	Size, in. [mm] Not Over	Tensile Strength, min psi	Tensile Strength, min MPa	Yield Point, Yield Strength 0.2 % Offset, min psi	Yield Point, Yield Strength 0.2 % Offset, min MPa	Elongation in 2 in. or 50 mm, min, %	Reduction of Area, min, %	Brinell Hardness
Carbon Steel									
A (AH) (Untreated)	...	20 [500]	47 000	325	...	...	...	...	183 max
B (BH) (Annealed, or normalized, or normalized and tempered)	...	20 [500]	60 000	415	30 000	205	24	36	120–174
C (CH) (Annealed, or normalized, or normalized and tempered)	...	12 [300]	66 000	455	33 000	230	23	36	137–183
	12 [300]	20 [500]	66 000	455	33 000	230	22	34	137–183
D (DH) (Normalized, annealed, or normalized and tempered)	...	8 [200]	75 000	515	37 500	260	24	40	149–207
	8 [200]	12 [300]	75 000	515	37 500	260	22	35	149–207
	12 [300]	20 [500]	75 000	515	37 500	260	20	32	149–207
	20 [500]		75 000	515	37 500	260	19	30	149–207
E (EH) (Normalized and tempered or double-normalized and tempered)	...	8 [200]	85 000	585	44 000	305	25	40	174–217
	8 [200]	12 [300]	83 000	570	43 000	295	23	37	174–217
	12 [300]	20 [500]	83 000	570	43 000	295	22	35	174–217
F (FH) (Quenched and tempered, or normalized, quenched and tempered)	...	4 [100]	90 000	620	55 000	380	20	39	187–235
	4 [100]	7 [175]	85 000	585	50 000	345	20	39	174–217
	7 [175]	10 [254]	85 000	585	50 000	345	19	37	174–217
	10 [250]	20 [500]	82 000	565	48 000	330	19	36	174–217
Alloy Steel									
G (GH) (Annealed, or normalized, or normalized and tempered)	...	12 [300]	80 000	550	50 000	345	24	40	163–207
	12 [300]	20 [500]	80 000	550	50 000	345	22	38	163–207
H (HH) (Normalized and tempered)	...	7 [175]	90 000	620	60 000	415	22	44	187–235
	7 [175]	10 [250]	90 000	620	58 000	400	21	42	187–235
	10 [250]	20 [500]	90 000	620	58 000	400	18	40	187–235
J (JH) (Normalized and tempered, or normalized, quenched, and tempered)	...	7 [175]	95 000	655	70 000	485	20	50	197–255
	7 [175]	10 [250]	90 000	620	65 000	450	20	50	187–235
	10 [250]	20 [500]	90 000	620	65 000	450	18	48	207–255
K (KH) (Normalized, quenched, and tempered)	...	7 [178]	105 000	725	80 000	550	20	50	212–269
	7 [175]	10 [250]	100 000	690	75 000	515	19	50	207–269
	10 [250]	20 [500]	100 000	690	75 000	515	18	48	207–269
L (LH) (Normalized, quenched, and tempered)	...	4 [100]	125 000	860	105 000	725	16	50	255–321
	4 [100]	7 [175]	115 000	795	95 000	655	16	45	235–302
	7 [175]	10 [250]	110 000	760	85 000	585	16	45	223–293
	10 [250]	20 [500]	110 000	760	85 000	585	14	40	223–293
M (MH) (Normalized, quenched, and tempered)	...	4 [100]	145 000	1000	120 000	825	15	45	293–352
	4 [100]	7 [175]	140 000	965	115 000	790	14	40	285–341
	7 [178]	10 [254]	135 000	930	110 000	758	13	40	269–331
	10 [250]	20 [500]	135 000	930	110 000	758	12	38	269–341
N (NH) (Normalized, quenched, and tempered)	...	4 [100]	170 000	1175	140 000	965	13	40	331–401
	4 [100]	7 [175]	165 000	1140	135 000	930	12	35	331–401
	7 [175]	10 [250]	160 000	1100	130 000	900	11	35	321–388
	10 [250]	20 [500]	160 000	1100	130 000	900	11	35	321–402

(*3*) On disk forgings (see Fig. 1(*c*)) (with prolongation on OD), at midthickness and from the OD 3½ in. [90 mm] or ½ the thickness, whichever is less.

(*4*) On disk forgings (see Fig. 1(*c*)) (with prolongation on the width or thickness) 3½ in. [90 mm] or ½ the thickness, whichever is less, from any heat treated surface.

(*5*) On ring forgings (see Fig. 1(*d*)) (with prolongation on width), at midwall and from the ring face 3½ in. [90 mm] or ½ the wall thickness, whichever is less.

(*6*) On ring forgings (see Fig. 1(*d*)) (with prolongation on the OD), at midwidth and from the OD 3½ in. [90 mm] or ½ the width, whichever is less.

7.1.4.4 In place of prolongs, the manufacturer may: (*1*) elect to submit an extra forging(s) to represent each test lot; in this event, the representative forging must be made from the same heat of steel, have received the same reduction and type of hot working, be of the same nominal thickness, and have been heat treated in the same furnace charge as the forging(s) it represents; or (*2*) obtain the test specimen from the trepanned material of transverse or radial holes, provided depth is equal to or greater than the minimum depth required by 7.1.4.3.

7.1.4.5 With prior purchaser approval, test specimens may be taken at a depth (t) corresponding to the distance from the area of significant stress to the nearest heat treated surface and

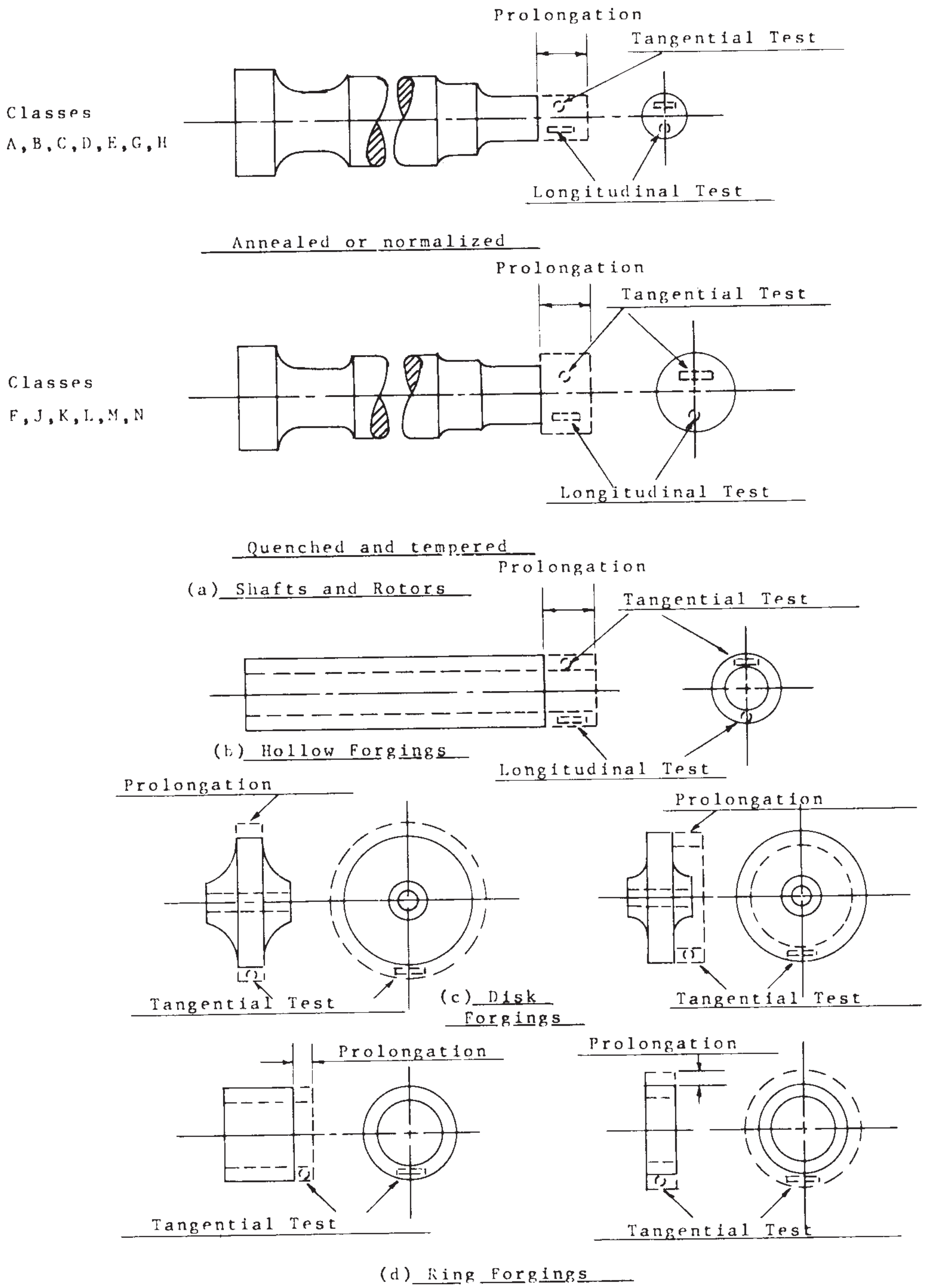

FIG. 1 Locations of Test Specimens for Various Types of Forgings

at least twice this distance (2t) from any second surface. However, the test depth shall not be nearer to one heat-treated surface than ¾ in. [19 mm] and to the second heat treated surface than 1 ½ in. [38 mm]. Sketches showing the exact test locations shall be approved by the purchaser when this method is used.

7.1.5 Tests for acceptance shall be made after final heat treatment of the forgings.

7.1.6 Test specimens shall be parallel to the axis of the forging in the direction in which the metal is most drawn out except that rings, hollow forgings which were expanded by forging, and disks shall be tested in the tangential direction.

7.1.7 Yield point shall be determined on carbon steel Grades A through F, and yield strength on alloy steel Grades G through N. For carbon steel grades not showing a yield point, the yield strength at 0.2 % offset shall be reported.

7.2 *Hardness Tests*—Brinell hardness tests shall be performed after heat treatment (except on Class A forgings) and rough machining on each forging weighing under 7000 lb [3200 kg] and each multiple forging made in accordance with 7.1.3.3 weighing under 7000 lb [3200 kg]. For exceptions see 7.1.3.4 and 7.2.3.

7.2.1 The average value of the hardness readings on each forging shall fall within the hardness ranges specified in Table

2. The permissible variation in hardness in any forging over 250 lb [110 kg] shall not exceed 30 HB for Classes A through E, 40 HB for Classes F through J, 50 HB for Classes K through N.

7.2.2 At least two hardness tests shall be taken on each flat face of disks, rings, and hollow forgings over 250 lb [110 kg] approximately at midradius and 180° apart, for example, at the 3:00 and 9:00 positions on one face, and 6:00 and 12:00 positions on the opposite face. On solid forgings over 250 lb [110 kg], at least four tests shall be taken on the periphery of the forging, two at each end 180° apart.

7.2.3 For forgings 250 lb [110 kg] and less, Brinell testing shall be performed on the broken test specimens representing the heat or heats included in each heat treating charge, or in the case of untreated forgings (Class A), on the test specimen representing each heat. The results shall meet the requirements of Table 2. If the purchaser desires Brinell testing of each forging, Supplementary Requirement S11 may be used.

7.3 If so specified by the purchaser, forgings may be supplied on the basis of hardness tests alone. If this option is exercised, the class shall be identified in certification and marking with the suffix "H," that is, "AH," "BH," "CH," etc.

8. Retreatment

8.1 When heat-treated forgings are specified, and the mechanical test results of any test lot do not conform to the requirements specified, the manufacturer may retreat the lot not more than three additional times, and retests shall be made according to Section 7. Retreatment is defined as complete re-austenization. Multiple retempering is not precluded by this requirement.

8.2 When untreated forgings (Class A) are specified, and the mechanical test results of any test lot do not conform to the requirements specified, the manufacturer may anneal, normalize, or normalize and temper, one or more times, but not more than three times; and retests shall be made in accordance with Section 7. The tensile properties shall conform to the requirements for the class of forgings ordered (Class A).

9. Inspection, Rejection, and Certification

9.1 Facilities for inspection at the place of manufacture, rejection of forgings and certification shall comply with Specification A 788.

10. Product Marking

10.1 The marking requirements of Specification A 788 shall be augmented as follows.

10.2 Each forging over 250 lb [110 kg] shall be legibly stamped by the manufacturer with the manufacturer's name or trademark, the manufacturer's serial number, the specification identification number, followed by the appropriate class number and, where applicable, a standard Grade designation.

10.3 For forgings 250 lb [110 kg] and under, the purchaser may indicate the nature and location of identification marks.

10.4 The type of stamps to be used shall be round-nosed or "interrupted-dot" die stamps having a minimum radius of $\frac{1}{32}$ in. [0.79 mm].

11. Keywords

11.1 alloy steel forgings; carbon steel forgings; general industrial applications; heat treatment classifications; strength classifications

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, and order. Details of these supplementary requirements shall be agreed upon by the manufacturer and the purchaser.

S1. Chemical Composition

S1.1 The supplier shall obtain approval of the grade of steel he proposes to apply to the order and reach agreement with the purchaser on the ranges of each element specified in the composition.

S2. Special Forging Techniques

S2.1 Special forging techniques are required to produce metal flow during the hot working operation in the direction most favorable for resisting the stresses encountered in service. Verification of forging flow lines shall be by macro-etch testing of sample forgings in accordance with Method E 381.

S3. Rough Turning and Boring

S3.1 The position of any rough turning or boring in the sequence of manufacturing operations.

S4. Carbon Content for Welding

S4.1 For forgings intended for welding, the carbon content (product analysis) shall be limited to 0.35 max %.

S5. Bend Tests

S5.1 The test specimen shall withstand being bent at room temperature through 180° without cracking on the outside of the bent portion of an inside diameter of 1½ in. [40 mm].

S6. Magnetic Particle Test

S6.1 Forgings shall be magnetic particle tested in accordance with the latest issue of Test Method A 275/A 275M.

S7. Ultrasonic Test

S7.1 Forgings shall be ultrasonically tested in accordance with the latest issue of Practice A 388/A 388M.

S8. Vacuum Treatment

S8.1 Vacuum degassed steel shall be supplied.

S9. Tensile Requirements

S9.1 When sizes larger than permitted in Table 2 are required, ductility values may be reduced from the specified values.

S9.2 Yield strengths higher than those listed in Table 2 for quenched and tempered grades may be specified.

S10. Heat Treatment

S10.1 A minimum tempering temperature shall be specified.

S11. Additional Tests

S11.1 Tests in addition to those prescribed in Section 7 may be specified.

S12. Additional Marking

S12.1 Additional identification marking or the locations of the stamping or both may be specified.

S14. Forge Procedure

S14.1 The forge procedure shall be submitted by the manufacturer to the purchaser for approval prior to production of the forging.

S15. Rough Forging Sketches

A dimensioned sketch or drawing of the proposed rough forging shall be supplied by the producer for approval before the forging is produced. This drawing or sketch shall indicate also the proposed heat treatment contour, including bores, if any, and the position of the required mechanical test coupons.

APPENDIXES

(Nonmandatory Information)

X1. COMPARISON OF SPECIFICATION A 668/A 668M VERSUS SUPERSEDED SPECIFICATIONS A 235, A 237, and A 243

X1.1 See specification comparison in Table X1.1.

TABLE X1.1 Specification Comparison

Superseded Specification and Class	Use A 668/A 668M, Class
A 235, A	A
A 235, C	B
A 235, C1	C
A 235, E	D
A 235, F	. . .
A 235, F1	E
A 235, G	F
A 237, A	G
A 237, B	. . .
A 237, C	H
A 237, C1	. . .
A 237, D	J
A 237, E	K
A 237, F	L
A 237, G	M
A 237, H	N
A 243, A	A
A 243, C	B
A 243, C1	C
A 243, E	D
A 243, F	. . .
A 243, F1	E
A 243, G	F
A 243, H	G
A 243, I	. . .
A 243, J	H
A 243, K	J
A 243, L	K
A 243, M	L
A 243, N	M
A 243, O	N

X2. TYPICAL GRADES OF STEEL USED FOR A 668/A 668M CLASSES

X2.1 See chemical composition and class/grade guide for typical grades of steel in Tables X2.1 and X2.2, respectively.

TABLE X2.1 Chemical Composition (Maximum Weight Percentage)

Element	Grade X1	Grade X2	Grade X3	Grade X4	Grade X5	Grade X6
Carbon	0.30	0.45	0.40	0.45	0.45	0.40
Manganese	0.90	0.90	0.85	1.10	0.90	0.90
Phosphorous	0.04	0.04	0.025	0.025	0.025	0.015
Sulfur	0.04	0.04	0.025	0.025	0.025	0.015
Silicon	0.35	0.35	0.35	0.35	0.35	0.35
Nickel	. . .	. . .	3.75	. . .	2.00	2.50
Chromium	. . .	. . .	. . .	1.10	1.00	1.25
Molybdenum	. . .	. . .	. . .	0.25	0.30	0.60
Vanadium	. . .	. . .	. . .	. . .	. . .	0.20

TABLE X2.2 Class/Grade Guide

Class	Brinell Hardness	Applicable Grades
Carbon Steel		
A	183 max	X1
B	120–174	X1
C	137–183	X1, X2
D	149–207	X1, X2
E	174–217	X2
F	187–235	X2
Alloy Steel		
G	163–207	X3, X4
H	187–235	X3, X4
J	197–255	X3, X4, X5
K	212–269	X3, X5
L	255–321	X4, X5
M	293–352	X5, X6
N	331–401	X6

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 668/A 668M-03 that may impact the use of this standard.

(1) Deletion of Table 2 and Incorporation of Section 10 with Section 4..
(2) Deletion of original sections 8, 9, 12, 13, 14 and 15.
(3) Addition of new section 9.
(4) Sections 11, and 16 renumbered as 8 and 10 respectively.
(5) New scope items 1.4 and 1.8 added and original 1.4, 1.5 and 1.6 renumbered. Supplementary requirement S13 deleted.
(1) Added 7.1.4.5, added new 4.2.3, re-numbered prior 4.1.3 and 4.1.4 to 4.1.4 and 4.1.5, respectively.

Standard Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties[1]

This standard is issued under the fixed designation A 675/A 675M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification[2] covers hot-wrought special quality carbon steel bars and bar size shapes produced to mechanical property requirements and intended for general constructional applications.

1.2 The bars are available in nine strength grades designated 45, 50, 55, 60, 65, 70, 75, 80, and 90 [310, 345, 380, 415, 450, 485, 515, 550, and 620] corresponding to the minimum ultimate tensile strength in ksi [MPa]. The chemical composition is selected by the manufacturer to develop the required mechanical properties.

1.3 Hot-wrought special quality carbon steel bars subject to mechanical property requirements are hot wrought in straight lengths only. Sections and sizes available are covered in Specification A 29/A 29M.

1.4 Some applications may require one or more of the available designations shown under Supplementary Requirements.

NOTE 1—Merchant-quality hot-wrought carbon steel bars subject to mechanical property requirements are covered in Specification A 663/A 663M.

1.5 The values stated in either inch-pound units or SI units are to be regarded separately as the standard. Within the text, the SI units are shown in brackets. The values stated in each system are not equivalents, therefore each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[3]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 663/A 663M Specification for Steel Bars, Carbon, Merchant Quality, Mechanical Properties[3]

E 290 Test Method for Semi-Guided Bend Test for Ductility of Metallic Materials

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *special quality*—Special quality bars are used when end use, method of fabrication, or subsequent processing treatment requires quality characteristics not available in merchant quality. Typical applications involve bending or machining for general constructional uses. Some end uses or fabricating procedures can necessitate one or more requirements which are described in the Supplementary Requirements.

4. Ordering Information

4.1 Orders for material under this specification should include the following information:

4.1.1 Quantity (weight or number of pieces),

4.1.2 Name of material (hot-wrought special quality bars),

4.1.3 Dimensions, including length,

4.1.4 Cross section (round, square, hexagon, equal leg angle, etc.),

4.1.5 Specification designation and date of issue,

4.1.6 Grade designation (Table 1),

4.1.7 Leaded steel, if required (6.2),

4.1.8 Copper bearing steel, if required (6.3),

4.1.9 Test report, if required (Section 10),

4.1.10 Supplementary Requirements or special requirements if required, and

4.1.11 Application and processing.

NOTE 2—A typical ordering description is as follows: 10 000 lb, [5000

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys, and is the direct responsibility of Subcommittee A01.15 on Bars.

Current edition approved October 10, 2003. Published November 2003. Originally approved in 1972. Last previous edition approved in 2000 as A 675/A 675M–90a (2000).

[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA 675 in Section II of that Code.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard.**

TABLE 1 Tensile Requirements

Grade Designa-tion^A	Tensile Strength	Yield Point, min^B		Elongation, min, %^C	
	ksi	ksi		8 in. or [200 mm] Gage Length	2 in. or [50 mm] Gage Length
45 [310]	45 to 55	22.5		27	33
50 [345]	50 to 60	25	[170]	25	30
55 [380]	55 to 65	27.5		23	26
60 [415]	60 to 72	30	[205]	21	22
65 [450]	65 to 77	32.5		17	20
70 [485]	70 to 85	35	[240]	14	18
75 [515]	75 to 90	37.5		14	18
80 [550]	80 min	40	[275]	13	17
90 [620]	90 min	55	[380]	10	14

^A When lead is required, add the letter "L" after the grade designation, for example, 45L.
^B When the tension test does not show a yield point (drop of the beam, halt of the pointer or sharp-kneed stress-strain diagram), yield strength shall be determined by either 0.5 % extension-under-load or 0.2 % offset. The minimum ksi (MPa) requirement does not change. The test report, if required, shall show yield strength.
^C See 7.1.1.3 through 7.1.1.6 for deduction in elongation due to section size.

kg] Hot Wrought Special Quality Carbon Steel Bars, 1 in. diameter × 10 ft, [25m × 3m] Round, ASTM A 675/A 675M dated ____ , Grade 50, [345] Copper Bearing, Test Report Required, S3 Special Straightness, Boiler Supports.

5. Materials and Manufacture

5.1 *Melting Practice*—The steel shall be made by one or more of the following primary processes: open-hearth, basic-oxygen, or electric-furnace. The primary melting may incorporate separate degassing or refining and may be followed by secondary melting using electroslag remelting or vacuum-arc remelting. Where secondary melting is employed, the heat shall be defined as all of the ingots remelted from a single primary heat.

5.2 *Deoxidation*:

5.2.1 Unless otherwise specified, the steel shall be rimmed, capped, semi-killed, or killed at the producer's option.

5.2.2 When required, the purchaser may specify the required deoxidation practice, dependent upon strength grade specified, purchaser's methods of fabrication, and end use requirements. Killed steels can be produced to coarse or fine austenitic grain size (Supplementary Requirement S1).

5.3 *Condition*—Unless otherwise specified, the bars shall be furnished as-rolled and not pickled, blast cleaned, or oiled. At the producer's option, bars may be cleaned for inspection.

6. Chemical Composition

6.1 The steel shall conform to the chemical requirements specified in Table 2.

6.2 *Leaded Steel*—When required, lead may be specified as an added element. When lead is specified as an added element, a range from 0.15 to 0.35 % inclusive shall be furnished. Such a steel is identified by adding the letter L after the grade designation, for example 60L [415L].

TABLE 2 Chemical Requirements (Heat Analysis)

Element	
Phosphorus, max	0.040
Sulfur, max	0.050
Copper, when copper steel is specified, min	0.20
Lead	^A

^A When required, lead may be specified as an added element. See 6.2.

6.3 *Copper-Bearing Steel*—When required copper may be specified as an added element. Copper-bearing steel is identified by stating "copper-bearing" on the purchase order.

6.4 When tension tests are waived in accordance with 7.1.1.2, chemistry consistent with the mechanical properties desired shall be applied.

7. Mechanical Properties

7.1 *Tension Tests*

7.1.1 *Requirements*:

7.1.1.1 The material as represented by the test specimen shall conform to the applicable requirements in Table 1.

7.1.1.2 Shapes less than 1 in.^{2} [645 mm^2] in cross section and bars (other than flats) less than ½ in. [12.5 mm] in thickness or diameter need not be subject to tension tests by the manufacturer.

7.1.1.3 For material over ¾ in. [19 mm] in thickness or diameter, a deduction of 0.25 % from the percentage of elongation in 8 in. [200 mm] specified in Table 1 shall be made for each increase of 1⁄32 in. [0.8 mm] in the specified thickness or diameter above ¾ in. [19 mm].

7.1.1.4 For material under 5⁄16 in. [8 mm] in thickness or diameter, a deduction of 2.00 % from the percentage of elongation in 8 in. [200 mm] specified in Table 1 shall be made for each decrease of 1⁄32 in. [0.8 mm] in the specified thickness or diameter below 5⁄16 in. [8 mm].

7.1.1.5 For Grades 45, 50, 55, 60, and 65 [310, 345, 380, and 415] for material over 2 in. [50 mm] in thickness or diameter, a deduction of 1.00 % from the percentage of elongation in 2 in. [50 mm] specified in Table 1 shall be made for each 1 in. [25 mm] of specified thickness or diameter or fraction thereof over 2 in. [50 mm] in thickness or diameter.

7.1.1.6 For Grades 70, 75, 80, and 90 [485, 515, 550 and 620] for material over 2 in. [50 mm] in thickness or diameter, a deduction of 1.00 % from the percentage of elongation in 2 in. [50 mm] specified in Table 1 shall be made for each 1 in. [25 mm] of specified thickness or diameter, or fraction thereof, over 2 in. [50 mm] in diameter or thickness, to a maximum deduction of 3 %.

7.1.2 *Test Specimens*:

7.1.2.1 Test specimens shall be prepared for testing from the material in its as-rolled condition unless otherwise specified (see Supplementary Requirements). The tension specimen may be aged as described in Test Methods and Definitions A 370.

7.1.2.2 Test specimens shall be taken longitudinally and may be tested in full thickness or section, or they may be machined to the dimensions shown in Fig. 4 or Fig. 5 of Test Methods and Definitions A 370. If test specimens are selected conforming to the dimensions of Fig. 5, they shall be machined from a position midway between the center and the surface of the bar.

7.1.2.3 Test specimens for shapes and flats may be machined to the form and dimensions shown in Fig. 4 of Test Methods and Definitions A 370 or with both edges parallel. Test specimens for material over 1½ in. [40 mm] in thickness or diameter may be machined to a thickness or diameter of at least ¾ in. [20 mm] for a length of at least 9 in. [230 mm], or they may conform to the dimensions shown in Fig. 5 of Test Methods and Definitions A 370.

7.1.3 *Number of Tests*—Two tension tests shall be made from each heat, unless the finished material from a heat is less than 50 tons [45 Mg], when one tension test will be sufficient. However, for material 2 in. [50 mm] and under in thickness, when the material from one heat differs ⅜ in. [9.5 mm] or more in thickness, one tension test shall be made from both the thickest and the thinnest material rolled (larger than the sizes in 7.1.1.2) regardless of the weight represented. For material over 2 in. [50 mm] thick, when the material from heat differs 1 in. [25 mm] or more in thickness, one tension test shall be made from both the thickest and the thinnest material rolled that is more than 2 in. [50 mm] thick regardless of the weight represented.

7.1.4 *Test Method*—Tension tests shall be made in accordance with Test Methods and Definitions A 370 using the applicable method for determining yield point.

7.2 *Bend Tests*:

7.2.1 *Requirements*:

7.2.1.1 Bend requirements apply only to flat bars (all sizes), bars other than flats less than ½ in. [12.5 mm] in thickness or diameter, and shapes less than 1 in.^{2} [645 mm^2] in cross section. When bend tests are required for other sizes, Supplementary Requirement S6 must be specified.

7.2.1.2 The bend test specimen shall stand being bent at room temperature through 180° without cracking on the outside of the bent portion, to an inside diameter which shall have the relation to the thickness or diameter of the specimen as given in Table 3.

7.2.2 *Test Specimens*:

7.2.2.1 Bend test specimens for material 1½ in. [40 mm] and under in diameter or thickness may be the full thickness of the section. For flat bars over 2 in. [50 mm] in width, the width may be reduced by milling to 1½ in. [40 mm].

7.2.2.2 Bend test specimens for material over 1½ in. [40 mm] in diameter or thickness may be machined to a thickness or diameter of at least ¾ in. [20 mm] or to 1 by ½ in. [25 by 12.5 mm] in section. Machined sides of bend test specimens may have the corners rounded to a radius of not over 1⁄16 in. [1.6 mm] for material 2 in. [50 mm] and under in thickness, and not over ⅛ in. [3.2 mm] in radius for material over 2 in. [50 mm] in thickness.

7.2.3 *Number of Tests*—When subject to bend test, two bend tests shall be made from each heat, unless the finished material from a heat is less than 50 tons [45 Mg], when one bend test will be sufficient. However, for material 2 in. [50 mm] and under in thickness, when the material from one heat differs ⅜ in. [9.5 mm] or more in thickness, one bend test shall be made from both the thickest and the thinnest material rolled regardless of the weight represented. For material over 2 in. [50 mm] thick, when the material from one heat differs 1 in. [25 mm] or more in thickness, one bend test shall be made from both the thickest and the thinnest material rolled that is more than 2 in. [50 mm] thick regardless of the weight represented.

7.2.4 *Test Methods*—Bend tests shall be made in accordance with Test Method E 290.

8. Workmanship, Finish, and Appearance

8.1 Bars shall be free of visible pipe, undue segregation, and injurious surface imperfections.

8.2 *Surface Finish*—The bars shall have a commercial hot-wrought finish obtained by conventional hot rolling. See 5.3 for producer's descaling option.

9. General Requirements

9.1 Material furnished under this specification shall conform to the applicable requirements for the current edition of Specification A 29/A 29 M.

10. Certification

10.1 When specified by the purchaser, a manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the heat analysis, tensile requirements, and bend test (if applicable)

TABLE 3 Bend Requirements

Grade Designation	Ratio of Bend Diameter to Thickness of Specimen for Thickness or Diameter of Bar, in. (mm)						
	¾ [20] and Under	Over ¾ [20] to 1 [25], incl	Over 1 [25] to 1½ , incl	Over 1½ [40] to 2 [50], incl	Over 2 [50] to 3 [75], incl	Over 3 [75] to 5 [125], incl	Over 5 [125]
45 [310]	flat	flat	½	1	1	2	3
50 [345]	flat	½	1	1½	2½	3	3½
55 [380]	½	1	1½	2	2½	3	3½
60 [415]	½	1	1½	2½	3	3½	4
65 [450]	1	1½	2	3	3½	4	5
70 [485]	1½	2	2½	3	3½	4	5
75 [515]	2	2	3	3½	4	4½	6
80 [550]	2	2½	3	3½	4	4½	6
90 [620][A]							

[A] Bend requirements are not required for Grade 90 [620], but may be specified by agreement between purchaser and manufacturer (see Supplementary Requirement S6).

test results shall be furnished. Only one test need be reported when the amount of material from a heat in a shipment is less than 10 tons [9 Mg] and when the thickness variations described in (7.1.3) and (7.2.3) are not exceeded. The report shall include the name of the manufacturer, ASTM designation number and year date and revision letter, if any, grade, heat number, and size.

10.2 The thickness of the product tested may not necessarily be the same as an individual ordered thickness since it is the heat that is tested rather than each ordered item.

10.3 When Supplementary Requirements are specified, the report shall include a statement of compliance with the requirement or the results of tests when the requirement involves measured test values.

11. Keywords

11.1 carbon steel bars; hot-wrought steel bars; steel bars

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order. Details of these supplementary requirements shall be agreed upon in writing by the manufacturer and purchaser. Supplementary requirements shall in no way negate any requirements of the specification itself.

S1. Grain Size

S1.1 The steel shall conform to the coarse austenitic grain size requirement, or the fine austenitic grain size requirement of Specification A 29/A 29M.

S2. Thermal Treatment

S2.1 When required, the purchaser may specify that the material be stress relieved.

S3. Special Straightness

S3.1 Bars may be specified to special straightness tolerance (refer to Specification A 29/A 29M).

S4. Cleaning

S4.1 The purchaser may specify that the surface of bars be descaled by pickling or blast cleaning.

S5. Coating

S5.1 The purchaser may specify oil on bars that have been descaled.

S6. Bend Requirement

S6.1 Bend requirements for Grade 90 [620] may be specified. The bend ratio shall be as agreed upon. Bend requirements for all other grades, when specified, shall be as specified in Table 3.

S7. Carbon Restriction

S7.1 On grades 45, 50, 55, and 60, carbon shall be 0.35 % max.

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 675/A 675M-90a (2000) that may impact the use of this standard.

(1) Added Supplementary Requirement S7.

Designation: A 681 – 94 (Reapproved 1999)

Standard Specification for Tool Steels Alloy[1]

This standard is issued under the fixed designation A 681; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers the chemical, mechanical, and physical requirements for available wrought alloy tool steel products.

1.2 These products, which include hot or cold finished bar, plate, sheet, strip, rod, wire, or forgings, are normally fabricated into tools, dies, or fixtures. The selection of a material for a particular application will depend upon design, service conditions, and desired properties.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are provided for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[2]

A 561 Practice for Macroetch Testing of Tool Steel Bars[3]

A 600 Specification for Tool Steel High Speed[3]

A 700 Practices for Packaging, Marking, and Loading Methods for Steel Products for Domestic Shipment[3]

E 3 Methods of Preparation of Metallographic Specimens[4]

E 30 Test Methods for Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron[5]

E 45 Test Methods for Determining the Inclusion Content of Steel[4]

E 59 Practice for Sampling Steel and Iron for Determination of Chemical Composition[5]

E 527 Practice for Numbering Metals and Alloys (UNS)[6]

2.2 *Military Standard:*

MIL-STD-163 Steel Mill Products, Preparation for Shipment and Storage[7]

2.3 *Federal Standards:*

Fed. Std. No. 123 Marking and Shipment (Civil Agencies)[7]

Fed. Std. No. 183 Continuous Identification Marking of Iron and Steel Products[7]

2.4 *Other Standards:*

SAE J1086 Recommended Practice for Numbering Metals and Alloys (UNS)[8]

3. Classification

3.1 Material in accordance with this specification is classified by chemical composition. Types correspond to respective AISI designations.

3.1.1 *Hot Work Tool Steels, Identification H*:

3.1.1.1 Types H10 to H19 are characterized by a controlled chromium content along with other alloying elements. The first four, containing molybdenum, offer excellent toughness and high hardenability and are frequently used in cold work applications requiring toughness at relatively high hardness levels.

3.1.1.2 Types H21 to H26 are characterized by a controlled tungsten content along with other alloying elements. These steels offer greater resistance to the softening effect of elevated service temperatures but exhibit a lower degree of toughness.

3.1.1.3 Types H41 to H43 are low-carbon modifications of molybdenum high speed tool steels (Note 1) and have characteristics similar to the tungsten types.

NOTE 1—High-speed tool steels are covered in Specification A 600.

3.1.2 *Cold Work Tool Steels, Identification A*—Types A2 to A10 cover a wide range of carbon and alloy contents but all have high hardenability and may be hardened in air. The low carbon Types A8 and A9 have less wear resistance but offer greater toughness than others in this group. Type A7, with high carbon and vanadium, offers exceptional wear resistance but at a very low level of toughness.

3.1.3 *Cold Work Tool Steels, Identification D*—Types D2 to D7 are characterized by high carbon and high chromium contents and exhibit high resistance to abrasion. The types containing molybdenum may be hardened in air and offer a high degree of dimensional stability in heat treatment.

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.29 on Tool Steels.

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[2] *Annual Book of ASTM Standards*, Vol 01.03.

[3] *Annual Book of ASTM Standards*, Vol 01.05.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] *Annual Book of ASTM Standards*, Vol 03.05.

[6] *Annual Book of ASTM Standards*, Vol 01.01.

[7] Available from the Standardization Documents, Order Desk, Bldg. 4, Section D 700 Robbins Ave. Philadelphia, PA 19111-5094 Attn: NPODS.

[8] Available from the Society of Automotive Engineers, 400 Commonwelth drive, Warrendale, PA 15096.

3.1.4 *Cold Work Tool Steels, Identification O*—Types O1 to O7 are low-alloy types that must be hardened by quenching in oil. Sizes over about 2 in. (50 mm) in cross section usually exhibit lower interior hardness.

3.1.5 *Shock-Resisting Steels, Identification S*—Types S1 to S7 vary in alloy content but are intended for shock-resisting applications.

3.1.6 *Special-Purpose Tool Steels, Identification L*—Types L2 to L6 are low-alloy steels with a wide range of carbon content. The low-carbon types are generally used for structural applications requiring good levels of toughness, while the high-carbon types may be used for short-run tools.

3.1.7 *Special-Purpose Tool Steels, Identification F*—Types F1 to F2 are high-carbon steels with varying tungsten content used primarily for relatively short-run fine edge cutting tools.

3.1.8 *Mold Steels, Identification P*:

3.1.8.1 Types P2 to P6 are very low-carbon steels and must be carburized after machining or hubbing.

3.1.8.2 Types P20 and P21 are usually supplied in the prehardened condition and can be placed in service directly after machining.

4. Ordering Information

4.1 Orders for material under this specification shall include the following information, as required to describe adequately the desired material:

4.1.1 Class of material (hot work tool steel, etc.),

4.1.2 Type (H11, D2, etc.),

4.1.3 Shape (sheet, strip, plate, flat bar, round bar, square bar, hexagon bar, octagon, special shapes),

4.1.4 Dimensions (thickness, width, diameter, length),

4.1.5 Finish (hot rolled, forged, blasted or pickled, cold drawn, machined, ground, precision ground and polished),

4.1.6 Condition (annealed, hardened and tempered, etc.),

4.1.7 ASTM designation and year of issue, and

4.1.8 Special requirements.

5. Materials and Manufacture

5.1 Unless otherwise specified, material covered by this specification shall be made by an electric melting process. It shall be made from ingots that have been reduced in cross section in such a manner and to such a degree as to ensure proper refinement of the ingot structure.

6. Chemical Composition

6.1 An analysis of each heat of steel shall be made by the manufacturer to determine the percentage of the elements specified, and these values shall conform to the requirements for chemical composition specified in Table 1. If requested or required, the chemical composition shall be reported to the purchaser or his representative.

6.2 Analysis may be made by the purchaser from finished bars and forgings by machining off the entire cross section and drilling parallel to the axis of the bar or forging at any point midway between the center and surface in accordance with the latest issue of Practice E 59. The chemical analysis of the drilling chips shall be made in accordance with the latest issue of Test Methods E 30. The chemical composition thus determined shall not vary from the limits specified in Table 1.

7. Hardness Requirements

7.1 Annealed hardness values shall be obtained in accordance with the latest issue of Test Methods and Definitions A 370, and shall not exceed the Brinell hardness values (or equivalent Rockwell hardness values) specified in Table 2.

7.2 Specimens for determination of minimum response to hardening shall be ¼ -in. (6.4-mm) thick disks cut so as to represent either the full cross-sectional area or that midway between the center and outer surface of the material. If the material form or size does not lend itself to accurate hardness determination on ¼ -in. thick cross-sectional disks, then longitudinal specimens may be used for hardness testing. Examples are round bars less than ½ in. (12.7 mm) in diameter or sheet. In this case, the specimen shall be a minimum of 3 in. (76 mm) in length and parallel flats shall be ground on the original mill surfaces. The specimens shall be heat treated as prescribed in Table 3.

7.2.1 The hardness of the specimen after the specified heat treatment shall meet the minimum hardness value for the particular type of steel shown in Table 3. Rockwell C tests should be used where possible but light load tests may be necessary on thin specimens. These tests should be specified by agreement between the seller and the purchaser. The hardness value shall be obtained in accordance with the latest issue of Test Methods and Definitions A 370, and shall be the average of at least five readings taken in an area midway between the center and surface of the largest dimension of the cross-sectional specimen or along the parallel surfaces of the longitudinal specimen.

8. Macrostructure

8.1 Specimens for the determination of the macrostructure shall represent the entire cross-sectional area in the annealed condition and be prepared in accordance with the latest issue of Practice A 561. Material supplied to this specification shall be capable of exhibiting a structure free of excessive porosity, segregation, slag, dirt or other nonmetallic inclusions, pipe, checks, cracks, and other injurious defects.

8.2 Macroetch severity levels for center porosity and ingot pattern, illustrated photographically in Practice A 561, shall not exceed the ratings specification in Table 4 for the appropriate material size and composition. More stringent requirements are available by agreement between seller and purchaser.

9. Decarburization

9.1 Specimens for the determination of decarburization shall represent a cross section of the material and be prepared in accordance with the latest issue of Methods E 3. Material supplied to this specification shall be capable, when examined at 20 times or greater magnification, of not exceeding the values given in Tables 5-8 for the appropriate size and shape of material. Lower limits of decarburization may be specified by agreement between the seller and purchaser.

9.2 Material ordered as ground and polished or ground finished or machine finished shall be free of scale and decarburization.

TABLE 1 Chemical Requirements, %[A]

UNS Designation[B]	Type	Carbon min	Carbon max	Manganese[C] min	Manganese[C] max	Phosphorus, max	Sulfur,[D] max	Silicon min	Silicon max	Chromium min	Chromium max	Vanadium min	Vanadium max	Tungsten min	Tungsten max	Molybdenum min	Molybdenum max	Nickel min	Nickel max
T20810	H10	0.35	0.45	0.20	0.70	0.030	0.030	0.80	1.25	3.00	3.75	0.25	0.75	...	...	2.00	3.00		
T20811	H11	0.33	0.43	0.20	0.60	0.030	0.030	0.80	1.25	4.75	5.50	0.30	0.60	...	...	1.10	1.60		
T20812	H12	0.30	0.40	0.20	0.60	0.030	0.030	0.80	1.25	4.75	5.50	0.20	0.50	1.00	1.70	1.25	1.75		
T20813	H13	0.32	0.45	0.20	0.60	0.030	0.030	0.80	1.25	4.75	5.50	0.80	1.20	...	...	1.10	1.75		
T20814	H14	0.35	0.45	0.20	0.60	0.030	0.030	0.80	1.25	4.75	5.50	...	...	4.00	5.25	...	...		
T20819	H19	0.32	0.45	0.20	0.50	0.030	0.030	0.15	0.50	4.00	4.75	1.75	2.20	3.75	4.50	0.30	0.55	Co 4.00–4.50	
T20821	H21	0.26	0.36	0.15	0.40	0.030	0.030	0.15	0.50	3.00	3.75	0.30	0.60	8.50	10.00	...	...		
T20822	H22	0.30	0.40	0.15	0.40	0.030	0.030	0.15	0.40	1.75	3.75	0.25	0.50	10.00	11.75	...	...		
T20823	H23	0.25	0.35	0.15	0.40	0.030	0.030	0.15	0.60	11.00	12.75	0.75	1.25	11.00	12.75	...	...		
T20824	H24	0.42	0.53	0.15	0.40	0.030	0.030	0.15	0.40	2.50	3.50	0.40	0.60	14.00	16.00	...	...		
T20825	H25	0.22	0.32	0.15	0.40	0.030	0.030	0.15	0.40	3.75	4.50	0.40	0.60	14.00	16.00	...	...		
T20826	H26	0.45	0.55[E]	0.15	0.40	0.030	0.030	0.15	0.40	3.75	4.50	0.75	1.25	17.25	19.00	...	...		
T20841	H41	0.60	0.75[E]	0.15	0.40	0.030	0.030	0.20	0.45	3.50	4.00	1.00	1.30	1.40	2.10	8.20	9.20		
T20842	H42	0.55	0.70[E]	0.15	0.40	0.030	0.030	0.20	0.45	3.75	4.50	1.75	2.20	5.50	6.75	4.50	5.50		
T20843	H43	0.50	0.65[E]	0.15	0.40	0.030	0.030	0.20	0.45	3.75	4.50	1.80	2.20	...	...	7.75	8.50		
T30102	A2	0.95	1.05	0.40	1.00	0.030	0.030	0.10	0.50	4.75	5.50	0.15	0.50	...	...	0.90	1.40		
T30103	A3	1.20	1.30	0.40	0.60	0.030	0.030	0.10	0.70	4.75	5.50	0.80	1.40	...	...	0.90	1.40		
T30104	A4	0.95	1.05	1.80	2.20	0.030	0.030	0.10	0.70	0.90	2.20	...	...	...	...	0.90	1.40		
T30105	A5	0.95	1.05	2.80	3.20	0.030	0.030	0.10	0.70	0.90	1.40	...	...	...	...	0.90	1.40		
T30106	A6	0.65	0.75	1.80	2.50	0.030	0.030	0.10	0.70	0.90	1.40	...	...	...	...	0.90	1.40		
T30107	A7	2.00	2.85	0.20	0.80	0.030	0.030	0.10	0.70	5.00	5.75	3.90	5.15	0.50	1.50	0.90	1.40		
T30108	A8	0.50	0.60	0.20	0.50	0.030	0.030	0.75	1.10	4.75	5.50	...	...	1.00	1.50	1.15	1.65		
T30109	A9	0.45	0.55	0.20	0.50	0.030	0.030	0.95	1.15	4.75	5.50	0.80	1.40	...	...	1.30	1.80	Ni 1.25–1.75	
T30110	A10	1.25	1.50	1.60	2.10	0.030	0.030	1.00	1.50	...	...	...	...	...	...	1.25	1.75	Ni 1.55–2.05	
T30402	D2	1.40	1.60	0.10	0.60	0.030	0.030	0.10	0.60	11.00	13.00	0.50	1.10	...	...	0.70	1.20	...	
T30403	D3	2.00	2.35	0.10	0.60	0.030	0.030	0.10	0.60	11.00	13.50	...	1.00	...	1.00	...	...		
T30404	D4	2.05	2.40	0.10	0.60	0.030	0.030	0.10	0.60	11.00	13.00	0.15	1.00	...	...	0.70	1.20		
T30405	D5	1.40	1.60	0.10	0.60	0.030	0.030	0.10	0.60	11.00	13.00	...	1.00	...	...	0.70	1.20	Co 2.50–3.50	
T30407	D7	2.15	2.50	0.10	0.60	0.030	0.030	0.10	0.60	11.50	13.50	3.80	4.40	...	...	0.70	1.20		
T31501	O1	0.85	1.00	1.00	1.40	0.030	0.030	0.10	0.50	0.40	0.70	...	0.30	0.40	0.60	...	...		
T31502	O2	0.85	0.95	1.40	1.80	0.030	0.030	...	0.50	...	0.50	...	0.30	...	...	...	0.30		
T31506	O6	1.25	1.55	0.30	1.10	0.030	0.030	0.55	1.50	...	0.30	...	...	...	...	0.20	0.30		
T31507	O7	1.10	1.30	0.20	1.00	0.030	0.030	0.10	0.60	0.35	0.85	0.15	0.40	1.00	2.00	...	0.30		
T41901	S1	0.40	0.55	0.10	0.40	0.030	0.030	0.15	1.20	1.00	1.80	0.15	0.30	1.50	3.00	...	0.50		
T41902	S2	0.40	0.55	0.30	0.50	0.030	0.030	0.90	1.20	...	...	...	0.50	...	...	0.30	0.60		
T41904	S4	0.50	0.65	0.60	0.95	0.030	0.030	1.75	2.25	0.10	0.50	0.15	0.35	...	...	...	...	...	...
T41905	S5	0.50	0.65	0.60	1.00	0.030	0.030	1.75	2.25	0.10	0.50	0.15	0.35	...	...	0.20	1.35	...	...
T41906	S6	0.40	0.50	1.20	1.50	0.030	0.030	2.00	2.50	1.20	1.50	0.20	0.40	...	...	0.30	0.50	...	...
T41907	S7	0.45	0.55	0.20	0.90	0.030	0.030	0.20	1.00	3.00	3.50	...	0.35	...	...	1.30	1.80	...	...
T61202	L2	0.45	1.00	0.10	0.90	0.030	0.030	0.10	0.50	0.70	1.20	0.10	0.30	...	...	...	0.25	...	...
T61203	L3	0.95	1.10	0.25	0.80	0.030	0.030	0.10	0.50	1.30	1.70	0.10	0.30	...	...	...	...	...	...
																		Nickel	
T61206	L6	0.65	0.75	0.25	0.80	0.030	0.030	0.10	0.50	0.60	1.20	...	...	...	...	...	0.50	1.25	2.00
T60601	F1	0.95	1.25	...	0.50	0.030	0.030	0.10	0.50	...	...	...	...	1.00	1.75	...	...	...	...
T60602	F2	1.20	1.40	0.10	0.50	0.030	0.030	0.10	0.50	0.20	0.40	...	...	3.00	4.50	...	...	...	...
T51602	P2	...	0.10	0.10	0.40	0.030	0.030	0.10	0.40	0.75	1.25	...	...	...	...	0.15	0.40	0.10	0.50
T51603	P3	...	0.10	0.20	0.60	0.030	0.030	...	0.40	0.40	0.75	...	...	...	...	...	...	1.00	1.50
T51604	P4	...	0.12	0.20	0.60	0.030	0.030	0.10	0.40	4.00	5.25	...	...	...	...	0.40	1.00	...	...
T51605	P5	0.06	0.10	0.20	0.60	0.030	0.030	0.10	0.40	2.00	2.50	...	...	...	...	...	...	...	0.35
T51606	P6	0.05	0.15	0.35	0.70	0.030	0.030	0.10	0.40	1.25	1.75	...	...	...	...	...	...	3.25	3.75
T51620	P20	0.28	0.40	0.60	1.00	0.030	0.030	0.20	0.80	1.40	2.00	...	...	...	...	0.30	0.55	...	...
T51621	P21[F]	0.18	0.22	0.20	0.40	0.030	0.030	0.20	0.40	0.20	0.30	0.15	0.25	...	...	...	...	3.90	4.25

[A] Chemistry limits include product analysis tolerances. Unless otherwise specified, nickel plus copper equal 0.75 % max for all types.
[B] New designation established in accordance with Practice E 527 and SAEJ1086.
[C] Manganese limit is 1.0 % max for H13 resulfurized.
[D] Where specified, sulfur may be 0.06 to 0.15 % to improve machinability.
[E] Available in several carbon ranges.
[F] Also contains 1.05–1.25 % aluminum.

10. Permissible Variations for Dimensions

10.1 Permissible variations for dimensions shall not exceed the applicable limits stated in Tables 9-28.

11. Workmanship, Finish, and Appearance

11.1 All alloy tool steels shall be free of heavy scale, deep pitting, laps, porosity, injurious segregations, excessive non-metallic inclusions, seams, cracks, checks, slivers, scale marks, dents, soft and hard spots, pipes, or any defects that would detrimentally affect the suitability of the material after removal of the recommended stock allowance.

TABLE 2 Maximum Brinell Hardness in Annealed or Cold-Drawn Condition

Type	Annealed BHN	Cold Drawn BHN	Type	Annealed BHN	Cold Drawn BHN
H10	229	255	O1	212	241
H11	235	262	O2	217	241
H12	235	262	O6	229	241
H13	235	262	O7	241	255
H14	235	262			
H19	241	262	S1	229	255
H21	235	262	S2	217	241
H22	235	262	S4	229	255
H23	255	269	S5	229	255
H24	241	262	S6	229	255
H25	235	262	S7	229	255
H26	241	262			
			L2	197	241
H41	235	262	L3	201	241
H42	235	262	L6	235	262
H43	235	262			
			F1	207	241
A2	248	262	F2	235	262
A3	229	255			
A4	241	262	P2	100	. . .
A6	248	262	P3	143	. . .
A7	269	285	P4	131	. . .
A8	241	262	P5	131	. . .
A9	248	262	P6	212	. . .
A10	269	285	P20	[A]	. . .
			P21	[A]	. . .
D2	255	269			
D3	255	269			
D4	255	269			
D5	255	269			
D7	262	277			

[A] Normally furnished in prehardened condition.

12. Sampling

12.1 Each particular shipment of a heat of steel by type, size, and shape shall be considered a lot and must conform to the provisions of this specification.

13. Inspection

13.1 Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. The supplier may utilize his own facilities or any other acceptable to the purchaser.

13.2 When specified in the purchase order, the inspector representing the purchaser shall have access to the material subject to inspection for the purpose of witnessing the selection of samples, preparation of test pieces, and performance of the tests. For such tests, the inspector shall have the right to indicate the pieces from which samples will be selected. Otherwise the seller shall report to the purchaser, or his representative, the results of the chemical analysis and the physical and mechanical property tests made in accordance with this specification.

13.3 The purchaser may perform any of the inspections set forth in this specification on the as-received material where such inspections are deemed necessary to ensure that supplies and services conform to the prescribed requirements.

14. Rejection and Rehearing

14.1 Unless otherwise specified, any rejections based on tests made in accordance with this specification shall be reported to the seller within 30 days from the date of receipt of the material.

14.2 Material that shows injurious defects subsequent to its acceptance by the purchaser shall be rejected and the seller notified.

14.3 Samples tested in accordance with this specification that represent rejected material shall be preserved for 30 days from the date of the test report. In case of dissatisfaction with the results of the test, the seller may make claim for a rehearing within that time.

15. Packaging, Loading, and Package Marking

15.1 *Packaging and Loading*:

15.1.1 Unless otherwise specified, shipments shall be packaged and loaded in accordance with Practices A 700.

15.1.2 When specified in the contract or order, and for direct procurement by or direct shipment to the government, when Level A is specified, preservation, packaging, and loading shall be in accordance with the Level A requirement of MIL-STD-163.

15.2 *Markings*:

15.2.1 Shipments shall be properly marked with the name or brand of manufacturer, purchaser's name and order number, designation (ASTM A 681), heat number, grade or type, and where appropriate, the size, length, and weight. Unless otherwise specified, method of marking is at the option of the manufacturer.

15.2.2 When specified in the contract or order, and for direct procurement by or direct shipment to the government, marking for shipment, in addition to any requirements specified in the contract or order, shall be in accordance with MIL-STD-163 for military agencies, and in accordance with Fed. Std. No. 123 for civil agencies.

15.2.3 For government procurement by the Defense Supply Agency, steel shall be continuously marked for identification in accordance with Fed. Std. No. 183.

TABLE 3 Heat-Treating Requirements

NOTE 1—The austenitizing temperatures are stipulated for the response to hardening test only. Other combinations of austenitizing and tempering temperatures may be used for particular applications.

NOTE 2—Preheating temperature may be ±25°F (14°C), but austenitizing and tempering temperatures shall be ±10°F (5.6°C). If samples are austenitized in salt, the sample shall be at the austenitizing temperature for the minimum time shown. If a controlled atmosphere furnace is used, the sample shall be at the austenitizing temperature for 5 to 15 min (10 to 20 min for D types). The time at temperature is the time after the sample reaches the austenitizing temperature. This range of time is given because of the difficulty in determining when the sample reaches temperature in some types of controlled atmosphere furnaces.

NOTE 3—Those steels tempered at 400°F (204°C) shall have a single 2-h temper, while those tempered at 950 (510), 1025 (552), or 1200°F (649°C) shall be double-tempered for 2 h each cycle.

NOTE 4—The P types shall not be tested for response to heat treatment since P2 to P6 are used in the carburized condition and P20 are normally furnished in the prehardened condition.

NOTE 5—Specimens as described in 7.2 shall be capable of producing the specified minimum hardness when the stipulated heat treating parameters are used.

Type	Preheat Temperature, °F (°C)	Austenitizing Temperature, °F (°C)		Austenitizing Time (minutes)	Quench Medium	Tempering Temperature, °F (°C)	Minimum Hardness, RC
		Salt Bath	Controlled Atmosphere Furnaces				
H10	1450 (788)	1850 (1010)	1875 (1024)	5–15	Air	1025 (552)	55
H11	1450 (788)	1825 (996)	1850 (1010)	5–15	Air	1025 (552)	53
H12	1450 (788)	1825 (996)	1850 (1010)	5–15	Air	1025 (552)	53
H13	1450 (788)	1825 (996)	1850 (1010)	5–15	Air	1025 (552)	52
H14	1450 (788)	1900 (1038)	1925 (1052)	5–15	Air	1025 (552)	55
H19	1450 (788)	2150 (1177)	2175 (1191)	5–15	Air	1025 (552)	55
H21	1450 (788)	2150 (1177)	2175 (1191)	5–15	Air	1025 (552)	52
H22	1450 (788)	2150 (1177)	2175 (1191)	5–15	Air	1025 (552)	53
H23	1500 (816)	2275 (1246)	2300 (1260)	5–15	Oil	1200 (649)	42
H24	1450 (788)	2200 (1204)	2225 (1218)	5–15	Air	1025 (552)	55
H25	1450 (788)	2250 (1232)	2275 (1246)	5–15	Air	1025 (552)	44
H26	1550 (843)	2275 (1246)	2300 (1260)	5–15	Air	1025 (552)	58
H41	1450 (788)	2125 (1163)	2150 (1177)	5–15	Air	1025 (552)	60
H42	1450 (788)	2175 (1191)	2200 (1204)	5–15	Air	1025 (552)	60
H43	1450 (788)	2150 (1177)	2175 (1191)	5–15	Air	1025 (552)	58
A2	1450 (788)	1725 (941)	1750 (954)	5–15	Air	400 (204)	60
A3	1450 (788)	1775 (968)	1800 (982)	5–15	Air	400 (204)	63
A4	1250 (677)	1550 (843)	1575 (857)	5–15	Air	400 (204)	61
A6	1200 (649)	1525 (829)	1550 (843)	5–15	Air	400 (204)	58
A7	1500 (816)	1750 (954)	1775 (968)	5–15	Air	400 (204)	63
A8	1450 (788)	1825 (996)	1850 (1010)	5–15	Air	950 (510)	56
A9	1450 (788)	1825 (996)	1850 (1010)	5–15	Air	950 (510)	56
A10	1200 (649)	1475 (802)	1500 (816)	5–15	Air	400 (204)	59
D2	1500 (816)	1825 (996)	1850 (1010)	10–20	Air	400 (204)	59
D3	1500 (816)	1750 (954)	1775 (968)	10–20	Oil	400 (204)	61
D4	1500 (816)	1800 (982)	1825 (996)	10–20	Air	400 (204)	62
D5	1500 (816)	1825 (996)	1850 (1010)	10–20	Air	400 (204)	61
D7	1500 (816)	1925 (1052)	1950 (1066)	10–20	Air	400 (204)	63
O1	1200 (649)	1450 (788)	1475 (802)	5–15	Oil	400 (204)	59
O2	1200 (649)	1450 (788)	1475 (802)	5–15	Oil	400 (204)	59
O6	. . .	1450 (788)	1475 (802)	5–15	Oil	400 (204)	59
O7	1200 (649)	1575 (857)	1600 (871)	5–15	Oil	400 (204)	62
S1	1250 (677)	1725 (941)	1750 (954)	5–15	Oil	400 (204)	56
S2	1250 (677)	1625 (885)	1650 (899)	5–15	Brine	400 (204)	58
S4	1250 (677)	1625 (885)	1650 (899)	5–15	Oil	400 (204)	58
S5	1250 (677)	1625 (885)	1650 (899)	5–15	Oil	400 (204)	58
S6	1450 (788)	1700 (927)	1725 (941)	5–15	Oil	400 (204)	56
S7	1250 (677)	1725 (941)	1750 (954)	5–15	Air	400 (204)	56
L2	1200 (649)	1575 (857)	1600 (871)	5–15	Oil	400 (204)	53[A]
L3	1200 (649)	1525 (829)	1550 (843)	5–15	Oil	400 (204)	62
L6	1200 (649)	1500 (816)	1525 (829)	5–15	Oil	400 (204)	58
F1	1200 (649)	1525 (829)	1550 (843)	5–15	Brine	400 (204)	64
F2	1200 (649)	1525 (829)	1550 (843)	5–15	Brine	400 (204)	64

[A] 0.45–0.55 % carbon type.

TABLE 4 Macroetch Standards (Maximum Allowable Rating)[A]

Bar Size, in. (mm)	Low-Alloy Tool Steels[B]		High-Alloy Tool Steels[C]	
	Porosity	Ingot Pattern	Porosity	Ingot Pattern
Up to 2 (50.8), incl	4	6	3	6
Over 2 to 3 (50.8 to 76), incl	4½	6	3½	6
Over 3 to 4 (76 to 102), incl	4½	6	4	6
Over 4 to 5 (102 to 127), incl	5	6	4½	6
Over 5 to 6 (127 to 152), incl	5	6	5	6
Over 6 (152)	As negotiated between seller and purchaser.			

[A] Refer to macroetch photographs in Practice A 561.
[B] Low-alloy tool steels include H10-13, A2-6, A8-10, A11O,S,L,F, and P types.
[C] High-alloy tool steels include H14-43, D2-7, and A7.

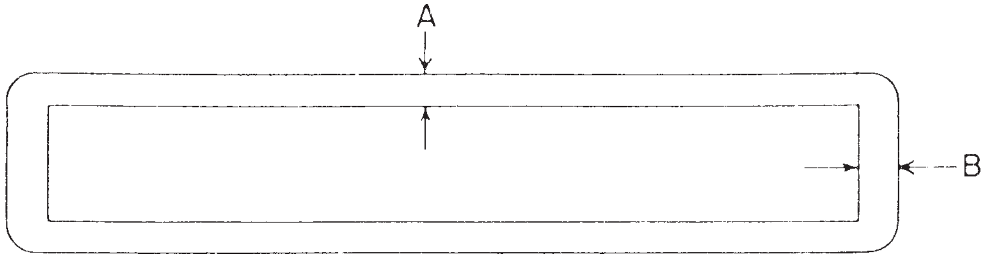
TABLE 5 Maximum Decarburization Limits (Rounds, Hexagons and Octagons Maximum Limit Per Side)

NOTE 1—The recommended minimum allowance for machining prior to heat treatment is 25 % greater than the maximum decarburization allowed.

Ordered Size, in. (mm)	Hot Rolled	Forged	Cold Drawn
Up to ½ (12.7), incl	0.013 (0.33)	. . .	0.013 (0.33)
Over ½ to 1 (12.7 to 25.4), incl	0.025 (0.64)	. . .	0.025 (0.64)
Over 1 to 2 (25.4 to 50.8), incl	0.038 (0.97)	0.058 (1.47)	0.038 (0.96)
Over 2 to 3 (50.8 to 76), incl	0.050 (1.27)	0.075 (1.91)	0.050 (1.27)
Over 3 to 4 (76 to 102), incl	0.070 (1.78)	0.096 (2.44)	0.070 (1.78)
Over 4 to 5 (102 to 127), incl	0.090 (2.29)	0.116 (2.95)	. . .
Over 5 to 6 (127 to 152), incl	0.120 (3.05)	0.136 (3.45)	. . .
Over 6 to 8 (152 to 203), incl	. . .	0.160 (4.06)	. . .
Over 8 to 10 (203 to 254), incl	. . .	0.160 (4.06)	. . .

TABLE 6 Maximum Decarburization Limits
(Hot Rolled Square and Flat Bars Maximum Limit Per Side)

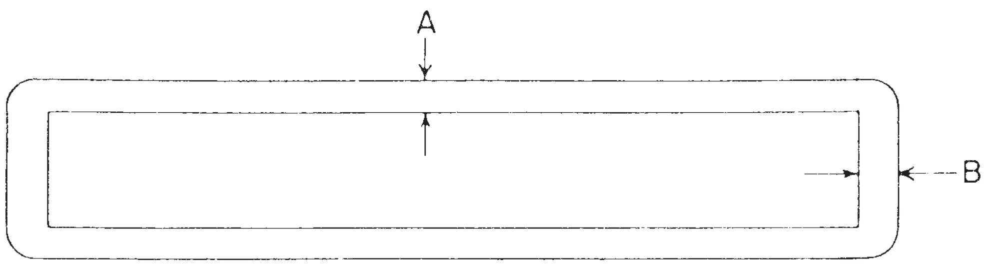
NOTE 1—The recommended minimum allowance for machining prior to heat treatment is 25 % greater than the maximum decarburization allowed.



Specified Thickness, in. (mm)		Specified Widths, in. (mm)										
		0 to ½ (0 to 12.7) incl	Over ½ to 1 (12.7 to 25.4), incl	Over 1 to 2 (25.4 to 50.8), incl	Over 2 to 3 (50.8 to 76), incl	Over 3 to 4 (76 to 102), incl	Over 4 to 5 (102 to 127), incl	Over 5 to 6 (127 to 152), incl	Over 6 to 7 (152 to 178), incl	Over 7 to 8 (178 to 203), incl	Over 8 to 9 (203 to 229), incl	Over 9 to 12 (229 to 304), incl
0 to ½ (0 to 12.7), incl	A	0.020 (0.51)	0.020 (0.51)	0.024 (0.61)	0.028 (0.71)	0.032 (0.81)	0.036 (0.91)	0.040 (1.02)	0.044 (1.12)	0.048 (1.22)	0.048 (1.22)	0.048 (1.22)
	B	0.020 (0.51)	0.026 (0.66)	0.032 (0.81)	0.038 (0.97)	0.044 (1.12)	0.054 (1.37)	0.062 (1.57)	0.066 (1.68)	0.078 (1.98)	0.082 (2.08)	0.096 (2.44)
Over ½ to 1 (12.7 to 25.4), incl	A	. . .	0.036 (0.91)	0.036 (0.91)	0.036 (0.91)	0.040 (1.02)	0.044 (1.12)	0.052 (1.32)	0.056 (1.42)	0.060 (1.52)	0.060 (1.52)	0.060 (1.52)
	B	. . .	0.036 (0.91)	0.042 (1.07)	0.046 (1.17)	0.056 (1.42)	0.064 (1.63)	0.082 (2.08)	0.090 (2.29)	0.098 (2.49)	0.102 (2.59)	0.108 (2.74)
Over 1 to 2 (25.4 to 50.8), incl	A	. . .	. . .	0.052 (1.32)	0.052 (1.32)	0.056 (1.42)	0.056 (1.42)	0.060 (1.52)	0.060 (1.52)	0.064 (1.63)	0.068 (1.73)	0.072 (1.83)
	B	. . .	. . .	0.052 (1.32)	0.056 (1.42)	0.060 (1.52)	0.072 (1.83)	0.086 (2.18)	0.098 (2.49)	0.112 (2.84)	0.118 (3.00)	0.122 (3.10)
Over 2 to 3 (50.8 to 76), incl	A	. . .	. . .	. . .	0.064 (1.63)	0.064 (1.63)	0.068 (1.73)	0.068 (1.73)	0.072 (1.83)	0.072 (1.83)	0.080 (2.03)	0.080 (2.03)
	B	. . .	. . .	. . .	0.064 (1.63)	0.072 (1.83)	0.082 (2.08)	0.094 (2.39)	0.110 (2.79)	0.122 (3.10)	0.130 (3.30)	0.136 (3.45)
Over 3 to 4 (76 to 102), incl	A	. . .	. . .	. . .	. . .	0.080 (2.03)	0.080 (2.03)	0.086 (2.18)	0.092 (2.34)	0.094 (2.39)	0.100 (2.54)	0.100 (2.54)
	B	. . .	. . .	. . .	. . .	0.080 (2.03)	0.090 (2.29)	0.100 (2.54)	0.120 (3.05)	0.132 (3.35)	0.132 (3.35)	0.150 (3.81)

TABLE 7 Maximum Decarburization Limits
(Forged Square and Flat Bars Maximum Limit Per Side)

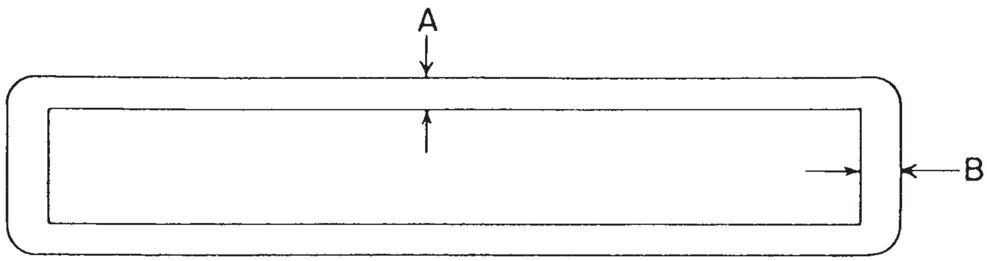
NOTE 1—The recommended minimum allowance for machining prior to heat treatment is 25 % greater than the maximum decarburization allowed.



Specified Thickness, in. (mm)		Specified Width, in. (mm)								
		Over 1 to 2 (25.4 to 50.0), incl	Over 2 to 3 (50.8 to 76), incl	Over 3 to 4 (76 to 102), incl	Over 4 to 5 (102 to 127), incl	Over 5 to 6 (127 to 152), incl	Over 6 to 7 (152 to 178), incl	Over 7 to 8 (178 to 203), incl	Over 8 to 9 (203 to 229), incl	Over 9 to 12 (229 to 305), incl
Over 12 to 1, (12.7 to 25.4), incl	A	0.038 (0.97)	0.042 (1.07)	0.048 (1.32)	0.052 (1.32)	0.056 (1.42)	0.062 (1.57)	0.066 (1.68)	0.072 (1.83)	0.080 (2.03)
	B	0.048 (1.22)	0.056 (1.42)	0.070 (1.78)	0.080 (2.03)	0.94 (2.39)	0.110 (2.79)	0.132 (3.35)	0.132 (3.35)	0.132 (3.35)
Over 1 to 2, (25.4 to 50.8), incl	A	0.058 (1.47)	0.062 (1.57)	0.066 (1.68)	0.070 (1.78)	0.074 (1.78)	0.080 (1.88)	0.084 (2.03)	0.094 (2.39)	0.106 (2.69)
	B	0.058 (1.47)	0.066 (1.68)	0.078 (1.98)	0.086 (2.18)	0.100 (2.54)	0.114 (2.90)	0.132 (3.35)	0.132 (3.35)	0.132 (3.35)
Over 2 to 3 (50.8 to 76), incl	A	. . .	0.080 (2.03)	0.084 (2.13)	0.088 (2.24)	0.092 (2.34)	0.098 (2.49)	0.106 (2.69)	0.114 (2.90)	0.126 (3.20)
	B	. . .	0.080 (2.03)	0.092 (2.34)	0.098 (2.49)	0.016 (2.69)	0.118 (3.00)	0.136 (3.45)	0.136 (3.45)	0.136 (3.45)
Over 3 to 4 (76 to 102), incl	A	. . .	. . .	0.102 (2.59)	0.106 (2.69)	0.112 (2.84)	0.120 (3.05)	0.132 (3.35)	0.140 (3.35)	0.158 (4.01)
	B	. . .	. . .	0.102 (2.59)	0.106 (2.69)	0.112 (2.84)	0.120 (3.05)	0.132 (3.35)	0.140 (3.56)	0.158 (4.01)
Over 4 to 5 (102 to 127), incl	A	. . .	. . .	. . .	0.126 (3.20)	0.130 (3.30)	0.138 (3.51)	0.146 (3.71)	0.156 (3.96)	0.170 (4.32)
	B	. . .	. . .	. . .	0.126 (3.20)	0.130 (3.30)	0.138 (3.51)	0.146 (3.71)	0.156 (3.96)	0.170 (4.32)
Over 5 to 6 (127 to 152), incl	A	. . .	. . .	. . .	. . .	0.150 (3.81)	0.158 (4.01)	0.166 (4.22)	0.176 (4.47)	0.188 (4.78)
	B	. . .	. . .	. . .	. . .	0.150 (3.81)	0.158 (4.01)	0.166 (4,22)	0.178 (4.47)	0.188 (4.78)
Over 6 to 7 (152 to 178) incl	A	. . .	. . .	. . .	. . .	. . .	0.178 (4.47)	0.186 (4.72)	0.186 (4.72)	0.198 (5.03)
	B	. . .	. . .	. . .	. . .	. . .	0.176 (4.47)	0.186 (4.72)	0.186 (4.72)	0.198 (5.03)

TABLE 8 Maximum Decarburization Limits
(Cold Drawn Square and Flat Bars Maximum Limits Per Side)

NOTE 1—The recommended minimum allowance for machining prior to heat treatment is 25 % greater than the maximum decarburization allowed.



Specified Thickness, in. (mm)		Specified Width, in. (mm)					
		0 to ½ (0 to 12.7), incl	Over ½ to 1 (12.7 to 25.4), incl	Over 1 to 2 (25.4 to 50.8), incl	Over 2 to 3 (50.8 to 76), incl	Over 3 to 4 (76 to 102), incl	Over 4 to 5 102 to 127), incl
0 to ½ (0 to 12.7), incl	A	0.020 (0.51)	0.020 (0.51)	0.024 (0.61)	0.028 (0.71)	0.032 (0.81)	0.036 (0.91)
	B	0.020 (0.51)	0.026 (0.66)	0.032 (0.81)	0.038 (0.97)	0.044 (1.12)	0.054 (1.37)
Over ½ to 1 (12.7 to 25.4), incl	A	. . .	0.036 (0.91)	0.036 (0.91)	0.036 (0.91)	0.040 (1.02)	0.044 (1.12)
	B	. . .	0.036 (0.91)	0.042 (1.07)	0.046 (1.17)	0.056 (1.42)	0.064 (1.63)
Over 1 to 2 (25.4 to 50.8), incl	A	. . .	. . .	0.052 (1.32)	0.052 (1.32)	0.056 (1.42)	. . .
	B	. . .	. . .	0.052 (1.32)	0.056 (1.42)	0.060 (.152)	. . .

TABLE 9 Hot-Rolled Bars
(Rounds, Squares, Octagons, Quarter Octagons, Hexagons Size Tolerance)

Specified Sizes, in. (mm)	Size Tolerances, in. (mm)	
	Under	Over
To ½ (12.7), incl	0.005 (0.13)	0.012 (0.30)
Over ½ to 1 (12.7 to 25.4), incl	0.005 (0.13)	0.016 (0.41)
Over 1 to 1½ (25.4 to 38.1), incl	0.006 (0.15)	0.020 (0.51)
Over 1½ to 2 (38.1 to 50.8), incl	0.008 (0.20)	0.025 (0.64)
Over 2 to 2½ (50.8 to 63.5), incl	0.010 (0.25)	0.030 (0.76)
Over 2½ to 3 (63.5 to 76.2), incl	0.010 (0.25)	0.040 (1.02)
Over 3 to 4 (76.2 to 101.6), incl	0.012 (0.30)	0.050 (1.27)
Over 4 to 5½ (101.6 to 139.7), incl	0.015 (0.38)	0.060 (1.52)
Over 5½ to 6½ (139.7 to 165.1), incl	0.018 (0.46)	0.100 (2.54)
Over 6½ to 8 (165.1 to 203.2), incl	0.020 (0.51)	0.150 (3.81)

TABLE 10 Forged Bars
(Rounds, Squares, Octagons, Hexagons Size Tolerances)[A]

Specified Sizes, in. (mm)	Size Tolerances, in. (mm)	
	Under	Over
Over 1 to 2 (25.4 to 50.8), incl	0.030 (0.76)	0.060 (1.52)
Over 2 to 3 (50.8 to 76), incl	0.030 (0.76)	0.080 (2.03)
Over 3 to 5 (76 to 127), incl	0.060 (1.52)	0.125 (3.18)
Over 5 to 7 (127 to 177.8) incl	0.125 (3.18)	0.187 (4.75)
Over 7 to 9 (177.8 to 229), incl	0.187 (4.75)	0.312 (7.92)

[A] Out-of-section tolerances to be three fourths of the total tolerance.

TABLE 11 Rough-Turned Round Bars
(Size Tolerance)[A]

Specified Sizes,[B] in. (mm)	Size Tolerance, in. (mm)	
	Under	Over
Over ¾ to 1½ (19.0 to 38.1), incl	0.00	0.010 (0.254)
Over 1½ to 3 1/16 (38.1 to 77.8), incl	0.00	0.015 (0.38)
Over 3 1/16 to 4 1/16 (77.8 to 103.2), incl	0.00	0.031 (0.79)
Over 4 1/16 to 6 1/16 (103.2 to 154), incl	0.00	0.062 (1.6)
Over 6 1/16 to 10 1/16 (154 to 255.6), incl	0.00	0.094 (2.4)
Over 10 1/16 Please consult producer		

[A] Out-of-round tolerances to be one half of the total tolerance.

[B] Consult producer for oversize allowance and decarburization limits for all sizes.

TABLE 12 Cold-Drawn Bars
(Rounds, Octagons, Quarter Octagons, and Hexagons Size Tolerances)[A]

Size Range, in. (mm)	Tolerance, in. (mm) Plus and Minus
¼ to ½ (6.4 to 12.7), excl	0.002 (0.05)
½ to 1 (12.7 to 25.4), excl	0.0025 (0.06)
1 to 2¾ (25.4 to 69.8), incl	0.003 (0.08)

[A] Out-of-round tolerances to be one half of the total thickness.

TABLE 13 Centerless Ground Bars Rounds (Diameter Tolerances)[A]

Diameter Range, in. (mm)	Tolerance, in. (mm)	
	Under	Over
¼ to ½ (6.4 to 12.7), excl	0.0015 (0.038)	0.0015 (0.038)
½ to 3¹⁄₁₆ (12.7 to 77.8), excl	0.002 (0.05)	0.002 (0.05)
3¹⁄₁₆ to 4¹⁄₁₆ (77.8 to 103.2), excl	0.003 (0.08)	0.003 (0.08)

[A] Out of round tolerances to be ½ of the total tolerance.

TABLE 14 Hot-Rolled Flat Bars (Width and Thickness Tolerances Width Tolerances)[A]

Specified Widths, in. (mm)	Width Tolerances, in. (mm)	
	Under	Over
To 1 (25.4), incl	0.016 (0.41)	0.031 (0.79)
Over 1 to 3 (25.4 to 76), incl	0.031 (0.79)	0.047 (1.19)
Over 3 to 5 (76 to 127), incl	0.047 (1.19)	0.063 (1.60)
Over 5 to 7 (127 to 178), incl	0.063 (1.60)	0.094 (2.39)
Over 7 to 10 (178 to 254), incl	0.078 (1.98)	0.125 (3.18)
Over 10 to 12 (254 to 305), incl	0.094 (2.39)	0.156 (3.96)

Specified Widths, in. (mm)	Thickness Tolerances for Specified Thicknesses, in. (mm)											
	To ¼ (6.4), incl		Over ¼ to ½ (6.4 to 12.7), incl		Over ½ to 1 (12.7 to 25.4), incl		Over 1 to 2 (25.4 to 50.8), incl		Over 2 to 3 (50.8 to 76), incl		Over 3 to 4 (76 to 102), incl	
	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over
To 1 (25.4), incl	0.006 (0.15)	0.010 (0.25)	0.008 (0.20)	0.012 (0.30)	0.010 (0.25)	0.016 (0.41)	. . .	. . .	. . .	. . .	. . .	. . .
Over 1 to 2 (25.4 to 50.8), incl	0.006 (0.15)	0.014 (0.36)	0.008 (0.20)	0.016 (0.41)	0.010 (0.25)	0.020 (0.51)	0.020 (0.51)	0.024 (0.61)	. . .	. . .	. . .	. . .
Over 2 to 3 (50.8 to 76),incl	0.006 (0.15)	0.018 (0.46)	0.008 (0.20)	0.020 (0.51)	0.010 (0.25)	0.024 (0.61)	0.020 (0.51)	0.027 (0.69)	0.026 (0.66)	0.034 (0.86)	. . .	. . .
Over 3 to 4 (76 to 102), incl	0.008 (0.20)	0.020 (0.51)	0.010 (0.25)	0.022 (0.56)	0.013 (0.33)	0.024 (0.61)	0.024 (0.61)	0.030 (0.76)	0.032 (0.81)	0.042 (1.07)	0.040 (1.02)	0.048 (1.22)
Over 4 to 5 (102 to 127), incl	0.010 (0.25)	0.020 (0.51)	0.012 (0.30)	0.024 (0.61)	0.015 (0.38)	0.030 (0.76)	0.027 (0.69)	0.035 (0.89)	0.032 (0.81)	0.042 (1.07)	0.042 (1.07)	0.050 (1.27)
Over 5 to 6 (127 to 152), incl	0.012 (0.30)	0.020 (0.51)	0.014 (0.36)	0.030 (0.76)	0.018 (0.46)	0.030 (0.76)	0.030 (0.76)	0.035 (0.89)	0.036 (0.91)	0.046 (1.17)	0.044 (1.12)	0.054 (1.37)
Over 6 to 7 (152 to 178), incl	0.014 (0.36)	0.027 (0.69)	0.016 (0.41)	0.032 (0.81)	0.018 (0.46)	0.035 (0.89)	0.030 (0.76)	0.040 (1.02)	0.036 (0.91)	0.048 (1.22)	0.046 (1.17)	0.056 (1.42)
Over 7 to 10 (178 to 254), incl	0.018 (0.46)	0.030 (0.76)	0.020 (0.51)	0.035 (0.89)	0.024 (0.61)	0.040 (1.02)	0.035 (0.89)	0.045 (1.14)	0.040 (1.02)	0.054 (1.37)	0.052 (1.32)	0.064 (1.62)
Over 10 to 12 (254 to 305), incl	0.020 (0.51)	0.035 (0.89)	0.025 (0.64)	0.040 (1.02)	0.030 (0.76)	0.045 (1.14)	0.040 (1.02)	0.050 (1.27)	0.046 (1.17)	0.060 (1.52)	0.056 (1.42)	0.072 (1.83)

[A] Out of square tolerance to be ¾ of total width tolerance max.

TABLE 15 Forged Flat Bars (Width Tolerances)

Specified Widths, in. (mm)	Width Tolerances, in. (mm) Under	Over
Over 1 to 3 (25.4 to 76), incl	0.031 (0.79)	0.078 (1.98)
Over 3 to 5 (76 to 127), incl	0.062 (1.57)	0.125 (3.18)
Over 5 to 7 (127 to 178), incl	0.125 (3.18)	0.187 (4.75)
Over 7 to 9 (178 to 229), incl	0.187 (4.75)	0.312 (7.92)

Specified Widths, in. (mm)	Thickness Tolerances for Specified Thicknesses, in. (mm)									
	To 1 (25.4), incl		Over 1 to 3 (25.4 to 76), incl		Over 3 to 5 (76 to 127), incl		Over 5 to 7 (127 to 178), incl		Over 7 to 9 (178 to 229), incl	
	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over
Over 1 to 3 (25.4 to 76), incl	0.016 (0.41)	0.031 (0.79)	0.031 (0.79)	0.078 (1.98)	. . .	. . .	. . .	. . .	. . .	. . .
Over 3 to 5 (76 to 127), incl	0.031 (0.79)	0.062 (1.57)	0.047 (1.19)	0.094 (2.39)	0.062 (1.57)	0.125 (3.18)	. . .	. . .	. . .	. . .
Over 5 to 7 (127 to 178), incl	0.047 (1.19)	0.094 (2.39)	0.062 (1.57)	0.125 (3.18)	0.078 (1.98)	0.156 (3.96)	0.125 (3.18)	0.187 (4.75)	. . .	. . .
Over 7 to 9 (178 to 229), incl	0.062 (1.57)	0.125 (3.18)	0.078 (1.98)	0.156 (3.96)	0.094 (2.39)	0.187 (4.75)	0.156 (3.96)	0.219 (5.56)	0.187 (4.75)	0.312 (7.92)

TABLE 16 Cold Drawn Square and Flat Bars (Size Tolerances)

Size Range, in. (mm)	Tolerance, in. (mm) Plus and Minus
¼ to ¾ (6.4 to 19.1), incl	0.002 (0.05)
Over ¾ to 1½ (19.1 to 38.1), incl	0.003 (0.08)
Over 1½ (38.1)	0.004 (0.10)

TABLE 17 Drill Rod, Rounds, Polished or Ground (Size Tolerances)^{A}

NOTE 1—Out-of-round to be ½ of total tolerance maximum.

Specified Size, in. (mm)	Standard Manufacturing Tolerance, in. (mm), plus and minus	Precision Tolerance, in. (mm), plus and minus
Up to 0.124 (3.15), incl	0.0003 (0.008)	0.0002 (0.005)
0.125 to 0.499 (3.18 to 12.7), incl	0.0005 (0.013)	0.00025 (0.006)
0.500 to 1.500 (12.7 to 38.1), incl	0.001 (0.025)	0.0005 (0.013)

^{A} Out-of-round tolerances to be one half of the total tolerance.

TABLE 18 Drill Rod, Shapes Other than Rounds, Cold Drawn (Size Tolerances)^{A}

Specified Size, in. (mm)	Tolerances, in. (mm), plus and minus
Up to ¼ (6.4), excl	0.0005 (0.013)
¼ to ¾ (6.4 to 19.0), excl	0.001 (0.025)
¾ to 1 (19.0 to 25.4), incl	0.0015 (0.038)

^{A} Out-of-round tolerances to be one half of the total tolerance.

TABLE 19 Precision Ground Square and Flat Bars (Thickness and Width Tolerances)

NOTE 1—Surface Finish, 35 µin. (0.89 µm) rms maximum. Free of decarburization.

Thickness, in. (mm)	Tolerance, in. (mm) Under	Over
	Thickness	
Up to 1¼ (31.8), incl	0.001 (0.03)	0.001 (0.03)
Over 1¼ to 2 (31.8 to 50.8), incl	0.002 (0.05)	0.002 (0.05)
	Width	
½ to 14 (12.7 to 355.6), incl	0.000	0.005 (0.13)

TABLE 20 Hot-Rolled or Forged Bars and Billets (Tolerances for Machine Cut Lengths)

Specified Sizes Apply to Rounds, Squares, Hexagons, Octagons, and Width of Flats, in. (mm)	Tolerances for Specified Lengths, 14 ft (4.27 m) max, in. (mm) Over	Under
To 9 (229), incl	⅜ (9.5)	0
Over 9 to 12 (229 to 305), incl	½ (12.7)	0
Over 12 to 18 (305 to 457), incl	¾ (19.1)	0
Over 18 (457)	1 (25.4)	0

TABLE 21 Straightened Hot-Rolled Annealed Bars or Cold-Finished Bars (Straightness Tolerances)

This table does not apply to flat bars having a width to thickness ratio of 6 to 1 or greater.

Measurement is taken on the concave side of the bar with a straightedge. Bars are furnished to the following straightness tolerances:

Hot rolled bars:

⅛ in. in any 5 ft, but may not exceed ⅛ in. × (no. of ft in length/5)

The foregoing formula applies also to bars under 5 ft in length. (3.2 mm in any 1.54 m, but may not exceed 3.2 mm × (no. of m in length/1.54). The foregoing formula applies also to bars under 1.54 m in length.)

Cold finished bars:

1⁄16 in. in any 5 ft, but may not exceed 1⁄16 in. × (no. of ft in length/5)

The foregoing formula applies also to bars under 5 ft in length. (1.6 mm in any 1.54 m, but may not exceed 1.6 mm × (no. of m in length/1.54). The foregoing formula applies also to bars under 1.54 m in length.)

TABLE 22 Forgings, Disks, Rings and Rectangular Blocks (Allowances for Machining; Tolerances Over Allowances)

NOTE 1—Unmachined tool steel forgings are furnished to size and surface allowances for machining and tolerances over allowances. Experience indicates that the allowances and tolerances in the tabulation below are satisfactory for many applications. When width and thickness differ, each dimension carries its individual allowance and tolerance in accordance with the tabulation; also, the ID and OD take their respective allowances and tolerances.

NOTE 2—When forgings are ordered, the purchaser should state whether the sizes are the forged or the finished sizes. The minimum sizes ordered for forgings should be the finished sizes plus allowances for machining; and the ordered forged sizes are subject to applicable tolerances.

Diameters of Disks and Rings and Dimension of Blocks			
Finished Size Diameters or Dimensions of Blocks, in. (mm)	Allowance for Machining Over Finished Size, in. (mm)	Tolerance Over the Allowance, in. (mm)	
		Plus	Minus
Up to 3 (76), incl	⅛ (3.2)	⅛ (3.2)	0
Over 3 to 5 (76 to 127), incl	3⁄16 (4.8)	3⁄16 (4.8)	0
Over 5 to 7 (127 to 178), incl	¼ (6.4)	¼ (6.4)	0
Over 7 to 10 (178 to 254), incl	5⁄16 (7.9)	5⁄16 (7.9)	0
Over 10 to 12 (254 to 305), incl	⅜ (9.5)	⅜ (9.5)	0
Over 12 to 15 (305 to 381), incl	7⁄16 (11.1)	7⁄16 (11.1)	0
Over 15 to 18 (381 to 457), incl	½ (12.7)	½ (12.7)	0
Over 18 to 24 (457 to 610), incl	⅝ (15.9)	½ (12.7)	0
Over 24 to 32 (610 to 813), incl	¾ (19.1)	½ (12.7)	0
Over 32 to 40 (813 to 1016), incl	⅞ (22.2)	½ (12.7)	0

Ring forgings: for the OD, use the same allowances and tolerances shown in the above tabulation; for the ID, double the tolerances shown in the above tabulation.

TABLE 23 Forgings, Disks, Rings, and Rectangular Blocks (Allowances for Machining: Tolerances Over Allowances)

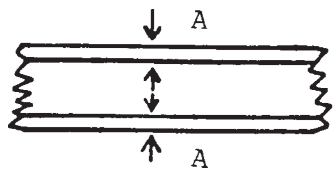
Thickness of Disks and Ring Forgings

Finished Diameter, in. (mm)	Finished Thickness, in. (mm)														
	Up to 3 (76), incl			Over 3 to 5 (76 to 127), incl			Over 5 to 7 (127 to 178), incl			Over 7 to 10 (178 to 254), incl			Over 10 to 12 (254 to 305), incl		
	Allowance	Tolerance Plus	Tolerance Minus	Allowance	Tolerance Plus	Tolerance Minus	Allowance	Tolerance Plus	Tolerance Minus	Allowance	Tolerance Plus	Tolerance Minus	Allowance	Tolerance Plus	Tolerance Minus
Up to 3 (76), incl	1⁄8 (3.2)	1⁄8 (3.2)	0	1⁄8 (3.2)	1⁄8 (3.2)	0									
Over 3 to 5 (76 to 127), incl	1⁄8 (3.2)	1⁄8 (3.2)	0	1⁄8 (3.2)	1⁄8 (3.2)	0									
Over 5 to 7 (127 to 178), incl	3⁄16 (4.8)	3⁄16 (4.8)	0	3⁄16 (4.8)	3⁄16 (4.8)	0	5⁄16 (7.9)	5⁄16 (7.9)	0	3⁄8 (9.5)	3⁄8 (9.5)	0			
Over 7 to 10 (178 to 254), incl	3⁄16 (4.8)	3⁄16 (4.8)	0	1⁄4 (6.4)	1⁄4 (6.4)	0	5⁄16 (7.9)	5⁄16 (7.9)	0	3⁄8 (9.5)	3⁄8 (9.5)	0			
Over 10 to 12 (254 to 305), incl	3⁄16 (4.8)	3⁄16 (4.8)	0	1⁄4 (6.4)	1⁄4 (6.4)	0	5⁄16 (7.9)	5⁄16 (7.9)	0	3⁄8 (9.5)	3⁄8 (9.5)	0	3⁄8 (9.5)	3⁄8 (9.5)	0
Over 12 to 15 (305 to 381), incl	1⁄4 (6.4)	1⁄4 (6.4)	0	5⁄16 (7.9)	5⁄16 (7.9)	0	3⁄8 (9.5)	3⁄8 (9.5)	0	3⁄8 (9.5)	3⁄8 (9.5)	0	7⁄16 (11.1)	7⁄16 (11.1)	0
Over 15 to 18 (381 to 457), incl	1⁄4 (6.4)	1⁄4 (6.4)	0	5⁄16 (7.9)	5⁄16 (7.9)	0	3⁄8 (9.5)	3⁄8 (9.5)	0	7⁄16 (11.1)	7⁄16 (11.1)	0	7⁄16 (11.1)	7⁄16 (11.1)	0
Over 18 to 24 (457 to 610), incl	1⁄4 (6.4)	1⁄4 (6.4)	0	5⁄16 (7.9)	5⁄16 (7.9)	0	3⁄8 (9.5)	3⁄8 (9.5)	0	7⁄16 (11.1)	7⁄16 (11.1)	0	7⁄16 (11.1)	7⁄16 (11.1)	0
Over 24 to 32 (610 to 813), incl	5⁄16 (7.9)	5⁄16 (7.9)	0	3⁄8 (9.5)	3⁄8 (9.5)	0	7⁄16 (11.1)	7⁄16 (11.1)	0	1⁄2 (12.7)	1⁄2 (12.7)	0	1⁄2 (12.7)	1⁄2 (12.7)	0
Over 32 to 40 (813 to 1016), incl	5⁄16 (7.9)	5⁄16 (7.9)	0	3⁄8 (9.5)	3⁄8 (9.5)	0	7⁄16 (11.1)	7⁄16 (11.1)	0	1⁄2 (12.7)	1⁄2 (12.7)	0	1⁄2 (12.7)	1⁄2 (12.7)	0

Finished Diameter, in. (mm)	Finished Thickness, in. (mm)[A]														
	Over 12 to 15 (304 to 381), incl			Over 15 to 18 (381 to 475), incl			Over 18 to 24 (457 to 610), incl			Over 24 to 32 (610 to 813), incl			Over 32 to 40 (813 to 1016), incl		
	Allowance	Tolerance Plus	Tolerance Minus	Allowance	Tolerance Plus	Tolerance Minus	Allowance	Tolerance Plus	Tolerance Minus	Allowance	Tolerance Plus	Tolerance Minus	Allowance	Tolerance Plus	Tolerance Minus
Up to 3 (76), incl															
Over 3 to 5 (76 to 127), incl															
Over 5 to 7 (127 to 178), incl															
Over 7 to 10 (178 to 254), incl															
Over 10 to 12 (254 to 305), incl	7⁄16 (11.1)	7⁄16 (11.1)	0												
Over 12 to 15 (305 to 381), incl	1⁄2 (12.7)	1⁄2 (12.7)	0												
Over 15 to 18 (381 to 457), incl	1⁄2 (12.7)	1⁄2 (12.7)	0	1⁄2 (12.7)	1⁄2 (12.7)	0	5⁄8 (15.9)	5⁄8 (15.9)	0						
Over 18 to 24 (457 to 610), incl	1⁄2 (12.7)	1⁄2 (12.7)	0	1⁄2 (12.7)	1⁄2 (12.7)	0	5⁄8 (15.9)	5⁄8 (15.9)	0						
Over 24 to 32 (610 to 813), incl	9⁄16 (14.3)	9⁄16 (14.3)	0	5⁄8 (15.9)	5⁄8 (15.9)	0	3⁄4 (19.1)	3⁄4 (19.1)	0	3⁄4 (19.1)	3⁄4 (19.1)	0	3⁄4 (19.1)	3⁄4 (19.1)	0
Over 32 to 40 (813 to 1016), incl	9⁄16 (14.3)	9⁄16 (14.3)	0	5⁄8 (15.9)	5⁄8 (15.9)	0	3⁄4 (19.1)	3⁄4 (19.1)	0	3⁄4 (19.1)	3⁄4 (19.1)	0	7⁄8 (22.2)	7⁄8 (22.2)	0

[A] Forgings processed to the above allowances are free of decarburization and surface defects when machined or ground to the finished size by removal of equal amounts from opposite surfaces.

TABLE 24 Hot Rolled Sheet and Plate (Tolerances for Thickness and Minimum Allowances for Machining)



Thickness, in. (mm)	Thickness Tolerance, in. (mm)[A,B]	Machining Allowance, in. (mm)[C,D]
Up to 0.025 (0.64) incl.	0.006 (0.15)	0.013 (0.33)
Over 0.025 to 0.062 (0.64 to 1.6) incl.	0.012 (0.30)	0.013 (0.33)
Over 0.062 to 0.093 (1.6 to 2.4) incl.	0.016 (0.41)	0.015 (0.38)
Over 0.093 to 0.125 (2.4 to 3.2) incl.	0.020 (0.51)	0.015 (0.38)
Over 0.125 to 0.187 (3.2 to 4.8) incl.	0.028 (0.71)	0.018 (0.46)
Over 0.187 to 0.250 (4.8 to 6.4) incl.	0.050 (1.27)	0.023 (0.58)
Over 0.250 to 0.375 (6.4 to 9.5) incl.	0.060 (1.52)	0.035 (0.89)
Over 0.375 to 0.500 (9.5 to 12.7) incl.	0.070 (1.78)	0.035 (0.89)
Over 0.500 to 1.000 (12.7 to 25.4) incl.	0.100 (2.54)	0.063 (1.60)
Over 1.000 to 1.500 (25.4 to 38.1) incl.	0.125 (3.18)	0.063 (1.60)
Over 1.500 to 2.000 (38.1 to 50.8) incl.	0.125 (3.18)	0.075 (1.90)
Over 2.000 to 4.000 (50.8 to 101.6) incl.	0.250 (6.35)	0.094 (2.36)

[A] Thickness is measured along the longitudinal edges of the sheet or plate at least ⅜ in. (9.5 mm), but not more than 3.0 in. (76.2 mm) from the edge.
[B] All tolerances are over the specified thickness.
[C] Maximum decarburization limits are 80 % the allowance per side for machining.
[D] Additional cleanup for deviations from flatness may be added. Consult with producer.

TABLE 25 Hot Rolled Trimmed Sheet and Plate (Tolerances for Width and Length)[A]

Thickness, in. (mm)	Tolerance, in. (mm)[B]	
	Width	Length
Up to 0.187 (4.8) incl.	0.125 (3.18)	0.250 (6.35)
Over 0.187 to 0.375 (4.8 to 9.5)	0.1875 (4.76)	0.250 (6.35)
Over 0.375 to 4.000 (9.5 to 101.6)	0.250 (6.35)	0.250 (6.35)

[A] Tolerances shown are for all trimming methods.
[B] All tolerances are on the plus side of the specified width or length.

TABLE 26 Hot Rolled Sheet and Plate (Tolerances for Flatness)

Thickness, in. (mm)	Tolerances, in. (mm)[A]
Up to 0.125 (3.18) incl.	0.750 (19.05)
Over 0.125 to 0.500 (3.18 to 12.7) incl.	0.500 (12.70)
Over 0.500 to 1.500 (12.7 to 38.1) incl.	0.375 (9.52)
Over 1.500 to 4.000 (38.1 to 101.6) incl.	0.250 (6.35)

[A] Maximum deviation from a horizontal flat surface in any 10 ft (3.05 m).

TABLE 27 Hot Rolled Trimmed Sheet and Plate (Tolerances for Camber)

NOTE 1—Camber is the deviation of a side edge from a straight line. Measurement is taken by placing a 5 ft (1.52 m) straight edge on the concave side and measuring the greatest distance between the sheet or plate edge and the straight edge.

Maximum camber = 0.125 in. in any 5 ft (3.18 mm in any 1.52 m)

TABLE 28 Machined Square and Flat Bars
(Size, Straightness and Squareness Tolerances, in. (mm))

NOTE 1—Bars shall be free of surface imperfections and decarburization and furnished oversize as shown. Surface finish shall be 125 µin. (3.18 µm) rms maximum for ground bars, and 250 µin. (6.36 µm) rms maximum for machined (milled) bars.

Specified Thickness	Thickness[A]		Width[A]			
	Machined or Plate		Machined		Cut From Plate	
	Oversize	Tolerance	Oversize	Tolerance	Oversize	Tolerance
½ to 4, incl (12.7 to 101.6)	0.015 (0.38)	+0.020, −0 (0.51)	0.015 (0.38)	+0.020, −0 (0.51)	0.015 (0.38)	+0.062, −0 (1.59)
Over 4 to 6, incl (101.6 to 152.4)	0.062 (1.59)	+0.031, −0 (0.79)	0.062 (1.59)	+0.031, −0 (0.79)	0.062 (1.59)	+0.062, −0 (1.59)
Straightness Tolerances						
1⁄16 in. in any 5 ft, but may not exceed 1⁄16 in. × no. of ft in length/5						
The foregoing formula applies also to bars under 5 ft in length.						
1.6 mm in any 1.54 m, but may not exceed 1.6 mm × no. of m in length/1.54						
The foregoing formula applies also to bars under 1.54 m in length.						
Squareness Tolerances						
The width and thickness dimensions specified must be attainable when surfaces are subsequently made to be parallel and square. Closer limits of squareness may be agreed upon between seller and purchaser.						

[A] For larger widths and thicknesses than shown, refer to producer.

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, and order. Details of these supplementary requirements shall be agreed upon by the seller and the purchaser.

S1. Ultrasonic Quality

S1.1 Material shall be ultrasonically tested at appropriate stages of the manufacture to ensure the quality, when and as agreed upon between seller and purchaser.

S2. Cleanliness

S2.1 In special situations such as where the surface finish of the part requires optimum polishing characteristics, the cleanliness of the steel shall be ascertained in accordance with the latest issue of Practice E 45. The permissible limits shall be agreed upon between seller and purchaser.

Designation: A 686 – 92 (Reapproved 1999)

Standard Specification for Tool Steel, Carbon[1]

This standard is issued under the fixed designation A 686; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers the chemical, mechanical, and physical requirements for available wrought carbon tool steel products.

1.2 These products, which include hot- or cold-finished bar, plate, sheet, rod, wire, or forgings, are normally fabricated into tools, dies, or fixtures. The selection of a material for a particular application will depend upon design, service conditions, and desired properties.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are provided for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[2]

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings[3]

A 561 Practice for Macroetch Testing of Tool Steel Bars[3]

A 700 Practices for Packaging, Marking, and Loading Methods for Steel Products for Domestic Shipment[3]

E 3 Methods of Preparation of Metallographic Specimens[4]

E 30 Test Methods for Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron[5]

E 45 Test Methods for Determining the Inclusion Content of Steel[4]

E 59 Practice for Sampling Steel and Iron for Determination of Chemical Composition[5]

2.2 *Military Standard:*

MIL-STD-163 Steel Mill Products, Preparation for Shipment and Storage[6]

2.3 *Federal Standards:*

Fed. Std. No. 123 Marking for Shipment (Civil Agencies)[6]

Fed. Std. No. 183 Continuous Identification Marking of Iron and Steel Products[6]

3. Classification

3.1 Material in accordance with this specification is classified by chemical composition. Types correspond to respective AISI designations.

3.1.1 *Carbon Tool Steels, Identification W*—Types W1, W2, and W5 are often referred to as water hardening tool steels since they require rapid quenching rates to attain the necessary hardness. Except in very small sizes they will harden with a hard case and a soft core.

3.1.1.1 Type W1 is an unalloyed carbon steel available in several carbon ranges.

3.1.1.2 Type W2 is characterized by a nominal vanadium content of 0.25 % and is also available in several carbon ranges.

3.1.1.3 Type W5 is characterized by a nominal chromium content of 0.50 %.

3.1.1.4 A suffix following the type designation is added to denote the minimum carbon content of the carbon range to be specified.

3.1.2 Types W1 and W2 are further classified by quality levels, namely, Grade A and Grade C.

3.1.2.1 Grade A is sometimes referred to as *Extra* or *Special.* It is controlled for hardenability; the chemical composition is held to closest limits; and it is subject to rigid tests to ensure uniformity. Grade A is available with three degrees of hardenability, namely, shallow hardening, regular hardening, and deep hardening.

3.1.2.2 Grade C is sometimes referred to as *Regular* or *Standard*. It is intended for applications that do not require controlled hardenability and where some latitude in uniformity is permissible.

4. Ordering Information

4.1 Orders for material under this specification shall include the following information, as required to describe adequately the desired material:

4.1.1 Class of material (carbon tool steel),

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.29 on Tool Steels.

Current edition approved July 15, 1992. Published September 1992. Originally published as A 686 – 73. Last previous edition A 686 – 89.

[2] *Annual Book of ASTM Standards*, Vol 01.03.

[3] *Annual Book of ASTM Standards*, Vol 01.05.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] *Annual Book of ASTM Standards*, Vol 03.05.

[6] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

4.1.2 Type (W1, W2, W5),

4.1.3 Suffix denoting carbon range (where applicable, such as W1–9, W2–10, etc.),

4.1.4 Grade and hardenability (where applicable, for example, Grade A deep hardening, and so forth),

4.1.5 Shape (sheet, plate, flat bar, round bar, square bar, hexagon bar, octagon, special shapes),

4.1.6 Dimensions (thickness, width, diameter, length),

4.1.7 Finish (hot rolled, forged, blasted or pickled, cold drawn, machined, ground, precision ground and polished),

4.1.8 Condition (annealed, unannealed, hardened and tempered, and so forth),

4.1.9 ASTM specification number and date of issue, and

4.1.10 Special requirements.

5. Materials and Manufacture

5.1 Unless otherwise specified, material covered by this specification shall be made by an electric melting process. It shall be made from ingots that have been reduced in cross section in such a manner and to such a degree as to ensure proper refinement of the ingot structure.

6. Chemical Composition

6.1 An analysis of each heat of steel shall be made by the manufacturer to determine the percentage of the elements specified and these values shall conform to the chemical composition specified in Table 1. If requested or required, the chemical composition shall be reported to the purchaser or his representative.

6.2 Analysis may be made by the purchaser from finished bars and forgings by machining off the entire cross section and drilling parallel to the axis of the bar or forging at any point midway between the center and surface in accordance with the latest issue of Method E 59. The chemical analysis of the drilling chips shall be made in accordance with the latest issue of Methods E 30. The chemical composition thus determined shall not vary from the limits specified in Table 1.

7. Hardness Properties

7.1 Annealed hardness values shall be obtained in accordance with the latest issue of Test Methods and Definitions A 370, and shall not exceed the Brinell hardness values (or equivalent Rockwell hardness values) specified in Table 2.

7.2 Specimens for determination of minimum response to hardening shall be ¼-in. (6.4-mm) thick disks cut so as to represent either the full cross-sectional area or that midway between the center and outer surface of the material. If the material form or size does not lend itself to accurate hardness determination on ¼-in. (6.4-mm) thick cross-sectional disks, then longitudinal specimens may be used for hardness testing. Examples are round bars less than ½ in. (12.7 mm) in diameter or sheet. In this case, the specimen shall be a minimum of 3 in. (76.2 mm) in length and parallel flats shall be ground on the original mill surfaces. The specimens shall be heat treated as prescribed in Table 3.

7.2.1 The hardness of the specimen after the specified heat treatment shall meet the minimum hardness value for the particular type of steel shown in Table 3. Rockwell C tests should be used where possible but light load tests may be necessary on thin specimens. These tests should be specified by agreement between seller and purchaser. The hardness value shall be obtained in accordance with the latest issue of Test Methods and Definitions A 370, and shall be the average of at least five readings taken in an area midway between the center and surface of the largest dimension of the cross-sectional specimen or along the parallel surfaces of the longitudinal specimen. The surface to be tested shall be ground sufficiently to remove any surface condition, scale, carburization, or decarburization which might affect readings.

7.2.2 Hardness penetration and fracture grain size for Grade A shall be determined on test pieces of ¾ in. (19.1 mm) diameter and 3 in. (76.2 mm) length. Two pieces for each test shall be given a preliminary treatment by heating uniformly to 1600 ± 10°F (871 ± 5°C) and holding at temperature for 40

TABLE 1 Chemical Composition, %[A]

UNS Designation	Type	Grade	Carbon		Manganese		Silicon		Phosphorus, max	Sulfur, max	Chromium		Vanadium		Tungsten, max	Molybdenum, max	Copper, max	Nickel, max
			min	max	min	max	min	max			min	max	min	max				
T72301	W1	A	[B]	[B]	0.10	0.40	0.10	0.40	0.030	0.030	. . .	0.15	. . .	0.10	0.15	0.10	0.20	0.20
T72301	W1	C	[B]	[B]	0.10	0.40	0.10	0.40	0.030	0.030	. . .	0.30	. . .	0.10	0.15	0.10	0.20	0.20
T72302	W2	A	[C]	[C]	0.10	0.40	0.10	0.40	0.030	0.030	. . .	0.15	0.15	0.35	0.15	0.10	0.20	0.20
T72302	W2	C	[C]	[C]	0.10	0.40	0.10	0.40	0.030	0.030	. . .	0.30	0.15	0.35	0.15	0.10	0.20	0.20
T72305	W5	...	1.05	1.15	0.10	0.40	0.10	0.40	0.030	0.030	0.40	0.60	. . .	0.10	0.15	0.10	0.20	0.20

[A] Chemistry limits include product analysis tolerances.

[B] The carbon ranges for W1 and their respective suffix identification, sometimes referred to as tempers, are as follows:

Suffix	Carbon Range, %	Suffix	Carbon Range, %
8	0.80–0.90	10	1.00–1.10
8½	0.85–0.95	10½	1.05–1.15
9	0.90–1.00	11	1.10–1.20
9½	0.95–1.05	11½	1.15–1.25

[C] The carbon ranges for W2 and their respective suffix identification are as follows:

Suffix	Carbon Range, %
8½	0.85–0.95
9	0.90–1.00
9½	0.95–1.10
13	1.30–1.50

TABLE 2 Maximum Brinell Hardness in Annealed or Cold Drawn Condition

Type	Annealed BHN	Cold Drawn BHN
W1	202	241
W2	202	241
W5	202	241

Drill Rod (W1, W2, or W5)

Ordered Diameter, in. (mm)	Brinell	Rockwell
To ⅛ (3.2)	HB 341	HRC 37
Over ⅛ to ¼ (3.2 to 6.4), incl	HB 275	HRC 28
Over ¼ to ½ (6.4 to 12.7), incl	HB 241	HRC 23
Over ½ (12.7)	HB 207	HRB 96

min, then quenching in oil. One piece shall be reheated to 1450 ± 10°F (788 ± 5°C) and the other to 1550± 10°F (843 ± 5°C). Each piece shall be held in the furnace at the respective temperature for 30 min and then quenched in brine (5 to 10 % sodium chloride solution). The pieces shall be nicked with an abrasive wheel in the center of the length and fractured. The fracture face of one portion of each broken test piece shall be ground smooth and etched in 1 + 1 muriatic acid at 165°F (74°C) for measurement of the depth of penetration to be expressed in 64ths of an inch. The fracture grain size shall be determined on the remaining portion of each broken test piece by comparison of the fracture surface of the hardened case with the Shepherd Fracture Grain Size Standards.[7] These standards consist of ten pieces of steel with fracture faces representing graduated grain sizes from the coarsest (No. 1) to the finest (No. 10). The fracture grain size is estimated to the nearest quarter number. The hardness penetration and fracture grain size for Grade A shall meet the requirements shown in Table 3.

8. Macrostructure

8.1 The macrostructure of a specimen representing the entire cross-sectional area in the annealed condition shall be prepared in accordance with the latest issue of Practice A 561. It shall exhibit a structure free of excessive porosity, segregation, slag, dirt or other nonmetallic inclusions, pipes, checks, cracks, and other injurious defects.

8.2 Macroetch severity levels for center porosity and ingot pattern, illustrated photographically in Practice A 561, shall not exceed the ratings specification in Table 4 for the appropriate material size and composition. More stringent requirements are available by agreement between seller and purchaser.

9. Decarburization

9.1 Decarburization shall be determined on a specimen representing a cross section of the material and prepared in accordance with the latest issue of Methods E 3. When examined at 20× or greater magnification it shall not exceed the values given in Tables 5-9 for the appropriate size and shape of material. Lower limits of decarburization may be specified by agreement between the seller and purchaser.

9.2 Material ordered as ground and polished or ground finished or machine finished shall be free of scale and decarburization.

[7] The Shepherd Fracture Grain Size Standards may be purchased from Metallurgical Services, Inc., Box 1075, 925 Main St., Niagara Falls, NY 14302.

10. Permissible Variations for Dimensions

10.1 Permissible variations for dimensions shall not exceed the applicable limits stated in Table 6, and Tables 10-22 and Note 1.

NOTE 1—Unmachined tool steel forgings are furnished to size and surface allowances for machining and tolerances over allowances. Experience indicates that the allowances and tolerances in the tabulation below are satisfactory for many applications. When width and thickness differ, each dimension carries its individual allowance and tolerance in accordance with the tabulation: also, the ID and OD take their respective allowances and tolerances. When forgings are ordered, the purchaser should state whether the sizes are the forged or the finished sizes. The minimum sizes ordered for forgings should be the finished sizes plus allowances for machining; and the ordered forged sizes are subject to applicable tolerances

10.2 Out-of-round tolerances for round bars shall be one half the permissible dimensional variations stated in Table 6, Table 10, Table 12, Table 14, Table 15, and Table 17.

11. Workmanship, Finish, and Appearance

11.1 All carbon tool steels shall be free of heavy scale, deep pitting, laps, porosity, injurious segregations, excessive nonmetallic inclusions, seams, cracks, checks, slivers, scale marks, dents, soft and hard spots, pipes, or any defects that would detrimentally affect the suitability of the material after removal of the recommended stock allowance.

12. Sampling

12.1 Each particular shipment of a heat of steel by type, size, and shape shall be considered a lot and must conform to the provisions of this specification.

13. Inspection

13.1 When specified in the purchase order, the inspector representing the purchaser shall have access to the material subject to inspection for the purpose of witnessing the selection of samples, preparation of test pieces, and performance of the tests. For such tests, the inspector shall have the right to indicate the pieces from which samples will be selected. Otherwise, the seller shall report to the purchaser, or his representative, the results of the chemical analysis and the physical and mechanical property tests made in accordance with this specification.

14. Rejection and Rehearing

14.1 Unless otherwise specified, any rejections based on tests made in accordance with this specification shall be reported to the seller within 30 days from the date of receipt of the material.

14.2 Material that shows injurious defects subsequent to its acceptance by the purchaser shall be rejected and the seller notified.

14.3 Samples tested in accordance with this specification that represent rejected material shall be preserved for 30 days from the date of the test report. In case of dissatisfaction with the results of the test, the seller may make claim for a rehearing within that time.

15. Packaging, Loading, and Package Marking

15.1 *Packaging and Loading*:

TABLE 3 Heat-Treating Requirements

Type	Carbon Range, %	Austenitizing Temperature, °F (°C)	Quench Medium	Minimum Hardness, HRC
W1	0.70–0.85	1475 (802)	brine	64
	0.85–0.95	1475 (802)	brine	65
	0.95–1.50	1450 (788)	brine	65
W2	0.85–0.95	1475 (802)	brine	65
	0.95–1.50	1450 (788)	brine	65
W5	1.05–1.15	1475 (802)	brine	65

Hardness Penetration and Fracture Grain Size for Grade A

Specified Depth of Hardening	Quench Temperature, ° F (°C)	W1 (0.70 to 0.95 C)	W2 (0.85 to 0.95 C)[A]	W1 (0.95 to 1.10 C) W2 (0.95 to 1.10 C)[A]	W1 (1.10 to 1.30 C)[A]
		Penetration 64th in.	Grain Size (Shepherd) Not Coarser Than	Penetration 64th in.	Grain Size (Shepherd) Not Coarser Than
Shallow	1450 (788)	10 max	8	8 max	8½
	1550 (843)	not more than 5⁄64 deeper than at 1450	6½	not more than 5⁄64 deeper than at 1450	6½
Regular	1450 (788)	9 to 13	8	7 to 11	8½
	1550 (843)	not more than 8⁄64 deeper than at 1450	6½	not more than 8⁄64 deeper than at 1450	6½
Deep	1450 (788)	12 min	8	10 to 16	8
	1550 (843)	not more than 10⁄64 deeper than at 1450	6½	not more than 10⁄64 deeper than at 1450	6½

[A] Applicable to shallow and regular hardening material only.

TABLE 4 Macroetch Standards Maximum Allowable Rating[A]

Size Round, in. (mm)	Carbon Tool Steels	
	Porosity	Ingot Pattern
Up to 2 (50.8), incl	4	6
Over 2 to 3 (50.8 to 76.2), incl	4½	6
Over 3 to 4 (76.2 to 101.6), incl	4½	6
Over 4 to 5 (101.6 to 127.0), incl	5	6
Over 5 to 6 (122.0 to 152.4), incl	5	6
Over 6 (152.4)	as negotiated between seller and purchaser.	

[A] Refer to macroetch photographs in Practice A 561.

15.1.1 Unless otherwise specified, shipments shall be packaged and loaded in accordance with Practices A 700.

15.1.2 When specified in the contract or order, and for direct procurement by or direct shipment to the government, when Level A is specified, preservation, packaging, and loading shall be in accordance with the Level A requirements of MIL-STD-163.

15.2 *Marking*:

15.2.1 Shipments shall be properly marked with the name or brand of manufacturer, purchaser's name and order number, specification number (ASTM A 686), heat number, grade or type, and where appropriate, the size, length, and weight. Unless otherwise specified, method of marking is at the option of the manufacturer.

TABLE 5 Maximum Decarburization Limits Rounds, Hexagons and Octagons Maximum Limit Per Side

NOTE—The recommended minimum allowance for machining prior to heat treatment is 25 % greater than the maximum decarburization allowed.

Ordered Size, in. (mm)	Hot Rolled	Forged	Cold Drawn
Up to ½ (12.7), incl	0.013 (0.33)	...	0.013 (0.33)
Over ½ to 1 (12.7 to 25.4), incl	0.025 (0.64)	...	0.025 (0.64)
Over 1 to 2 (25.4 to 50.8), incl	0.038 (0.97)	0.058 (1.47)	0.038 (0.96)
Over 2 to 3 (50.8 to 76), incl	0.050 (1.27)	0.075 (1.91)	0.050 (1.27)
Over 3 to 4 (76 to 102), incl	0.070 (1.78)	0.096 (2.44)	0.070 (1.78)
Over 4 to 5 (102 to 127), incl	0.090 (2.29)	0.116 (2.95)	...
Over 5 to 6 (127 to 152),incl	0.120 (3.05)	0.136 (3.45)	...
Over 6 to 8 (152 to 203),incl	...	0.160 (4.06)	...
Over 8 to 10 (203 to 254), incl	...	0.160 (4.06)	...

15.2.2 When specified in the contract or order, and for direct procurement by or direct shipment to the government, marking for shipment, in addition to any requirements specified in the contract or order, shall be in accordance with MIL-STD-163 for military agencies, and in accordance with Fed. Std. No. 123 for civil agencies.

15.2.3 For government procurement by the Defense Supply Agency, steel shall be continuously marked for identification in accordance with Fed. Std. No. 183.

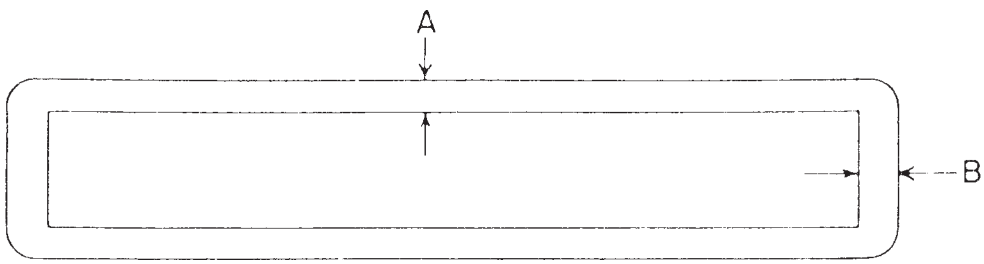
TABLE 6 Rough-Turned Round Bars Size Tolerance[A]

Specified Sizes,[B] in. (mm)	Size Tolerance, in. (mm)	
	Under	Over
Over ¾ to 1½ (19.0 to 38.1), incl	0.00	010 (0.254)
Over 1½ to 3¹⁄₁₆ (38.1 to 77.8), incl	0.00	015 (0.38)
Over 3¹⁄₁₆ to 4¹⁄₁₆ (77.8 to 103.2), incl	0.00	031 (0.79)
Over 4¹⁄₁₆ to 6¹⁄₁₆ (103.2 to 154), incl	0.00	062 (1.6)
Over 6¹⁄₁₆ to 10¹⁄₁₆ (154 to 255.6), incl	0.00	094 (2.4)
Over 10¹⁄₁₆ Please consult producer		

[A] Out-of-round tolerances to be one half of the total tolerance.
[B] Consult producer for oversize allowance and decarburization limits for all sizes.

TABLE 7 Maximum Decarburization Limits Hot Rolled Square and Flat Bars Maximum Limit Per Side

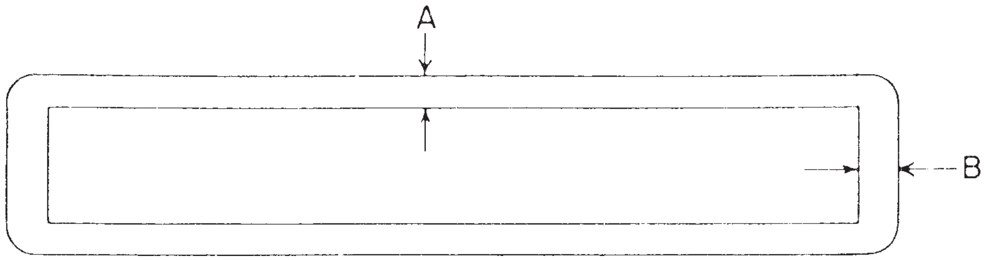
NOTE—The recommended minimum allowance for machining prior to heat treatment is 25 % greater than the maximum decarburization allowed.



Specified Thickness, in. (mm)		Specified Widths, in. (mm)										
		0 to ½ (0 to 12.7) incl.	Over ½ to 1 (12.7 to 25.4), incl	Over 1 to 2 (25.4 to 50.8), incl	Over 2 to 3 (50.8 to 76), incl	Over 3 to 4 (76 to 102), incl	Over 4 to 5 (102 to 127), incl	Over 5 to 6 (127 to 152), incl	Over 6 to 7 (152 to 178), incl	Over 7 to 8 (178 to 203), incl	Over 8 to 9 (203 to 229), incl	Over 9 to 12 (229 to 304), incl
0 to ½ (0 to 12.7), incl	A	0.020 (0.51)	0.020 (0.51)	0.024 (0.61)	0.028 (0.71)	0.032 (0.81)	0.036 (0.91)	0.040 (1.02)	0.044 (1.12)	0.048 (1.22)	0.048 (1.22)	0.048 (1.22)
	B	0.020 (0.51)	0.026 (0.66)	0.032 (0.81)	0.038 (0.97)	0.044 (1.12)	0.054 (1.37)	0.062 (1.57)	0.066 (1.68)	0.078 (1.98)	0.082 (2.08)	0.096 (2.44)
Over ½ to 1 (12.7 to 25.4), incl	A	...	0.036 (0.91)	0.036 (0.91)	0.036 (0.91)	0.040 (1.02)	0.044 (1.12)	0.052 (1.32)	0.056 (1.42)	0.060 (1.52)	0.060 (1.52)	0.060 (1.52)
	B	...	0.036 (0.91)	0.042 (1.07)	0.046 (1.17)	0.056 (1.42)	0.064 (1.63)	0.082 (2.08)	0.090 (2.29)	0.098 (2.49)	0.102 (2.59)	0.108 (2.74)
Over 1 to 2 (25.4 to 50.8), incl	A	...	...	0.052 (1.32)	0.052 (1.32)	0.056 (1.42)	0.056 (1.42)	0.060 (1.52)	0.060 (1.52)	0.064 (1.63)	0.068 (1.73)	0.072 (1.83)
	B	...	...	0.052 (1.32)	0.056 (1.42)	0.060 (1.52)	0.072 (1.83)	0.086 (2.18)	0.098 (2.49)	0.112 (2.84)	0.118 (3.00)	0.122 (3.10)
Over 2 to 3 (50.8 to 76), incl	A	...	...	...	0.064 (1.63)	0.064 (1.63)	0.068 (1.73)	0.068 (1.73)	0.072 (1.83)	0.072 (1.83)	0.080 (2.03)	0.080 (2.03)
	B	...	...	...	0.064 (1.63)	0.072 (1.83)	0.082 (2.08)	0.094 (2.39)	0.110 (2.79)	0.122 (3.10)	0.130 (3.30)	0.136 (3.45)
Over 3 to 4 (76 to 102), incl	A	...	...	...	...	0.080 (2.03)	0.080 (2.03)	0.086 (2.18)	0.092 (2.34)	0.094 (2.39)	0.100 (2.54)	0.100 (2.54)
	B	...	...	...	...	0.080 (2.03)	0.090 (2.29)	0.100 (2.54)	0.120 (3.05)	0.132 (3.35)	0.132 (3.35)	0.150 (3.81)

TABLE 8 Maximum Decarburization Limits
Cold Drawn Square and Flat Bars
Maximum Limits Per Side

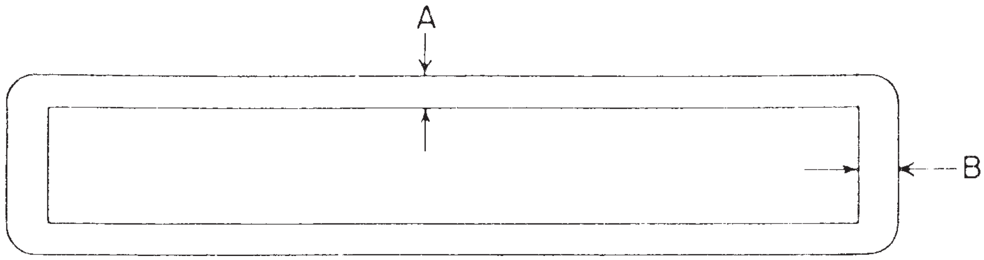
NOTE—The recommended minimum allowance for machining prior to heat treatment is 25 % greater than the maximum decarburization allowed.



Specified Thickness, in. (mm)		Specified Width, in. (mm)					
		0 to ½ (0 to 12.7), incl	Over ½ to 1 (12.7 to 25.4), incl	Over 1 to 2 (25.4 to 50.8), incl	Over 2 to 3 (50.8 to 76), incl	Over 3 to 4 (76 to 102), incl	Over 4 to 5 (102 to 127), incl
0 to ½ (0 to 12.7), incl	A	0.020 (0.51)	0.020 (0.51)	0.024 (0.61)	0.028 (0.71)	0.032 (0.81)	0.036 (0.91)
	B	0.020 (0.51)	0.026 (0.66)	0.032 (0.81)	0.038 (0.97)	0.044 (1.12)	0.054 (1.37)
Over ½ to 1 (12.7 to 25.4), incl	A	...	0.036 (0.91)	0.036 (0.91)	0.036 (0.91)	0.040 (1.02)	0.044 (1.12)
	B	...	0.036 (0.91)	0.042 (1.07)	0.046 (1.17)	0.056 (1.42)	0.064 (1.63)
Over 1 to 2 (25.4 to 50.8), incl	A	...	...	0.052 (1.32)	0.052 (1.32)	0.056 (1.42)	...
	B	...	...	0.052 (1.32)	0.056 (1.42)	0.060 (1.52)	...

**TABLE 9 Maximum Decarburization Limits
Forged Square and Flat Bars
Maximum Limit Per Side**

NOTE—The recommended minimum allowance for machining prior to heat treatment is 25 % greater than the maximum decarburization allowed.



Specified Thickness, in. (mm)		Specified Width, in. (mm)								
		Over 1 to 2 (25.4 to 50.8), incl	Over 2 to 3 (50.8 to 76), incl	Over 3 to 4 (76 to 102), incl	Over 4 to 5 (102 to 127), incl	Over 5 to 6 (127 to 152), incl	Over 6 to 7 (152 to 178), incl	Over 7 to 8 (178 to 203), incl	Over 8 to 9 (203 to 229), incl	Over 9 to 12 (229 to 305), incl
Over ½ to 1, (12.7 to 25.4), incl	A	0.038 (0.97)	0.042 (1.07)	0.048 (1.22)	0.052 (1.32)	0.056 (1.42)	0.062 (1.57)	0.066 (1.68)	0.072 (1.83)	0.080 (2.03)
	B	0.048 (1.22)	0.056 (1.42)	0.070 (1.78)	0.080 (2.03)	0.094 (2.39)	0.110 (2.79)	0.132 (3.35)	0.132 (3.35)	0.132 (3.35)
Over 1 to 2, (25.4 to 50.8), incl	A	0.058 (1.47)	0.062 (1.57)	0.066 (1.68)	0.070 (1.78)	0.074 (1.88)	0.080 (2.03)	0.084 (2.13)	0.094 (2.39)	0.106 (2.69)
	B	0.058 (1.47)	0.066 (1.68)	0.078 (1.98)	0.086 (2.18)	0.100 (2.54)	0.114 (2.90)	0.132 (3.35)	0.132 (3.35)	0.132 (3.35)
Over 2 to 3 (50.8 to 76), incl	A	...	0.080 (2.03)	0.084 (2.13)	0.088 (2.24)	0.092 (2.34)	0.098 (2.49)	0.106 (2.69)	0.114 (2.90)	0.126 (3.20)
	B	...	0.080 (2.03)	0.092 (2.34)	0.098 (2.49)	0.106 (2.69)	0.118 (3.00)	0.136 (3.45)	0.136 (3.45)	0.136 (3.45)
Over 3 to 4 (76 to 102), incl	A	...	...	0.102 (2.59)	0.106 (2.69)	0.112 (2.84)	0.120 (3.05)	0.132 (3.35)	0.140 (3.56)	0.158 (4.01)
	B	...	...	0.102 (2.59)	0.106 (2.69)	0.112 (2.84)	0.120 (3.05)	0.132 (3.35)	0.140 (3.56)	0.158 (4.01)
Over 4 to 5 (102 to 127), incl	A	...	...	...	0.126 (3.20)	0.130 (3.30)	0.138 (3.51)	0.146 (3.71)	0.156 (3.96)	0.170 (4.32)
	B	...	...	...	0.126 (3.20)	0.130 (3.30)	0.138 (3.51)	0.146 (3.71)	0.156 (3.96)	0.170 (4.32)
Over 5 to 6 (127 to 152), incl	A	...	...	...	...	0.150 (3.81)	0.158 (4.01)	0.166 (4.22)	0.176 (4.47)	0.188 (4.78)
	B	...	...	...	...	0.150 (3.81)	0.158 (4.01)	0.166 (4.22)	0.176 (4.47)	0.188 (4.78)
Over 6 to 7 (152 to 178), incl	A	...	...	...	...	...	0.176 (4.47)	0.186 (4.72)	0.186 (4.72)	0.198 (5.03)
	B	...	...	...	...	...	0.176 (4.47)	0.186 (4.72)	0.186 (4.72)	0.198 (5.03)

**TABLE 10 Hot Rolled Bars
Rounds, Squares, Octagons, Quarter Octagons, Hexagons
Size Tolerances[A]**

Specified Sizes, in. (mm)	Size Tolerances, in. (mm)	
	Under	Over
To ½ (12.7), incl	0.005 (0.13)	0.012 (0.30)
Over ½ to 1 (12.7 to 25.4), incl	0.005 (0.13)	0.016 (0.41)
Over 1 to 1½ (25.4 to 38.1), incl	0.006 (0.15)	0.020 (0.51)
Over 1½ to 2 (38.1 to 50.8), incl	0.008 (0.20)	0.025 (0.64)
Over 2 to 2½ (50.8 to 63.5), incl	0.010 (0.25)	0.030 (0.76)
Over 2½ to 3 (63.5 to 76.2), incl	0.010 (0.25)	0.040 (1.02)
Over 3 to 4 (76.2 to 101.6), incl	0.012 (0.30)	0.050 (1.27)
Over 4 to 5½ (101.6 to 139.7), incl	0.015 (0.38)	0.060 (1.52)
Over 5½ to 6½ (139.7 to 165.1), incl	0.018 (0.46)	0.100 (2.54)
Over 6½ to 8 (165.1 to 203.2), incl	0.020 (0.51)	0.150 (3.81)

[A] Out of section tolerance to be [n|]P of total tolerance max.

TABLE 11 Hot Rolled Flat Bars
Width and Thickness Tolerances
Width Tolerances[A]

Specified Widths, in. (mm)	Width Tolerances, in. (mm)	
	Under	Over
To 1 (25.4), incl	0.016 (0.41)	0.031 (0.79)
Over 1 to 3 (25.4 to 76), incl	0.031 (0.79)	0.047 (1.19)
Over 3 to 5 (76 to 127), incl	0.047 (1.19)	0.063 (1.60)
Over 5 to 7 (127 to 178), incl	0.063 (1.60)	0.094 (2.39)
Over 7 to 10 (178-254), incl	0.078 (1.98)	0.125 (3.18)
Over 10 to 12 (254-305), incl	0.094 (2.39)	0.156 (3.96)

Thickness Tolerances

Specified Widths, in. (mm)	Thickness Tolerances for Specified Thicknesses, in. (mm)											
	To ¼ (6.4), incl		Over ¼ to ½ (6.4 to 12.7), incl		Over ½ to 1 (12.7 to 25.4), incl		Over 1 to 2 (25.4 to 50.8), incl		Over 2 to 3 (50.8 to 76), incl		Over 3 to 4 (76 to 102), incl	
	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over
To 1 (25.4), incl	0.006 (0.15)	0.010 (0.25)	0.008 (0.20)	0.012 (0.30)	0.010 (0.25)	0.016 (0.41)	...	...	...	...	...	...
Over 1 to 2 (25.4 to 50.8), incl	0.006 (0.15)	0.014 (0.36)	0.008 (0.20)	0.016 (0.41)	0.010 (0.25)	0.020 (0.51)	0.020 (0.51)	0.024 (0.61)	...	...	...	...
Over 2 to 3 (50.8 to 76), incl	0.006 (0.15)	0.018 (0.46)	0.008 (0.20)	0.020 (0.51)	0.010 (0.25)	0.024 (0.61)	0.020 (0.51)	0.027 (0.69)	0.026 (0.66)	0.034 (0.86)	...	...
Over 3 to 4 (76 to 102), incl	0.008 (0.20)	0.020 (0.51)	0.010 (0.25)	0.022 (0.56)	0.013 (0.33)	0.024 (0.61)	0.024 (0.61)	0.030 (0.76)	0.032 (0.81)	0.042 (1.07)	0.040 (1.02)	0.048 (1.22)
Over 4 to 5 (102 to 127), incl	0.010 (0.25)	0.020 (0.51)	0.012 (0.30)	0.024 (0.61)	0.015 (0.38)	0.030 (0.76)	0.027 (0.69)	0.035 (0.89)	0.032 (0.81)	0.042 (1.07)	0.042 (1.07)	0.050 (1.27)
Over 5 to 6 (127 to 152), incl	0.012 (0.30)	0.020 (0.51)	0.014 (0.36)	0.030 (0.76)	0.018 (0.46)	0.030 (0.76)	0.035 (0.89)	0.036 (0.91)	0.036 (0.91)	0.046 (1.17)	0.044 (1.12)	0.054 (1.37)
Over 6 to 7 (152 to 178), incl	0.014 (0.36)	0.027 (0.69)	0.016 (0.41)	0.032 (0.81)	0.018 (0.46)	0.035 (0.89)	0.030 (0.76)	0.040 (1.02)	0.036 (0.91)	0.048 (1.22)	0.046 (1.17)	0.056 (1.42)
Over 7 to 10 (178 to 254), incl	0.018 (0.46)	0.030 (0.76)	0.020 (0.51)	0.035 (0.89)	0.024 (0.61)	0.040 (1.02)	0.035 (0.89)	0.045 (1.14)	0.040 (1.02)	0.054 (1.37)	0.052 (1.32)	0.064 (1.62)
Over 10 to 12 (254 to 305), incl	0.020 (0.51)	0.035 (0.89)	0.025 (0.64)	0.040 (1.02)	0.030 (0.76)	0.045 (1.14)	0.040 (1.02)	0.050 (1.27)	0.046 (1.17)	0.060 (1.52)	0.056 (1.42)	0.072 (1.83)

[A] Out of square tolerance to be [n|]P of total width tolerance max.

TABLE 12 Cold Drawn Bars
Rounds, Octagons, Quarter Octagons and Hexagons
Size Tolerances[A]

Size Range, in. (mm)	Tolerance, in. (mm) Plus and Minus
¼ to ½ (6.4 to 12.7), excl	0.002 (0.05)
½ to 1 (12.7 to 25.4), excl	0.0025 (0.06)
1 to 2¾ (25.4 to 69.8), incl	0.003 (0.08)

[A] Out of section tolerance to be ½ the total tolerance max.

TABLE 13 Cold Drawn Square and Flat Bars
Size Tolerances[A]

Size Range, in. (mm)	Tolerance, in. (mm) ±
¼ to ¾ (6.4 to 19.1), incl	0.002 (0.05)
Over ¾ to 1½ (19.1 to 38.1), incl	0.003 (0.08)
Over 1½ (38.1)	0.004 (0.10)

[A] Out of square tolerance to be ½ total tolerance max.

TABLE 14 Centerless Ground Bars
Rounds Diameter Tolerances[A]

Diameter Range, in. (mm)	Tolerance, in. (mm)	
	Under	Over
¼ to ½ (6.4 to 12.7), excl	0.0015 (0.038)	0.0015 (0.038)
½ to 3 1/16 (12.7 to 77.8), excl	0.002 (0.05)	0.002 (0.05)
3 1/16 to 4 1/16 (77.8 to 103.2), incl	0.003 (0.08)	0.003 (0.08)

[A] Out of round tolerance to be ½ of the total tolerance, max.

TABLE 15 Forged Bars
Rounds, Squares, Octagons, Hexagons
Size Tolerances[A]

Specified Sizes, in. (mm)	Size Tolerances, in. (mm)	
	Under	Over
Over 1 to 2 (25.4 to 50.8), incl	0.030 (0.76)	0.060 (1.52)
Over 2 to 3 (50.8 to 76), incl	0.030 (0.76)	0.080 (2.03)
Over 3 to 5 (76 to 127), incl	0.060 (1.52)	0.125 (3.18)
Over 5 to 7 (127 to 177.8), incl	0.125 (3.18)	0.187 (4.75)
Over 7 to 9 (178 to 229), incl	0.187 (4.75)	0.312 (7.92)

[A] Out of section tolerance to be [n|]P
of total tolerance max.

TABLE 16 Forged Flat Bars
Width Tolerances[A]

Specified Widths, in. (mm)	Width Tolerances, in. (mm)	
	Under	Over
Over 1 to 3 (25.4 to 76), incl	0.031 (0.79)	0.078 (1.98)
Over 3 to 5 (76 to 127), incl	0.062 (1.57)	0.125 (3.18)
Over 5 to 7 (127 to 178), incl	0.125 (3.18)	0.187 (4.75)
Over 7 to 9 (178 to 229), incl	0.187 (4.75)	0.312 (7.92)

Thickness Tolerances

Specified Widths, in. (mm)	Thickness Tolerances for Specified Thicknesses, in. (mm)									
	To 1 (25.4), incl		Over 1 to 3 (25.4 to 76), incl		Over 3 to 5 (76 to 127), incl		Over 5 to 7 (127 to 178), incl		Over 7 to 9 (178 to 229), incl	
	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over
1 to 3 (25.4 to 76), incl	0.016 (0.41)	0.031 (0.79)	0.031 (0.79)	0.078 (1.98)	...	...	...	...	...	...
Over 3 to 5 (76 to 127), incl	0.031 (0.79)	0.062 (1.57)	0.047 (1.19)	0.094 (2.39)	0.062 (1.57)	0.125 (3.18)	...	...	...	...
Over 5 to 7 (127 to 178), incl	0.047 (1.19)	0.094 (2.39)	0.062 (1.57)	0.125 (3.18)	0.078 (1.98)	0.156 (3.96)	0.125 (3.18)	0.187 (4.75)	...	...
Over 7 to 9 (178 to 229), incl	0.062 (1.57)	0.125 (3.18)	0.078 (1.98)	0.156 (3.96)	0.094 (2.39)	0.187 (4.75)	0.156 (3.96)	0.219 (5.56)	0.187 (4.75)	0.312 (7.92)

[A] Out of square tolerance to be [n|]P
of total width tolerance max.

TABLE 17 Drill Rod
Rounds, Polished or Ground
Size Tolerances[A]

Size Range, in. (mm)	Standard Manufacturing Tolerance, in. (mm),±	Precision Tolerance, in. (mm), ±
Up to 0.124 (3.15), incl	0.0003 (0.008)	0.0002 (0.005)
0.125 to 0.499 (3.18 to 12.7), incl	0.0005 (0.013)	0.00025 (0.006)
0.500 to 1.500 (12.7 to 38.1), incl	0.001 (0.03)	0.0005 (0.013)

[A] Out of round tolerance to be ½ the total tolerance.

TABLE 18 Drill Rod
Shapes Other Than Rounds, Cold Drawn
Size Tolerances[A]

Size Range, in. (mm)	Tolerance, in. (mm), ±
Up to ¼ (6.4), excl	0.0005 (0.013)
¼ to ¾ (6.4 to 19.1), excl	0.001 (0.03)
¾ to 1 (19.1 to 25.4), incl	0.0015 (0.04)

[A] Out of section tolerance to be ½ the total tolerance.

TABLE 19 Hot Rolled or Forged Bars and Billets
Tolerances for Machine Cut Lengths

Specified Sizes Apply to Rounds, Squares, Hexagons, Octagons, and Width of Flats. in. (mm)	Tolerances for Specified Lengths, 14 ft (4.27 m) max, in. (mm)	
	Over	Under
To 9 (229), incl	⅜ (9.5)	0
Over 9 to 12 (229 to 305), incl	½ (12.7)	0
Over 12 to 18 (305 to 457), incl	¾ (19.1)	0
Over 18 (457)	1 (25.4)	0

TABLE 20 Straightened Hot Rolled Annealed Bars or Cold Finished Bars
Straightness Tolerances

This table does not apply to flat bars having a width to thickness ratio of 6 to 1 or greater.

Measurement is taken on the concave side of the bar with a straight edge. Bars are furnished to the following straightness tolerances:

Hot rolled bars:

$1/8$ in. in any 5 ft, but may not exceed $1/8$ in. $\times$ (no. of ft in length/5)

The foregoing formula applies also to bars under 5 ft in length. (3.2 mm in any 1.54 m), but may not exceed 3.2 mm $\times$ (no. of m in length/1.54). The foregoing formula applies also to bars under 1.54 m in length.)

Cold finished bars:

$1/16$ in. in any 5 ft, but may not exceed $1/16$ in. $\times$ (no. of ft in length/5)

The foregoing formula applies also to bars under 5 ft in length. (1.6 mm in any 1.54 m, but may not exceed 1.6 mm $\times$ (no. of m in length/1.54). The foregoing formula applies also to bars under 1.54 m in length.)

TABLE 21 Forgings, Disks, Rings and Rectangular Blocks
Allowances for Machining; Tolerances Over Allowances

NOTE 1—Unmachined tool steel forgings are furnished to size and surface allowances for machining and tolerances over allowances. Experience indicates that the allowances and tolerances in the tabulation below are satisfactory for many applications. When width and thickness differ, each dimension carries its individual allowance and tolerance in accordance with the tabulation: also, the ID and OD take their respective allowances and tolerances.

NOTE 2—When forgings are ordered, the purchaser should state whether the sizes are the forged or the finished sizes. The minimum sizes ordered for forgings should be the finished sizes plus allowances for machining; and the ordered forged sizes are subject to applicable tolerances.

Diameters of Disks and Rings and Dimension of Blocks

Finished Size Diameters or Dimensions of Blocks, in. (mm)	Allowance for Machining Over Finished Size, in. (mm)	Tolerance Over the Allowance, in. (mm)	
		+	–
Up to 3 (76), incl	1/8 (3.2)	1/8 (3.2)	0
Over 3 to 5 (76 to 127), incl	3/16 (4.8)	3/16 (4.8)	0
Over 5 to 7 (127 to 178), incl	1/4 (6.4)	1/4 (6.4)	0
Over 7 to 10 (178 to 254), incl	5/16 (7.9)	5/16 (7.9)	0
Over 10 to 12 (254 to 305), incl	3/8 (9.5)	3/8 (9.5)	0
Over 12 to 15 (305 to 381), incl	7/16 (11.1)	7/16 (11.1)	0
Over 15 to 18 (381 to 457), incl	1/2 (12.7)	1/2 (12.7)	0
Over 18 to 24 (457 to 610), incl	5/8 (15.9)	1/2 (12.7)	0
Over 24 to 32 (610 to 813), incl	3/4 (19.1)	1/2 (12.7)	0
Over 32 to 40 (813 to 1016), incl	7/8 (22.2)	1/2 (12.7)	0

Ring forgings for the OD, use the same allowances and tolerances shown in the above tabulation; for the ID, double the tolerances shown in the above tabulation.

Thickness of Disks and Ring Forgings

Finished Diameter, in. (mm)	Finished Thickness, in. (mm)														
	Up to 3 (76), incl			Over 3 to 5 (76 to 127), incl			Over 5 to 7 (127 to 178), incl			Over 7 to 10 (178 to 254), incl			Over 10 to 12 (254 to 305), incl		
	Allowance	Tolerance +	Tolerance –	Allowance	Tolerance +	Tolerance –	Allowance	Tolerance +	Tolerance –	Allowance	Tolerance +	Tolerance –	Allowance	Tolerance +	Tolerance –
Up to 3 (76), incl	1/8 (3.2)	1/8 (3.2)	0	1/8 (3.2)	1/8 (3.2)	0									
Over 3 to 5 (76 to 127), incl	1/8 (3.2)	1/8 (3.2)	0	1/8 (3.2)	1/8 (3.2)	0									
Over 5 to 7 (127 to 178), incl	3/16 (4.8)	3/16 (4.8)	0	3/16 (4.8)	3/16 (4.8)	0	5/16 (7.9)	5/16 (7.9)	0	3/8 (9.5)	3/8 (9.5)	0			
Over 7 to 10 (178 to 254), incl	3/16 (4.8)	3/16 (4.8)	0	1/4 (6.4)	1/4 (6.4)	0	5/16 (7.9)	5/16 (7.9)	0	3/8 (9.5)	3/8 (9.5)	0			
Over 10 to 12 (254 to 305), incl	3/16 (4.8)	3/16 (4.8)	0	1/4 (6.4)	1/4 (6.4)	0	5/16 (7.9)	5/16 (7.9)	0	3/8 (9.5)	3/8 (9.5)	0	3/8 (9.5)	3/8 (9.5)	0
Over 12 to 15 (305 to 381), incl	1/4 (6.4)	1/4 (6.4)	0	5/16 (7.9)	5/16 (7.9)	0	3/8 (9.5)	3/8 (9.5)	0	3/8 (9.5)	3/8 (9.5)	0	7/16 (11.1)	7/16 (11.1)	0
Over 15 to 18 (381 to 457), incl	1/4 (6.4)	1/4 (6.4)	0	5/16 (7.9)	5/16 (7.9)	0	3/8 (9.5)	3/8 (9.5)	0	7/16 (11.1)	7/16 (11.1)	0	7/16 (11.1)	7/16 (11.1)	0
Over 18 to 24 (457 to 610), incl	1/4 (6.4)	1/4 (6.4)	0	5/16 (7.9)	5/16 (7.9)	0	3/8 (9.5)	3/8 (9.5)	0	7/16 (11.1)	7/16 (11.1)	0	7/16 (11.1)	7/16 (11.1)	0
Over 24 to 32 (610 to 813), incl	5/16 (7.9)	5/16 (7.9)	0	3/8 (9.5)	3/8 (9.5)	0	7/16 (11.1)	7/16 (11.1)	0	1/2 (12.7)	1/2 (12.7)	0	1/2 (12.7)	1/2 (12.7)	0
Over 32 to 40 (813 to 1016), incl	5/16 (7.9)	5/16 (7.9)	0	3/8 (9.5)	3/8 (9.5)	0	7/16 (11.1)	7/16 (11.1)	0	1/2 (12.7)	1/2 (12.7)	0	1/2 (12.7)	1/2 (12.7)	0

Finished Diameter, in. (mm)	Finished Thickness, in. (mm)[A]														
	Over 12 to 15 (304 to 381), incl			Over 15 to 18 (381 to 457), incl			Over 18 to 24 (457 to 610), incl			Over 24 to 32 (610 to 813), incl			Over 320 to 40 (813 to 1016), incl		
	Allowance	Tolerance +	Tolerance –	Allowance	Tolerance +	Tolerance –	Allowance	Tolerance +	Tolerance –	Allowance	Tolerance +	Tolerance –	Allowance	Tolerance +	Tolerance –
Up to 3 (76), incl															
Over 3 to 5 (76 to 127), incl															
Over 5 to 7 (127 to 178), incl															
Over 7 to 10 (178 to 254), incl															
Over 10 to 12 (254 to 305), incl	7/16 (11.1)	7/16 (11.1)	0												
Over 12 to 15 (305 to 381), incl	1/2 (12.7)	1/2 (12.7)	0												
Over 15 to 18 (381 to 457), incl	1/2 (12.7)	1/2 (12.7)	0	1/2 (12.7)	1/2 (12.7)	0	5/8 (15.9)	5/8 (15.9)	0						
Over 18 to 24 (457 to 610), incl	1/2 (12.7)	1/2 (12.7)	0	1/2 (12.7)	1/2 (12.7)	0	5/8 (15.9)	5/8 (15.9)	0						
Over 24 to 32 (610 to 813), incl	9/16 (14.3)	9/16 (14.3)	0	5/8 (15.9)	5/8 (15.9)	0	3/4 (19.1)	3/4 (19.1)	0	3/4 (19.1)	3/4 (19.1)	0	3/4 (19.1)	3/4 (19.1)	0
Over 32 to 40 (813 to 1016), incl	9/16 (14.3)	9/16 (14.3)	0	5/8 (15.9)	5/8 (15.9)	0	3/4 (19.1)	3/4 (19.1)	0	3/4 (19.1)	3/4 (19.1)	0	7/8 (22.2)	7/8 (22.2)	0

[A] Forgings processed to the above allowances are free of decarburization and surface defects when machined or ground to the finished size by removal of equal amounts from opposite surfaces.

TABLE 22 Hot Rolled Plates and Sheets
Tolerances for Width and Thickness

Thickness, in. (mm)	Width, in. (mm)			
	Up to 15 (381)		Over 15 (381)	
	All tolerances over specified width and specified thickness, in. (mm)			
	Width	Thickness	Width	Thickness
Up to 0.025, (0.64), incl	1⁄8 (3.2)	0.006 (0.15)	3⁄16 (4.8)	0.006 (0.15)
Over 0.025 to 0.065, (0.64 to 1.65), incl	1⁄8 (3.2)	0.008 (0.20)	3⁄16 (4.8)	0.008 (0.20)
Over 0.065 to 0.120, (1.65 to 3.05), incl	1⁄8 (3.2)	0.010 (0.25)	3⁄16 (4.8)	0.010 (0.25)
Over 0.120 to 0.1875, (3.05 to 4.76), incl	3⁄16 (4.8)	0.016 (0.41)	1⁄4 (6.4)	0.016 (0.41)
Over 0.1875 to 0.250, (4.76 to 6.35), incl	3⁄16 (4.8)	0.018 (0.46)	1⁄4 (6.4)	0.018 (0.46)

Thickness, in. (mm)	Width, in. (mm)	
	Over 12 (305)	
	All tolerances over specified width and specified thickness, in. (mm)	
	Width	Thickness
1⁄4 to 1⁄2 (6.4 to 12.7), incl	1⁄4 (6.4)	1⁄16 (1.6)
Over 1⁄2 to 2 (12.7 to 50.8), incl	1⁄4 (6.4)	1⁄8 (3.2)
Over 2 (50.8)	1⁄4 (6.4)	1⁄4 (6.4)

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, and order. Details of these supplementary requirements shall be agreed upon by the seller and purchaser.

S1. Ultrasonic Quality

S1.1 Material shall be ultrasonically tested at appropriate stages of the manufacture to ensure the quality, when and as agreed upon between seller and purchaser. When required, it shall be performed in accordance with the latest issue of Practice A 388/A 388M.

S2. Cleanliness

S2.1 In special situations, such as where the surface finish of the part requires optimum polishing characteristics, the cleanliness of the steel shall be ascertained in accordance with the latest issue of Practice E 45. The permissible limits shall be agreed upon between seller and purchaser.

Designation: A 689 – 97 (Reapproved 2002)

Standard Specification for Carbon and Alloy Steel Bars for Springs[1]

This standard is issued under the fixed designation A 689; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers hot-wrought steel bars to be used for the manufacture of general-purpose springs such as coil, torsion, and leaf.

1.2 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 255 Test Method for End-Quench Test for Hardenability of Steel[2]

A 304 Specification for Carbon and Alloy Steel Bars, Subject to End-Quench Hardenability Requirements[2]

A 322 Specification for Steel Bars, Alloy, Standard Grades[2]

A 576 Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality[2]

E 112 Test Methods for Determining the Average Grain Size[3]

3. Ordering Information

3.1 Purchase orders for material to this specification shall include the following information as required to describe the desired material adequately:

3.1.1 ASTM designation A 689,

3.1.2 AISI grade number indicating the chemical composition (see 5.1), special chemistry required (see 5.2), or hardenability (see 5.3),

3.1.3 Quantity (number of bars or weight),

3.1.4 Cross section description and dimensions or drawings of section,

3.1.5 Bar lengths,

3.1.6 When purchaser's processing requires cold shearing, cold punching, and cold trimming, this should be noted.

3.1.7 When special straightness or machine-cut lengths are required, reference on the purchase order should be made to Tables A1.10 and A1.9 or Tables A2.10 and A2.9 for SI units of Specification A 29/A 29M, and

3.1.8 Weight limitations per shipping bundle.

4. Melting Practice

4.1 The steel shall be made by one or more of the following primary processes: open-hearth, basic-oxygen, or electric-furnace. The primary melting may incorporate separate degassing or refining and may be followed by secondary melting using electroslag remelting or vacuum arc remelting. Where secondary melting is employed, the heat shall be defined as all of the ingots remelted from a single primary heat.

5. Chemical Composition or Hardenability Requirements

5.1 When the steel is specified by chemical composition, the standard steel grades are the AISI series 1000, 4100, 5100, 6100, 8600, and 9200, and those including Boron AISI series 10B00, 15B00, 50B00, and 51B00. The specific grades are listed in Specifications A 322 and A 576.

5.2 Modifications may be made in the chemistry of the standard AISI grades to suit the hardenability required for a particular bar size, spring shape, or other special requirements. The steel supplier should be consulted on availability of any special chemical compositions.

5.2.1 A chemical analysis of each heat of steel purchased under 5.1 and 5.2 shall be made by the steel producer to determine the percentage of the elements, which percentages shall conform to the requirements of the designated AISI grade or special chemistry. The chemical analysis thus determined shall be reported to the purchaser.

5.3 When the steel is specified by end-quench hardenability requirements (alloy steels), the grade is identified by the suffix letter "H." The standard alloy steel grades are the AISI series 4100H, 5100H, 6100H, 8600H, and 9200H and those including Boron AISI series 50B00H and 51B00H. The specific grades are listed in Specification A 304.

5.3.1 Hardenability requirements (band limits) shall be shown on the purchase order as outlined in the applicable sections of Specification A 304.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.15 on Bars.

Current edition approved June 10, 1997. Published October 1997. Originally published as A 689 – 74. Last previous edition A 689 – 81a(1993)$^{\epsilon 2}$.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

5.3.2 The end-quench hardenability tests from each heat of steel shall be made in accordance with Test Method A 255, with the exception that a cast hardenability test specimen may be acceptable. The test results shall conform within the specified limits and shall be reported to the purchaser.

6. General Requirements

6.1 The hot-wrought bars shall be furnished in the as-wrought condition and shall conform to the general requirements as outlined in Specification A 29/A 29M, excepting that the spring steel bars shall not be marked by hot- or cold-stamping unless specified by the purchaser.

6.2 Flat bars for leaf springs unless otherwise specified shall be round-edge flat steel having two flat surfaces and two round (convex) edges. The cross section tolerances permit the two flat surfaces to be slightly concave. When there is concavity, the radii of the arcs of the two concave surfaces shall be approximately the same length.

6.2.1 The round edges shall approximate circular arcs with a radius of curvature between 65 to 85 % of the thickness of the bar.

6.2.2 Round-edge flat bars shall conform to the cross section tolerances specified in Table 1.

6.3 *Flat (Rectangular and Including Square) Bars with Rounded Corners:*

6.3.1 The rounded corner radii shall be in accordance with Table 2.

6.3.2 For section tolerances see Table A1.3 or A2.3 for SI units (for rectangular bars) and Table A1.1 or A2.1 for SI units (for square bars) of Specification A 29/A 29M.

6.4 *Round Bars*—For section tolerances see Table A1.1 or A2.1 for SI units of Specification A 29/A 29M.

6.5 *Special Cross Section Shapes, such as Keystone*—A drawing of the cross section including the tolerances should accompany the purchase order. It is recommended that the steel supplier be contacted concerning the availability of any special cross section.

6.6 *Length and Straightness of Bars*:

6.6.1 For straightness and length tolerances, see Tables A1.10 and A1.8, or Tables A2.10 and A2.8 for SI units of Specification A 29/A 29M.

6.6.2 When special straightness or machine-cut length are required, this must be clearly noted on the purchase order and reference made to Tables A1.10 and A1.9 or Tables A2.10 and A2.9 for SI units of Specification A 29/A 29M.

6.7 The austenitic grain size shall be No. 5 or finer as determined by Test Methods E 112.

7. Workmanship, Finish, and Appearance

7.1 The bars shall be free of injurious defects and shall have a workmanlike finish consistent with good hot-rolling practices for bars intended for use in springs.

8. Rejection and Rehearing

8.1 Steel that fails to conform to the requirements of this specification or shows injurious defects after its receipt by the purchaser, or both, shall be rejected and the supplier shall be notified for disposition.

9. Product Marking

9.1 The bars shall be properly bundled for shipment and identified as to size, weight, heat number, grade designation, purchase order number, and name of supplier.

TABLE 1 Cross Section Tolerances for Round-Edge Flat Bars

Specified Width, in. (mm)		Tolerance in Width, in. (mm)	Tolerance[A] in Thickness, in. (mm)			Tolerance in Concavity[B] of Flat Surfaces, in. (mm)			Max Difference in Thickness,[C] in. (mm)		
Over	To and including	Minus 0.000	0.375 (9.52) or Under	Over 0.375 (9.52) to 0.875 (22.22), incl	Over 0.875 (22.22) to 1.500 (38.10), incl	0.375 (9.52) or Under	Over 0.375 (9.52) to 0.875 (22.22), incl	Over 0.875 (22.22) to 1.500 (38.10), incl	0.375 (9.52) or Under	Over 0.375 (9.52) to 0.875 (22.22), incl	Over 0.875 (22.22) to 1.500 (38.10), incl
0.00	2.50 (63.5)	+0.030 (0.76)	±0.005 (0.13)	±0.006 (0.15)	...	0.005 (0.13)	0.006 (0.15)	...	0.002 (0.05)	0.002 (0.05)	...
2.50 (63.5)	4.00 (101.6)	+0.045 (1.14)	±0.006 (0.15)	±0.008 (0.20)	±0.012 (0.30)	0.006 (0.15)	0.008 (0.20)	0.012 (0.30)	0.003 (0.07)	0.004 (0.10)	0.006 (0.15)
4.00 (101.6)	5.00 (127.0)	+0.065 (1.65)	±0.007 (0.18)	±0.010 (0.25)	±0.016 (0.40)	00.007 (0.18)	0.010 (0.25)	0.016 (0.40)	0.004 (0.10)	0.005 (0.13)	0.008 (0.20)
5.00 (127.0)	6.00 (152.4)	+0.090 (2.28)	...	±0.012 (0.30)	±0.020 (0.51)	...	0.012 (0.30)	0.020 (0.51)	...	0.006 (0.15)	0.010 (0.25)

[A] Thickness measurements are taken at the edges of the bar where the flat surfaces intersect the rounded edges.
[B] Concavity is the difference between the thickness at the center of the bar and the thickness at the edges. The thickness at the center should not exceed the thickness at the edges.
[C] Maximum difference in thickness between the two edges of each bar.

TABLE 2 Rounded Corner Radii

Specified Sizes,[A] in. (mm)	Nominal Corner Radii, in. (mm)
0.250 (6.35) to 0.375 (9.92)	0.031 (0.78)
0.375 (9.52) to 0.500 (12.70)	0.063 (1.60)
Over 0.500 (12.70) to 0.813 (20.65)	0.094 (2.38)
Over 0.813 (20.65) to 1.469 (37.31)	0.125 (3.18)
Over 1.469 (37.31) to 1.938 (49.23)	0.250 (6.35)
Over 1.938 (49.23) to 2.438 (61.93)	0.313 (7.94)

[A] Sizes are distances between opposite sides of square bars and the thickness of rectangular bars.

Standard Specification for Steel Bars, Carbon, Hot-Wrought or Cold-Finished, Special Quality, for Pressure Piping Components[1]

This standard is issued under the fixed designation A 696; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification[2] covers hot-wrought and cold-finished special quality carbon steel bars, in straight lengths only, subject to mechanical property requirements and intended for use in manufacturing components for pressure piping and other pressure-containing applications.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[3]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[4]

3. Classification

3.1 The bars are furnished in two grades as follows:

3.1.1 *Grade B*—Tensile strength 60 000 psi (415 MPa), minimum; yield strength 35 000 psi (240 MPa), minimum.

3.1.2 *Grade C*—Tensile strength 70 000 psi (485 MPa), minimum; yield strength 40 000 psi (275 MPa), minimum.

3.2 The bars are intended for machining, welding, hot forming, and threading by machining or cold rolling.

4. Ordering Information

4.1 Orders for material under this specification should include the following information:

4.1.1 Quantity (weight or number of bars),

4.1.2 Name of material (carbon steel bars),

4.1.3 Condition: hot wrought or cold finished (5.4.1),

4.1.4 Finish (if descaled required, so state) (9.1),

4.1.5 Dimensions (diameter, thickness, width, and length),

4.1.6 Cross section (round, square, hexagon),

4.1.7 ASTM designation and date of issue,

4.1.8 Grade (Table 1 and Table 2),

4.1.9 End use, and

4.1.10 Additions to the specification and supplementary requirements, if required.

NOTE 1—A typical ordering description is as follows: 10 000 lb, Carbon Steel Bars, Hot Wrought, Descaled, 1.000-in. diameter by 10 ft, Round, ASTM A 696 dated ______, Grade B; Supplementary Requirement S1 Straightness 0.125 in. in any 5 ft.

5. Materials and Manufacture

5.1 *Melting Practice*—The steel shall be made by one or more of the following primary processes: open-hearth, basic-oxygen, or electric-furnace. The primary melting may incorporate separate degassing or refining, and may be followed by secondary melting using electroslag remelting or vacuum arc remelting. Where secondary melting is employed, the heat shall be defined as all of the ingots remelted from a single primary heat.

5.2 *Deoxidation*—The steel shall be fully killed.

5.3 *Quality*—The bars shall be special quality.

5.4 *Hot or Cold Working*:

5.4.1 The bars shall be hot wrought or cold finished as specified by the purchaser.

5.4.2 Cold-finished bars reduced in cross-sectional area more than 10 % by cold drawing or rolling shall be heat treated as specified in 5.5.2.

5.5 *Heat Treatment*:

5.5.1 Except as provided in 5.5.2, the bars shall be furnished as-hot wrought or as-cold finished.

5.5.2 Cold-finished bars cold worked in excess of 10 % (see 5.4.2) shall be stress relief annealed at not less than 1200°F (649°C), normalized, or fully annealed. The specific heat treatment shall be at the option of the manufacturer.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

Current edition approved Aug. 31, 1990. Published October 1990. Originally published as A 696–74. Last previous edition A 694–90.

[2] For ASME Boiler and Pressure Vessel Code Applications, see related Specification SA-696 in Section II of that Code.

[3] *Annual Book of ASTM Standards*, Vol 01.05.

[4] *Annual Book of ASTM Standards*, Vol 01.03.

TABLE 1 Chemical Requirements (Heat Analysis), %

	Grades B and C
Carbon, max[A]	0.32
Manganese, max	1.04
Phosphorus, max	0.035[B]
Sulfur, max	0.045[B]
Silicon	0.15 to 0.35
Lead	[B]

[A] For each reduction of 0.01 % below the specified carbon maximum, an increase of 0.06 % manganese above the specified maximum will be permitted up to a maximum of 1.35 %.
[B] Phosphorus, sulfur, or lead, or a combination thereof, shall not be added.

TABLE 2 Tensile Requirements

	Grade B	Grade C
Tensile strength, min, ksi (MPa)	60 (415)	70 (485)
Yield strength, min, ksi (MPa)	35 (240)	40 (275)
Elongation in 2.0 in. or 50 mm, min, %	20.0	18.0
Elongation in 8.0 in. or 200 mm, min, %[A]	17.0	15.0

[A] Applicable to bars 1½ in. (38 mm) in diameter tested full size.

6. Chemical Composition

6.1 The heat analysis shall conform to the requirements for chemical composition specified in Table 1.

6.2 A product analysis of the steel may be made by the purchaser and shall conform to the requirements of Table 1 subject to the product analysis tolerances specified in Specification A 29/A 29M.

7. Tensile Requirements

7.1 *Requirements*:

7.1.1 The material, as represented by the test specimens, shall conform to the tensile requirements specified in Table 2.

7.1.2 A deduction from the percentage of elongation specified in Table 2 of 1.0 % shall be made for each 1.0 in. (25.4 mm) of specified diameter over 2.0 in. (51 mm) or fraction thereof to a maximum of 3 %.

7.2 *Specimens*:

7.2.1 Tension test specimens shall be taken longitudinally from a position midway between the center and the surface of the bar or as close as practical to this location for small sizes.

7.2.2 When it is impractical to remove specimens in accordance with 7.2.1, they shall be taken in accordance with Test Methods and Definitions A 370.

7.3 *Number of Tests*—One tension test shall be made from each lot. A lot shall consist of all bars of one size from one heat processed at one time and subjected to the same heat treatment when heat treated.

7.4 *Test Methods*—Tension tests shall be made in accordance with Test Methods and Definitions A 370. The yield strength shall be determined by the 0.2 % offset or 0.5 % extension under load methods.

8. Workmanship, Finish, and Appearance

8.1 *Descaling*—When descaled bars are required, Supplementary Requirement S7 must be specified.

8.2 The bars shall be free of visible pipe and conditioned as necessary to remove injurious surface imperfections.

9. General Requirements

9.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 29/A 29M unless otherwise provided herein.

10. Certification and Test Reports

10.1 A manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the heat analysis and tension test results shall be furnished at the time of shipment. The report shall include the name of the manufacturer, ASTM designation number and grade, shape, size, and finish.

11. Packaging and Package Marking

11.1 Bars less than 2.0 in. (51 mm) in diameter or thickness shall be tightly banded with a sufficient number of bands of adequate strength to minimize bundle breakage during handling and shipping. Larger sizes shall be packaged in accordance with Specification A 29/A 29M.

11.2 For bars less than 2.0 in. (51 mm) in diameter or thickness, each bundle shall bear a weather-resistant tag showing the purchase order number, ASTM designation number and grade, heat number, size, and name of manufacturer.

11.3 Bars 2.0 in. (51 mm) and larger in diameter or thickness shall have the heat number steel stamped on one end.

12. Keywords

12.1 pressure piping components; special quality steel bars; steel bars

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall be applied only when specified by the purchaser in the inquiry, contract, or order. Details of these supplementary requirements shall be agreed upon in writing by the manufacturer and purchaser. Supplementary requirements shall in no way negate any requirement of the specification itself.

S1. Special Straightness

S1.1 Bars shall be within the tolerances for special straightness.

S2. Stress Relief Anneal

S2.1 Bars shall be stress relief annealed (may be specified for bars that have been ordered to special straightness tolerance).

S3. Surface Quality

S3.1 Bars shall be produced to special surface quality requirements which shall be negotiated between the purchaser and the supplier.

S4. Special Internal Soundness

S4.1 Bars shall be produced with special internal soundness to be verified by one or more macro-etch samples. Acceptance limits shall be negotiated between the purchaser and the seller.

S5. Fine Grain Practice

S5.1 The steel shall conform to the fine austenitic grain size requirement of Specification A 29/A 29M.

S6. Restricted Size Tolerances for Hot-Wrought Bars

S6.1 Bars shall be furnished with tolerances on dimensions more restrictive than specified in Specification A 29/A 29M. Tolerance requirements to apply shall be negotiated between the purchaser and the manufacturer.

S7. Descaling

S7.1 Bars shall be furnished descaled and oiled.

Designation: A 700 – 99$^{\epsilon 1}$

Standard Practices for Packaging, Marking, and Loading Methods for Steel Products for Domestic Shipment[1]

This standard is issued under the fixed designation A 700; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

ϵ[1] NOTE—In 8.2.1.2, the standard size of a steel die-stamp was corrected editorially in October 2000.

1. Scope

1.1 These practices cover the packaging, marking, and loading of steel products for domestic shipment. Assuming proper handling in transit, the practices are intended to deliver the products to their destination in good condition. It is also intended that these recommendations be used as guides for attaining uniformity, simplicity, adequacy, and economy in the domestic shipment of steel products.

1.2 These practices cover semi-finished steel products, bars, bar-size shapes and sheet piling, rods, wire and wire products, tubular products, plates, sheets, and strips, tin mill products, and castings. A glossary of packaging, marking, and loading terms is also included.

1.3 The practices are presented in the following sequence:

	Section
General Provisions	4
General	4.1
Railcar Loading	4.2
Truck Loading	4.3
Barge Loading	4.4
Air Shipment	4.5
Packaging Materials	4.6
Package Identification	4.7
Weight and Count	4.8
Packaging Lists or Tally	4.9
Loss or Damage	4.10
Semifinished Steel Products	5
Hot-Rolled Bars and Bar-Size Shapes	6
Cold-Finished Bars	7
Structural Shapes and Steel Sheet Piling	8
Rods, Wire, and Wire Products	9
Tubular Products	10
Plates	11
Sheets and Strip	12
Tin Mill Products	13
Castings	14

2. Referenced Documents

2.1 *ASTM Standards:*

D 245 Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber[2]

D 774 Test Method for Bursting Strength of Paper[3]

D 828 Test Methods for Tensile Breaking Strength of Paper and Paperboard[3]

D 2555 Test Methods for Establishing Clear-Wood Strength Values[2]

D 3953 Specification for Strapping, Flat Steel and Seals[3]

2.2 *Association of American Railroads:*[4]

Rules Governing the Loading of Commodities on Open Top Cars

Pamphlet 23 —The Rules Governing the Loading of Steel Products in Closed Cars and Protection of Equipment

2.3 *American Society of Agricultural Engineers:*[5]

ASAE Standard S 229, Baling Wire for Automatic Balers

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 The following glossary defines packaging, marking, and loading terms:

3.1.2 *AAR*—Association of American Railroads.

3.1.3 *"A" end of car*—arbitrary definition used to describe the end of a freight car opposite the end on which the manual brake control is located. In the event there is a manual brake control on both ends, the ends are designated by stenciling the letters "A" and "B" respectively on both sides near the ends.

3.1.4 *air tool*— tool operated by air pressure used for strap tensioning, sealing, nailing, etc.

3.1.5 *anchor plate*—a plate that is nailed to side or floor of car used to attach steel strapping for load securement.

3.1.6 *anchor tie*—a coil eye-tie that is applied in a special manner to resistant movement on bar or rod coils. A typical method is to wrap the tie around several strands, then around the complete coil.

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[1] These practices are under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys and are the direct responsibility of Subcommittee A01.94 on Government Specifications.

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[2] *Annual Book of ASTM Standards*, Vol 04.10.

[3] *Annual Book of ASTM Standards*, Vol 15.09.

[4] Available from Association of American Railroads, American Railroads Bldg., 1920 L St., NW, Washington, DC 20036.

[5] Available from American Society of Agricultural Engineers, 2950 Niles Rd., St. Joseph, MI 49085.

3.1.7 *anti-skid plate*—a device with sharp projections placed under the package to retard shifting of the load in transit.

3.1.8 *"A" rack*—a rack built in the form of the letter "A" for storing steel bars.

3.1.9 *asphalt-laminated paper*—paper used for packaging or shrouding, or both, composed of two or more sheets of paper bonded by asphalt.

3.1.10 *back-up cleat*—wood strip nailed to floor or side of car to strengthen or prevent displacement of the primary blocking.

3.1.11 *banding, band*—See *strapping.*

3.1.12 *band protector*—material used under package or load ties to protect product from damage and to prevent shearing of the package ties.

3.1.13 *bare*—any product that has not been protectively wrapped or covered when packaged.

3.1.14 *barrel, slack*—wooden barrel, not watertight by construction, used for solid materials.

3.1.15 *basis weight*—standard weight accepted by trade customs, based upon standard size for the given class of material. The weights of all other standard sizes are proportionate to the size and weight established for the given class of material.

3.1.16 *batten strips*—strips of wood used to protect machined surface or projections on castings from damage by the securing tie or contact with other objects. Their location is optional but must be so located to afford maximum protection.

3.1.17 *bearing pieces*—supports beneath but not secured to lift, package, or load.

3.1.18 *belt rails*—perforated angle or channel, running lengthwise at various levels along wall of vehicle, used to affix load-securement devices such as cross members or bulkheads.

3.1.19 *"B" end of car*—the end of a freight car on which the manual brake control is located. In the event there is a manual brake control on both ends, the ends are designated by stenciling the letters "A" and "B" respectively, on both sides near the ends.

3.1.20 *beveled*— usually refers to a packaging or loading member with ends or edges cut at an angle other than 90 deg.

3.1.21 *binder*—a clamping device used to secure chains or cables.

3.1.22 *blocking*—material used to prevent or control movement of the unit or load or to facilitate handling.

3.1.23 *box*—a fully enclosed rigid container having length, width, and depth.

3.1.24 *box car*—a freight car completely enclosed by ends, sides, and roof equipped with doors to permit entry of loading equipment and lading.

3.1.25 *bracing*—material used to make the unit or load firm or rigid.

3.1.26 *brand*—producer's or consumer's identification marks.

3.1.27 *bulkhead*—fabricated and affixed barrier used to prevent lengthwise movements of a unit or load.

3.1.28 *bulkhead, movable*—bulkhead, part of railroad equipment, that is capable of being adjusted for load securement.

3.1.29 *bumper block*—material affixed to ends or sides of a unit or load to prevent damaging contact.

3.1.30 *bundle*— two or more pieces secured together.

3.1.31 *cleat*—a piece of material, such as wood or metal, attached to a structural body to strengthen, secure, or furnish a grip.

3.1.32 *clinched tie*—a coil eye-tie (round wire) that is tensioned after manual twisting. Normally done with special twisting tool or a bar.

3.1.33 *coil*—a continuous length of wire, bar, rod, strip, sheet, etc., cylindrically wound.

3.1.34 *coil car*—railroad car specially equipped for the transportation of sheet or strip coils.

3.1.35 *coil carrier*—a carrying and dispensing device primarily for wire coils.

3.1.36 *coil group*— two or more coils secured into a unit that can be handled as a single package.

3.1.37 *coil skid*— See (coil) *platform.*

3.1.38 *core*—a cylinder on which coiled products are wound and which remains in the inside diameter after winding.

3.1.39 *corrosion inhibitor*—any material used by the steel industry to inhibit corrosion. This includes chemicals, oils, treated packaging materials, etc.

3.1.40 *corrugated box*—shipping container made of corrugated fiber board.

3.1.41 *covered*—top, sides, and ends of package covered with paper under the ties.

3.1.42 *crate*—a container of open-frame construction.

3.1.43 *cross member "DF"*— a wood or metal support of rated strength that is attached to the belt rails of a vehicle and that may be used with or without a bulkhead to contain the load.

3.1.44 *cushion underframe*—a device affixed to the underframe of a railroad car to absorb longitudinal shocks caused by impacts.

3.1.45 *damage-free box car*—box car equipped with load securement.

3.1.46 *deck*—top surface of a platform or pallet.

3.1.47 *desiccant*—chemical used to absorb moisture.

3.1.48 *double deck*—two-level stacking.

3.1.49 *double-door box car*—box car equipped with two doors on each side. The doors may be staggered or directly opposite.

3.1.50 *drums*—fiber or metal cylindrical containers.

3.1.51 *eye (of coil)*—center opening of coil.

3.1.52 *eye vertical*—placement of coil with eye of coil vertical.

3.1.53 *filler block*—wood block used to fill voids when necessary for effective packaging or loading.

3.1.54 *fixed bulkhead*—immovable bulkhead permanently attached to car.

3.1.55 *floating load*—a rail load that is permitted to move in a longitudinal direction so that impact shocks are dissipated through movement of the load.

3.1.56 *gondola*—a freight car with sides and ends but without a top covering. May be equipped with high or low sides, drop or fixed ends, solid or drop bottoms, and is used for shipment of any commodity not requiring protection from the weather.

3.1.57 *gondola, covered*—a gondola with a movable or removable cover. Used for the shipment of any commodity that requires protection from the weather.

3.1.58 *gondola, drop-end*—a gondola with ends in the form of doors which can be lowered to facilitate loading and unloading, or for transporting long material that extends beyond the ends of the car.

3.1.59 *gondola, fixed-end*—a gondola with fixed ends and sides but without top covering.

3.1.60 *gondola, low-side*—a gondola with car sides under 45 in. (1.14 m).

3.1.61 *greaseproof paper*—paper treated to inhibit absorption of grease or oil.

3.1.62 *gross weight*—See definitions under *weights.*

3.1.63 *guide strips*—lumber secured to car floor to prevent lateral movement of lading.

3.1.64 *hand bundle*—a secured or unsecured unit that can be handled manually.

3.1.65 *headerboard*—bulkhead on the front end of a trailer to protect the cab from shifting of the load.

3.1.66 *ID*—inside diameter or inside dimension.

3.1.67 *idler car*— flat car or drop-end gondola placed adjacent to a car carrying an overhanging load.

3.1.68 *insert*—a support used in the inside diameter of a coil placed in position after the coil is formed to prevent collapse.

3.1.69 *integral cover*—a retractable permanently affixed cover on a gondola or flat car.

3.1.70 *interleaving*—placing paper between sheets in a lift or between coil wraps for protection against abrasion.

3.1.71 *interlocking*—procedure for stacking small channels and shapes.

3.1.72 *joint strength*—the tension measured in pounds that a tied joint can withstand before the joint slips or breaks.

3.1.73 *keg*—a small barrel.

3.1.74 *knee brace*—a triangular brace against the load consisting of a vertical and a diagonal member used to prevent shifting of the load. It is frequently supplemented with cleats.

3.1.75 *kraft paper*—wood pulp paper made by the sulfate process.

3.1.76 *label*—paper or other material affixed to the package containing identification of product, consignee, producer, etc.

3.1.77 *lagging*—narrow strips of protective material, usually wood, spaced at intervals around a cylindrical object as protection against mechanical damage.

3.1.78 *laminant*—the bonding agent used to combine two or more sheeted materials such as films, foils, paper, etc. Often selected to improve barrier qualities of the laminated product.

3.1.79 *lift*—a unit prepared for handling by mechanical equipment. It may be either secured or loose.

3.1.80 *lift truck*—a wheeled device used to lift and to transport material. May be a fork lift, ram lift, platform, or straddle truck.

3.1.81 *light weight*—See definition under *weights*.

3.1.82 *load limit*—the maximum load in pounds that the conveyance is designed to carry.

3.1.83 *loose*—often used to mean shipping unsecured.

3.1.84 *LTL*—less truck load; quantities shipped in amounts less than truck load.

3.1.85 *marking*—term applied to any of several methods of identifying steel products such as stenciling, stamping, free handwriting, printing, or bar coding.

3.1.86 *metal package*—a paper-wrapped package enclosed with metal intended for overseas shipment.

3.1.87 *multiple lift*—usually refers to unsecured individual lifts of sheets combined one on top of another to make a package.

3.1.88 *MVT*—moisture vapor transmission.

3.1.89 *nailable steel floor*—steel floor designed with slots or perforations to permit nailing of lumber blocking.

3.1.90 *nestable steel products*—rolled or formed steel products or containers that can be fitted into each other when packaged or loaded.

3.1.91 *net weight*—See definition under *weights.*

3.1.92 *OD*—outside diameter or outside dimension.

3.1.93 *oilproof*—a term used to describe packaging materials that are oil resistant.

3.1.94 *package*—one or more articles or pieces contained or secured into a single unit.

3.1.95 *pallet*—a structure of wood, metal, or other materials having two faces separated by stringers. Either or both faces may be solid or skeleton construction.

3.1.96 *piggy back*—highway trailers transported on freight cars.

3.1.97 *platform*—a structure of wood, metal, or other materials consisting of a deck supported by runners used to facilitate mechanical handling. The deck may be solid or skeleton.

3.1.98 *pneumatic tool*—a tool operated by air pressure for purpose of tensioning, sealing, nailing, etc.

3.1.99 *polyethylene*—a synthetic material used as a free film or in combination with other materials (usually paper) as a protective wrap, cover, or shroud.

3.1.100 *port mark*—marking that identifies the port of discharge.

3.1.101 *racks, storage*—a structure on which material is stored.

3.1.102 *reel*—any device with a flange on each end of which material may be wound, having a flange diameter of 12 in. (305 mm) or over.

3.1.103 *retarder plates*—formed metal plates secured to the floor through which unit securement bands are threaded. They are used to retard movement of loads.

3.1.104 *rub rail:*

—a rail extending around the perimeter of a flat-bed trailer.

—a buffer strip used in a conveyance between the side and the lading.

—a guide on flat cars used in TOFC service.

3.1.105 *runner*—member supporting platform deck.

3.1.106 *rust inhibitor*—a chemical agent used to retard oxidation.

3.1.107 *seal:*

—means of effecting strapping joints.

—protective device used to provide evidence that closure has not been disturbed.

3.1.108 *seal protector*—a protector to prevent strapping seal indentation damage to the product.

3.1.109 *secured lift*—See *lift.*

3.1.110 *separator*—any material placed between units of the package or load to provide clearance.

3.1.111 *shroud*— a protective cover placed over the load, unit, or package, covering the top and four sides.

3.1.112 *skeleton platform*—See *platform.*

3.1.113 *skid protector (stain protector)*—any of various practices followed to prevent corrosion damage from packaging lumber.

3.1.114 *skids*—supporting members placed either lengthwise or crosswise beneath and secured to the material to facilitate handling.

3.1.115 *solid platform*—See *platform.*

3.1.116 *spool*—a device with a flange at each end on which material may be wound, having flange diameters up to 12 in. (305 mm).

3.1.117 *stack*—placement of materials or package in tiers.

3.1.118 *stake pocket*—a metal receptacle that is part of the vehicle and that is designed for the acceptance of stakes.

3.1.119 *stakes*— metal or lumber placed vertically along sides of vehicle to prevent movement of the lading beyond the side of the vehicle. Also used to provide clearance between the lading and the side of the vehicle.

3.1.120 *stamp*—to identify with either metal or rubber die.

3.1.121 *stencil*—to provide identification through the use of a precut stencil.

3.1.122 *strapping*—flxible material used as a medium to fasten, hold, or reinforce, for example, steel strapping; flat steel band designed for application with tensioning tools.

3.1.123 *strapping joint*—location or method of providing a strapping closure.

3.1.124 *stringers*—supporting members that separate the two faces of a pallet.

3.1.125 *tag*—material, such as paper, plastic, or metal, on which product or shipping data are furnished and which is fastened to a package or container by wires, staples, tacks, etc.

3.1.126 *tally*—a recapitulation of items comprising a load.

3.1.127 *tare weight*—weight of container or packaging materials.

3.1.128 *tarpaulin*—water-resistant material used to protect load or materials from the elements.

3.1.129 *tension tie*—strapping applied with mechanical tools.

3.1.130 *theoretical weight*—a calculated weight based on nominal dimensions and the density of material.

3.1.131 *tier*—one of two or more rows placed one above the other.

3.1.132 *TOFC*—trailer on flat car. See *piggy back.*

3.1.133 *truck*—a rubber-tired highway vehicle in the form of a straight truck, semi-trailer, full trailer, or any combination thereof.

3.1.133.1 *flat bed*—a truck whose cargo-carrying area is a flat surface without sides, ends, or tops.

3.1.133.2 *low side*—a truck whose cargo-carrying area is a flat surface equipped with side and ends and approximately 2 ft 6 in. to 4 ft (0.76 to 1.22 m) in height.

3.1.133.3 *removable side*—a truck whose cargo-carrying area is a flat surface equipped with removable sides and rear door approximately 2 ft 6 in. to 8 ft(0.76 to 2.44 m) in height.

3.1.133.4 *open top high side*—a truck whose cargo-carrying area is a flat surface equipped with high sides and ends but no permanent top. The end at rear of vehicle opens to facilitate loading.

3.1.133.5 *pole trailer*—highway trailer with a pole-like connection between the front and back wheels for transporting long material.

3.1.133.6 *expandable trailer*—a flat trailer of more than one section which may be extended for long product.

3.1.133.7 *van*—a truck or trailer with nonremovable top.

3.1.134 *twist ties*—round or oval ties in which the joint is made by twisting the two ends together.

3.1.135 *unitized*— segments of the load secured into one unit.

3.1.136 *unsecured lifts*—See *lift.*

3.1.137 *VCI*—volatile corrosion inhibitor. One type of rust inhibitor.

3.1.138 *waster sheet*—a secondary grade sheet, sometimes used in packaging to increase resistance to mechanical damage.

3.1.139 *waterproof paper*—paper constructed or treated to resist penetration of water in liquid form for specific lengths of time.

3.1.140 *weights (package):*

3.1.140.1 *gross weight*—total weight of commodity and all packaging.

3.1.140.2 *lift weight*—the weight of the material in a lift.

3.1.140.3 *net weight*—the weight of the commodity alone excluding the weight of all packaging material or containers.

3.1.140.4 *tare weight*—weight of packaging components.

3.1.141 *weights (transportation):*

3.1.141.1 *gross weight*—total weight of lading and transporting vehicle.

3.1.141.2 *light weight*—the weight of the empty transporting vehicle. On rail cars, the light weight is stenciled on car sides.

3.1.141.3 *tare weight*—same as *light weight.*

3.1.142 *wrapped*—a package or shipping unit completely enclosed with protective material.

4. General Provisions

4.1 *General*—It is recommended that producers and users follow the packaging, marking, and loading methods for individual steel products so described and illustrated herein. It is the responsibility of the purchaser to provide the producer with his requirements concerning protective wrapping materials. When unusual or special conditions require packaging, marking, and loading methods not covered herein, the purchaser should consult with the supplier. Each load involves variables in lading and equipment which cannot be precisely covered by loading rules. Therefore, it is essential that the receiver supply the shipper with pertinent information on his unloading methods and equipment.

TABLE 1 Protective Coatings Used to Protect Steel Mill Products

Type	Method of Application	Purpose
Type A—Thin soft film preservative consisting of a rust inhibitor in petroleum oil	cold; spray, dip or brush	to provide protection against corrosion and staining of steel mill products for short-term preservation periods (up to 3 months indoor storage)
Type C—Hard drying varnish resinous or plastic coating	cold; spray, dip or brush	to provide protection against corrosion of steel mill products for intermediate-term preservation periods (up to 6 months outdoor storage)
Type D—Medium soft film preservative in a solvent	cold; spray, dip or brush	to provide protection for edges of coils or cut lengths

4.2 *Railcar Loading*—All rail shipments of steel products are loaded in accordance with the latest rules governing the loading of either open top cars or closed cars as published by the Association of American Railroads. These publications are entitled "Rules Governing the Loading of Commodities on Open Top Cars" and "Pamphlet 23—The Rules Governing the Loading of Steel Products in Closed Cars and Protection of Equipment."

4.3 *Truck Loading*—The trucker is responsible for the arrangement and securement of the load for safe transit, the protection of the lading from damage by binders, and the prevention of damage to the lading from the elements. These loads shall be in accordance with applicable state and federal regulations.[6]

4.4 *Barge Loading*—There are no formal rules covering barge loading. Steel products are suitably packaged and the barge is loaded to provide ample clearance or blocking, or both, for subsequent handling and unloading. Covered or open-top barges may be used depending upon the nature of the product.

4.5 *Air Shipment*:

4.5.1 When metal plates, strips, sheets, bars, rods, angle stock, tubes, and pipe are to be shipped by air, they shall be packed as follows:

4.5.1.1 Plate, sheet, and strip shall be packed in snug–fitting boxes reinforced with steel straps or in metal packs.

4.5.1.2 Bar, rod, angle stock, pipe, and tube shall be packed in snug-fitting crates with solid wood ends or in boxes, as required for protection.

4.5.1.3 Single pieces or bundles of steel stock shall have a snug-fitting wood cap secured over each end. End caps shall be fabricated as shown in Fig. 1. Lumber and construction of end caps shall be as specified in 4.6.2. End capse shall be secured to each other by flat or round wire steel strapping. Straps should be secured to end caps with staples. Caps shall be a minimum of 18 in. (450 mm) in length and a minimum of 2½ in. (60 mm) square at the end.

4.5.1.4 Castings, forgings, and other large or irregular shapes shall be preserved, packed, and marked as agreed between purchaser and seller.

4.6 *Packaging Materials*:

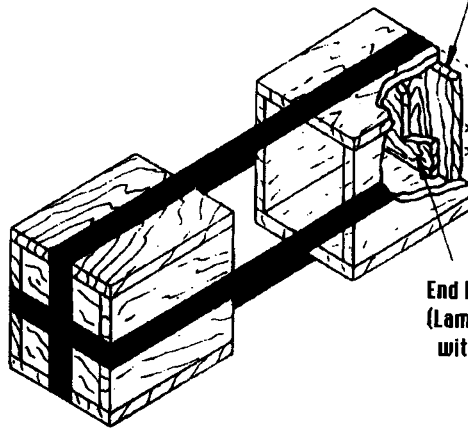

FIG. 1 End Caps for Air Shipment

4.6.1 *General*—Materials not covered by specifications or which are not specifically described herein shall be of a quality suitable for the intended purpose. Specifications described are intended as the minimum requirements for packaging of steel products. After the product has been delivered, purchasers are faced with the problems of disposal of the packaging materials. For this reason the simplest effective packaging is the most desirable. The packaging materials described are subject to change in accordance with the rapidly developing technology and the changing regulations affecting ecology.

4.6.2 *Lumber*—The proper selection of lumber for use in the packaging of steel products depends upon many factors, such as end use, compressive strength, beam strength, hardness, moisture content, nail-holding power, condition, etc. Detailed information is contained in Specifications D 245 and Test Methods D 2555.

4.6.3 *Protective Wrapping Material*—Protective wrappings are used in packaging to (*1*) retard moisture penetration, (*2*) minimize loss of oil, and (*3*) provide protection from dirt.

4.6.3.1 *Paper*—The basis weight is determined by the number of pounds per 500 sheets of 24 by 36 in. For example, 50-lb kraft paper will equal 50 lb per 500 sheets of 24 by 36 in. The following tests may be used to determine the physical properties of paper:

Test	ASTM Method
Bursting strength	D 774
Tensile strength	D 828

4.6.3.2 *Oil-Resistant Paper*—Paper treated, laminated, or constructed to resist absorption of oil from the packaged product.

[6] Code of Federal Regulations Title 49—Transportation, Chapter III-Federal Highway Administration, Department of Transportation, Subchapter B-Motor Carrier Safety Regulations, Part 393, Parts and Accessories Necessary for Safe Operation, Safe Loading of Motor Vehicles.

4.6.3.3 *Waterproof Paper*—These papers are laminated, coated, or impregnated with a moisture-barrier material.

4.6.4 *Protective Coatings*—In selecting corrosion-preventive materials to protect steel mill products during shipment and storage, consideration should be given to ease and method of application, coverage desired, severity of conditions expected, and ease of removal. The material and method of application determined to be the best suited for protection of a product are based on experience. Therefore, selection of protective coatings should be left to the discretion of the steel supplier whenever possible. The protective coatings used on steel products are listed in Table 1.

4.6.5 *Package Ties*—Tying of packages shall be accomplished by tension-tying with bands or wire; or by hand tying and twisting heavy gage wire or rods. Either bands or wire may be used for package ties, regardless of which type of tie is shown in illustrations in the individual product sections of this practice.

4.6.5.1 *Breaking Strength Ties* used in packaging steel mill products shall have the minimum breaking strengths of Specification D 3953.

4.6.6 *Protectors*—Protectors are used with certain products to protect them from damage and to prevent shearing of the ties. Various materials, such as lumber, metal, plastic, fiber, or other suitable materials, are used under the package ties as required.

4.7 *Package Identification*:

4.7.1 All marking shall be legible and of a size consistent with the space available to be marked. All tags shall be securely affixed to the package to prevent loss in transit. Tags shall be of a size to show clearly all of the information required, and shall be able to withstand reasonable exposure to the elements.

4.7.2 *Marking Metal Surfaces*—Unless otherwise specified, metal surfaces shall be marked with either permanent ink or paint.

4.7.3 *Marking Containers*—All materials used for marking containers shall be resistant to the elements.

4.8 *Weight and Count*—When steel products are invoiced on mill scale weights and such weights are checked after shipment, variations from invoice weights up to 1 % are normally expected due to differences in the kind, type, and location of the scales. When invoiced on mill scale weights, where there are large quantities of one size or thickness, or where the number of pieces in a lift or bundle is required to be shown on the identification tags and shipping papers, the count is considered approximate and the weight is the more accurate. When steel products are invoiced on theoretical weights, the invoice weights are based on the number of pieces or lineal feet shipped.

4.9 *Packaging Lists or Tally*—Furnished as required. Such lists are compiled as accurately as practicable, subject to confirmation by the official shipping notice or invoice.

4.10 *Loss or Damage*—If upon delivery there is any evidence of loss or damage, exception should be taken by notation on the freight bill, and the carrier's representative should be called in to inspect the lading before unloading.

5. Semifinished Steel Products

5.1 Semifinished steel products are generally produced for further processing and, because of their nature, only the simple methods of packaging and loading described below are recommended.

5.2 *Product Grades*:

5.2.1 Carbon, alloy, and stainless steel ingots, blooms, billets, and slabs.

5.2.2 Carbon steel skelp in coils.

5.3 *Marking*:

5.3.1 It is normal practice to stamp or paint the heat number on each piece shipped loose and to show the heat number on a tag attached to each secured lift of smaller size billets. The ordered size and weight may be painted on at least one piece of each size when shipped loose or on at least one piece of each secured lift. Each skelp coil is tagged or marked with the heat number and the size.

5.3.2 *Color Marking*—There is no generally recognized color code for identification of steel grades. When specified, color marking to denote grade is applied. In such cases a dash of color on one end of loose pieces is sufficient. In the case of secured lifts of smaller sizes, the grade is shown on a tag attached to the lift or by a dash of one color on one end of the lift.

5.4 *Packaging*:

5.4.1 Semifinished steel products are usually shipped loose. When specified, lifts of billets 9 in.[7] (58 cm[7]) and under in cross section may be secured into lifts of 5 tons (4.5 Mg) or heavier. The securement of this type of package consists of ties of soft wire rod or tensioned flat bands. The number of ties to be used on any specific lift can best be determined by the shipper's experience.

5.4.2 Skelp in coils is secured with a minimum of two ties per coil.

5.4.3 Semifinished steel products are usually shipped in open-top equipment and require no further protection from the elements.

5.5 *Loading*—Semifinished steel products are usually shipped loose with different sizes or weights segregated. Unitizing requires additional labor and material.

6. Hot-Rolled Bars and Bar-Size Shapes

6.1 Hot-rolled bars and bar-size shapes are usually further processed by the purchaser. Simple methods of packaging and loading are recommended. The major consideration is the prevention of physical damage in transit, such as bending or twisting.

6.2 *Product Grades*:

6.2.1 Carbon, alloy, and stainless steel bars, and bar-size shapes.

6.2.2 Concrete reinforcing bars.

6.3 *Marking*:

6.3.1 *Carbon, Alloy, and Stainless Steel Bars, and Bar-Size Shapes*:

[7] A revision of Simplified Practice Recommendation R 247–62, formerly published by the U. S. Department of Commerce.

6.3.1.1 It is normal practice to identify each lift or coil with a tag containing the following information:

(1) Producer's name, brand, or trademark,

(2) Size,

(3) ASTM designation (year date is not required),

(4) Heat number,

(5) Weight (except coils),

(6) Customer's name, and

(7) Customer's order number.

6.3.1.2 *Die Stamping of Carbon Steel Bars*— The ultimate uses of the products do not usually require die stamping. Therefore, this method of marking for other than mill identification requires additional labor and handling.

6.3.1.3 *Die Stamping of Alloy and Stainless Steel Bars*—When specified, heat numbers or symbols are stamped on one end or on the surface near the end of rounds, squares, hexagons, and octagons 2 in. (51 mm) and larger, and on flats 2 in. in width or 2 in. or over in thickness.

6.3.1.4 The above described marking is practicable on smaller sizes down to a minimum of 1 in. (25 mm) in thickness and 1 in. in width for flats, and not less than 1 in. in thickness or diameter for other bars, but because of its precise nature, such marking delays normal production.

6.3.1.5 Stamping of sizes under 1 in. is not practicable. These sizes are secured in lifts and tagged to show heat numbers or symbols.

6.3.1.6 *Color Marking*—There is no standard color code for identification of steel grades. When marking of bars with identification colors is required, the following practices are regularly employed:

(1) Sizes 2 in. (51 mm) and over are marked on one end with not more than two colors.

(2) Sizes 1½ in. (38 mm) up to 2 in. (51 mm) are marked on one end with not more than one color.

(3) Sizes smaller than 1½ in. (38 mm) are not marked individually; but the bundle, lift, or pile (any size bar or flats) is marked on one end with a dab of paint of one color or not more than two different colored stripes.

(4) Bars are regularly painted after assembly into lifts, and due to the nonuniformity of ends, it is not expected that paint will be on every bar in the lift. Any other paint marking slows normal production. Superimposed color marking requires additional labor and time for drying.

(5) When the back of the tag is color marked, one or two colors are used or the names of the colors are given.

6.3.2 *Concrete Reinforcing Bars*:

6.3.2.1 It is normal practice to identify each lift with a tag containing the following information:

(1) Producer's name, brand, or trademark,

(2) Size or bar designation number, and

(3) Grade and specification.

6.3.2.2 *Color Marking*—When specified, a dab of paint, one color only for each grade, is placed on one end of each lift to distinguish grades. Such marking augments but does not replace the marking requirements contained in the product specification.

6.4 *Packaging*:

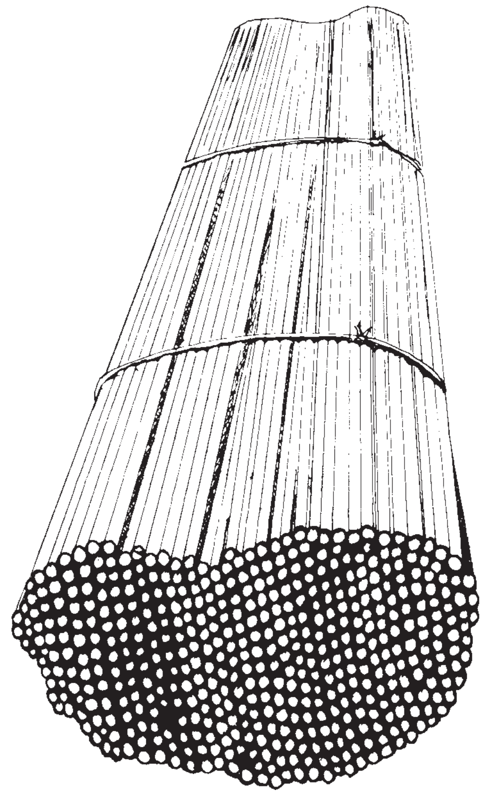

FIG. 2 Suitable Secured Lift-Hot-Rolled and Cold-Finished Bars and Bar-Size Shapes

6.4.1 *Carbon, Alloy, and Stainless Steel Bars, and Bar-Size Shapes*:

6.4.1.1 *Secured Lifts*—Bars are generally packaged into secured lifts (see Fig. 2 and Fig. 3). The recommended weight of hot-rolled bars in a secured lift is 10 000 lb (4.5 Mg). Lifts under 10 000 lb require additional material and handling. Producers recommend that purchasers specify the maximum possible weight for lifts because heavier units withstand transportation hazards better and result in greater economy to both the purchaser and the producer. The securement of this type of package consists of ties of soft wire rod or tensioned flat bands. The number of ties to be used on any specific lift can best be determined by the shipper's experience. This recommended securement is adequate for normal handling and transit requirements. Handling by means of the package ties or by magnet is considered an unsafe practice and is not recommended.

6.4.1.2 *Loose Bars*—The term "loose" means single pieces that can be handled individually. This method of loading is sometimes used when shipping to purchasers who unload by hand or magnet or for shipping large bars.

6.4.1.3 *Stack Piling*—This method of piling is regularly used for straightened flats and certain shapes and consists of arranging pieces in order and securing into lifts of 10 000 lb (4.5 Mg) minimum weight. Stack piling of bars under 1 in. (25 mm) in width is impractical. When stack piling is specified for other than straightened flats or shapes, additional handling is generally required. Fig. 4 illustrates a suitable lift of stack-piled straightened flats.

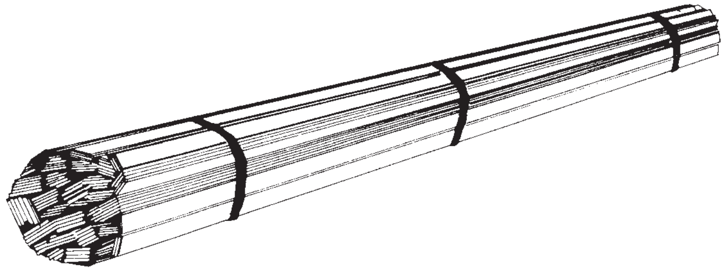

FIG. 3 Suitable Secured Lift-Flats

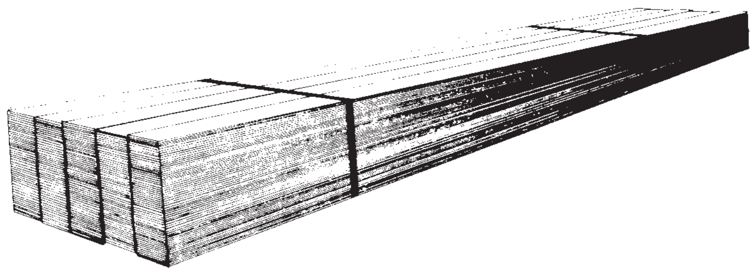

FIG. 4 Suitable Lift of Stack-Piled Straightened Flats

6.4.1.4 *Bar Coils*—Hot-rolled bar coils are regularly secured with two ties of soft wire or flat steel bands and loaded loose, unprotected, in open-top equipment. Bar coils that have had special treatment, such as cleaned and coated or cleaned and oiled, are loaded in closed or covered equipment and require additional labor and material. Securing two or more bar coils into a coil group requires additional labor and material.

6.4.1.5 *Protective Coatings*—The nature of hot-rolled bars or bar-size shapes is such that protective coatings are not regularly applied.

6.4.2 *Concrete Reinforcing Bars*—Concrete reinforcing bars are secured in lifts as illustrated in Fig. 2. The recommended weight of bars in the secured lift is 10 000 lb (4.5 Mg) or more. Lifts under 10 000 lb require additional labor and materials. The securement of this type of package consists of ties of soft wire rods or tensioned flat bands. The number of ties to be used on any specific lift can best be determined by the shipper's experience. Secured lifts in the smaller sizes may contain individually tied bundles within the lift. Bundling of the smaller sizes requires additional material and handling. Packaging of concrete reinforcing bars into units of specified count, weight, or dimensions requires additional handling and material.

6.5 *Loading*:

6.5.1 Carbon, alloy, and stainless steel bars, bar-size shapes, and concrete reinforcing bars are regularly shipped unprotected in open-top equipment. Loading of closed equipment and flatcars requires additional handling and materials.

6.5.2 When separation of lifts is required to allow sufficient clearances needed for unloading equipment, separators or bearing pieces are furnished up to a maximum of commercial 4-in. lumber.

6.5.3 *Weather Protection*—Hot-rolled bars, hot-rolled heat-treated bars, bar-size shapes, and concrete reinforcing bars generally require further processing or fabrication and, therefore, are regularly shipped in open-top equipment, unprotected. When the bars are scale-free or have been processed beyond the as-rolled or heat-treated condition, such as by pickling and oiling or by pickling and liming, producers usually recommend protection by shipment in covered equipment or by wrapping or shrouding when loaded in open-top equipment. In covered rail equipment, shrouding may be required. Fig. 5 illustrates a suitable method of wrapping lifts for loading in open-top equipment. Fig. 6 illustrates a suitable method of shrouding the carload. The material is a waterproof paper or plastic sheet placed over a number of lifts or over the entire carload and suitably secured.

7. Cold-Finished Bars

7.1 Cold-finished carbon, alloy, and stainless steel bars are among the most highly finished products of the steel industry. Because of their high finish and the exacting uses to which such products are put, packaging and loading methods are very important.

7.2 *Product Grades*—Carbon, alloy, and stainless steel bars.

7.3 *Marking*:

7.3.1 *Carbon, Alloy, and Stainless Steel Bars*:

7.3.1.1 It is normal practice to identify each lift with a tag containing the following information:

(1) Producer's name, brand, or trademark,
(2) Size,
(3) ASTM designation (year date is not required),
(4) Heat number,
(5) Weight,
(6) Customer's name, and
(7) Customer's order number.

7.3.1.2 *Die Stamping*—It is not regular practice to die-stamp cold-finished bars. Therefore, when specified, this method of marking retards the normal flow of materials.

7.3.1.3 *Color Marking*—When the marking of bars with identification colors is required, the following practices are employed:

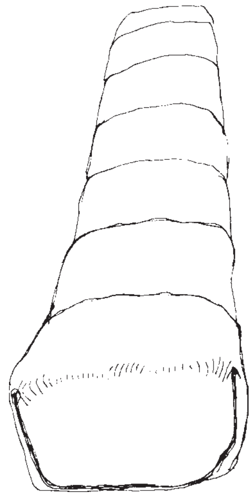

FIG. 5 Suitable Method of Wrapping Lifts for Loading in Open-Top Equipment

(1) Sizes 1½ in. (38 mm) and over are marked on one end with not more than two colors.

(2) Sizes smaller than 1½ in. are not marked individually, but the bundle, lift, or pile is marked on one end with a dab of paint of one color or not more than two different colored stripes.

(3) Any other paint marking slows normal production.

(4) Superimposed color marking also requires additional labor and time for drying.

(5) When the back of the tag is marked, one or two colors are used or the names of the colors are spelled out.

7.4 *Packaging*:

7.4.1 *Carbon, Alloy, and Stainless Steel Bars*:

7.4.1.1 *Secured Lifts* (Fig. 2)—The recommended minimum quantity of cold-finished bars in the secured lift is 6000 lb (2.7 Mg). Producers recommend that purchasers specify the maximum possible weight for lifts because heavier lifts withstand transportation hazards better and result in greater economy to both the purchaser and the producer. The packaging of bars into lifts for closed-car loading requires additional handling. The securement of this type of package consists of ties of soft wire or flat steel bands. Ties are regularly applied as follows:

Up to 15 ft (4.57 m), incl	3 ties
Over 15 ft to 22 ft (4.57 to 6.71 m), incl	4 ties
Over 22 ft to 33 ft (6.71 to 10.06 m), incl	5 ties
Over 33 ft (10.06 m)	6 ties

The recommended securement is adequate for normal handling and transportation requirements. Handling by means of the package ties or by magnet is considered an unsafe practice and is not recommended.

7.4.1.2 *Loose Bars*—The term "loose" means single pieces that can be handled individually. This method of loading is used by producers in the loading of large sizes.

7.4.1.3 *Stack Piling*—This method of piling is regularly used for straightened flats and certain shapes and consists of arranging pieces in order, in one or more piles, into secured lifts of 6000 lb (2.7 Mg) minimum weight. Stack piling of bars under 1 in. (25 mm) in width is impractical. When stack piling is specified for other than straightened flats, additional handling is generally required. The stacking or piling of all bars or bar-size shapes, including straightened flats, into lifts of specified count or dimensions involves additional handling. Fig. 4 illustrates a suitable lift of stack-piled straightened flats.

7.4.1.4 *Bundling*—Cold-finished round, square, hexagon, or similar bar sections 5⁄16 in. (7.9 mm) and under are put up in hand bundles because of the flexible nature of the material. Bundling of sizes over 5⁄16 in. requires additional handling. Fig. 7 illustrates a suitable hand bundle. Such bundles regularly contain not less than three pieces, the package weighs from 150 to 200 lb (68 to 91 kg), and is tied with No. 14 gage (1.63-mm) wire or its equivalent as follows:

Up to 8 ft (2.44 m), incl	2 ties
Over 8 ft to 16 ft (2.44 to 4.88 m), incl	3 ties
Over 16 ft to 20 ft (4.88 to 6.10 m), incl	4 ties
Over 20 ft to 24 ft (6.10 to 7.32 m), incl	5 ties

Fig. 8 illustrates a bundle of bars banded to a board. Small quantity items unable to support their own weight without possible damage from bending or distortion are usually secured to boards or boxed.

7.4.1.5 *Containers*—Due to the special high finish and very close tolerances of some cold-finished bars, packaging in special containers for extra protection against damage is required. This type of packaging requires additional material and handling. Less than carload or less than truckload shipments of polished, turned ground and polished, cold-drawn ground and polished bars and shafting, or any bars produced to a high finish, are packaged in chipboard tubes, wood boxes, corrugated fiberboard boxes or other suitable containers. Fig. 9 illustrates a suitable chipboard container. Such containers are made of heavy spirally wound chipboard with various end closures. Fig. 10 illustrates a suitable wood box. Such boxes are made of seasoned lumber, lined with paper, and are reinforced with bands or wire at the ends and at intermediate points, as required.

7.4.1.6 *Protective Coatings*—Cold-finished bars are coated with corrosion preventatives or shipped without protective coating depending upon the use and the purchaser's specification.

7.5 *Loading*:

7.5.1 Cold-finished carbon, alloy, and stainless steel bars are normally shipped in closed or covered equipment. Loading in box cars requires additional handling.

7.5.2 When separation of lifts or piles in cars is required to allow sufficient clearances for unloading equipment, separators or bearing pieces are furnished up to a maximum of commercial 4-in. lumber. Loads are often shipped in bulkhead equipment or are rigidly braced for protection in transit.

7.5.3 Where additional protection is specified in covered gondolas, material may be wrapped or shrouded as illustrated in Fig. 9 or Fig. 10. Fig. 5 illustrates a suitable method for wrapping lifts of cold-finished bars. Fig. 6 illustrates a suitable method of shrouding the carload.

8. Structural Shapes and Steel Sheet Piling

8.1 *Product Grades*:

8.1.1 Carbon, high-strength low-alloy, and stainless steel structural shapes.

8.1.2 Steel sheet piling.

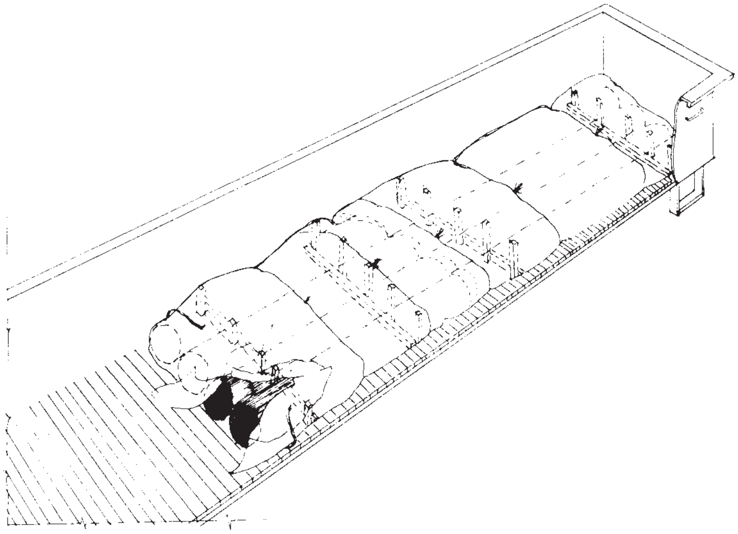

FIG. 6 Suitable Method of Shrouding Carload

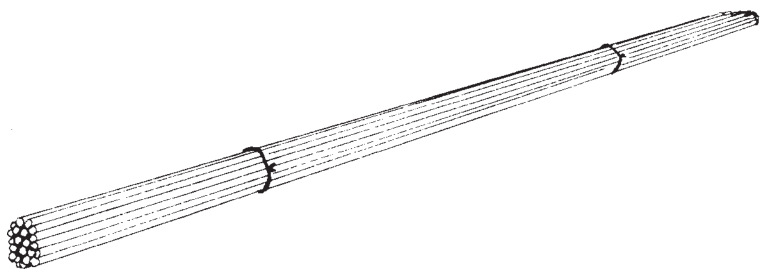

FIG. 7 Suitable Hand Bundle of Cold-Finished Bars

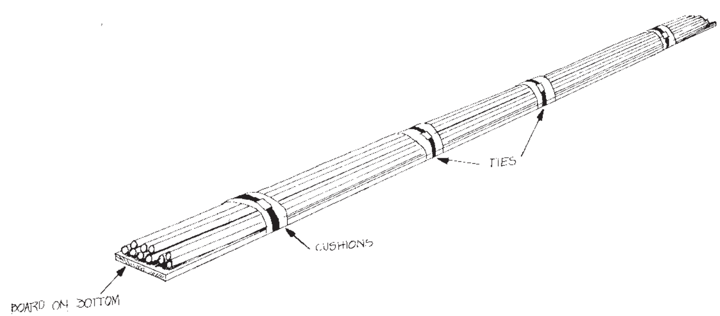

FIG. 8 Bundle of Cold-Finished Bars Secured to a Board

8.2 *Marking*:

8.2.1 *Carbon, High-Strength Low-Alloy, and Stainless Steel Structural Shapes*:

8.2.1.1 It is normal practice to mark each individual structural shape shipped loose or tag each secured lift with the following information:

(1) Producer's name, brand, or trademark,

(2) Section designation or size of section,

(3) Heat number,

(4) Length, and

(5) Grade or type (stainless steel).

8.2.1.2 *Die Stamping*—When specified, the heat number is die-stamped in one location. Die stamping or hot rolling the heat number into structural shapes is not universally practiced. The standard sizes of steel die-stamps are ¼ in., 5⁄16 in., and ⅜ in. (6.4 mm, 7.9 mm, and 9.5 mm). Any additional or different marking other than as indicated above or specifying stamping with steel die-stamps of sizes other than indicated is negotiated between purchaser and manufacturer.

8.2.1.3 *Color Marking*—On structural shapes made to certain ASTM specifications, color marking is required. Each structural shape shipped loose is marked with one or two color stripes. When shipped in secured lifts, the lift is marked with a vertical stripe for the full height of the lift. Each piece in the lift shall be marked by this stripe.

8.2.2 *Steel Sheet Piling*—It is normal practice to mark each steel sheet piling with the following:

(1) Producer's name, brand, or trademark,

(2) Heat number, and

(3) Length.

Additional or different marking requires additional handling and complicates the normal marking procedure.

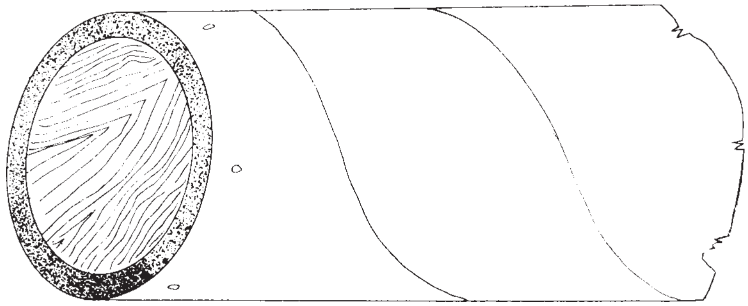

FIG. 9 Suitable Chipboard Container

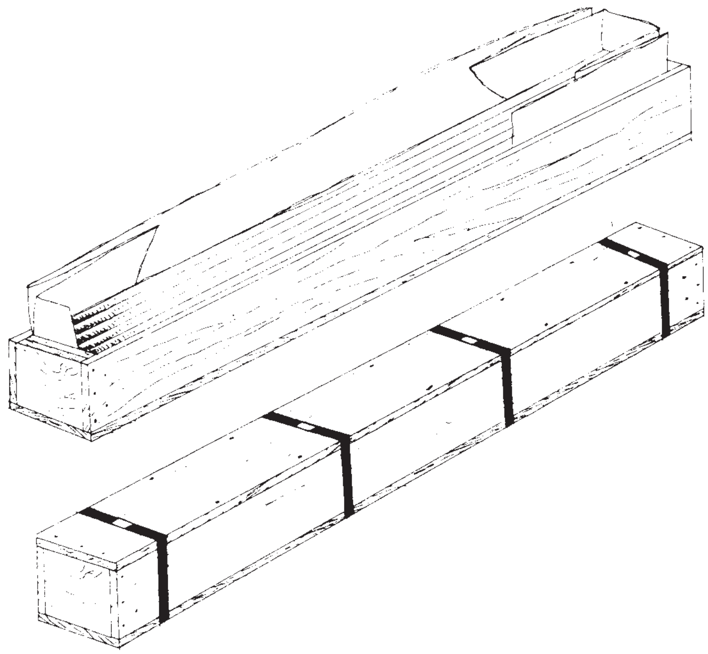

FIG. 10 Suitable Wood Box for Cold-Finished Bars

8.3 *Packaging*:

8.3.1 *Carbon, High-Strength Low-Alloy and Stainless Steel Structural Shapes*—Structural shapes are normally shipped in unsecured lifts or units weighing approximately 10 000 to 20 000 lb (4.5 to 9.0 Mg). Various methods are used to maintain the unity of such lifts during transit. At manufacturer's option, small sizes may be secured to facilitate identification, handling, or transportation.

8.3.2 *Steel Sheet Piling*—Steel sheet piling is normally handled and loaded in lifts or units weighing approximately 10 000 to 20 000 lb (4.5 to 9.0 Mg), depending on the size of piling sections.

8.4 *Loading*:

8.4.1 *Carbon, High-Strength Low-Alloy, and Stainless Steel Structural Shapes*:

8.4.1.1 *Loading Practice*—Structural shapes are loaded unprotected in open-top equipment because of their nature and the universal use of mechanical unloading equipment. The method used to separate lifts in the car to facilitate unloading can best be determined at the time of loading. Wood blocking and endwise staggering are typical means of separating lifts. Segregation of sections by size, type, or item into separate cars requires additional handling.

8.4.1.2 *Weather Protection*—Structural shapes, due to their nature, are seldom protected from the weather in transit. Protection such as shrouding requires additional labor and material.

8.4.2 *Steel Sheet Piling*—Because of its nature and the universal use of mechanical unloading equipment, steel sheet piling is loaded unprotected in open-top equipment. The method used to separate lifts in the car and thus facilitate unloading can best be determined at the time of unloading. Wood blocking and endwise staggering are typical means of separating lifts.

9. Rods, Wire, and Wire Products

9.1 Hot-rolled wire rods are regularly produced for further processing, and because of their nature only simple methods of marking, packaging, and loading are required.

9.1.1 The major consideration is the prevention of physical damage in transit, such as bending and twisting.

9.1.2 Other wire and wire products however, are among the most highly finished products of the steel industry, and marking, packaging, and loading methods are very important.

9.1.3 Because of the many specific combinations of size, grades, and types supplied in wire, no standard limits for types,

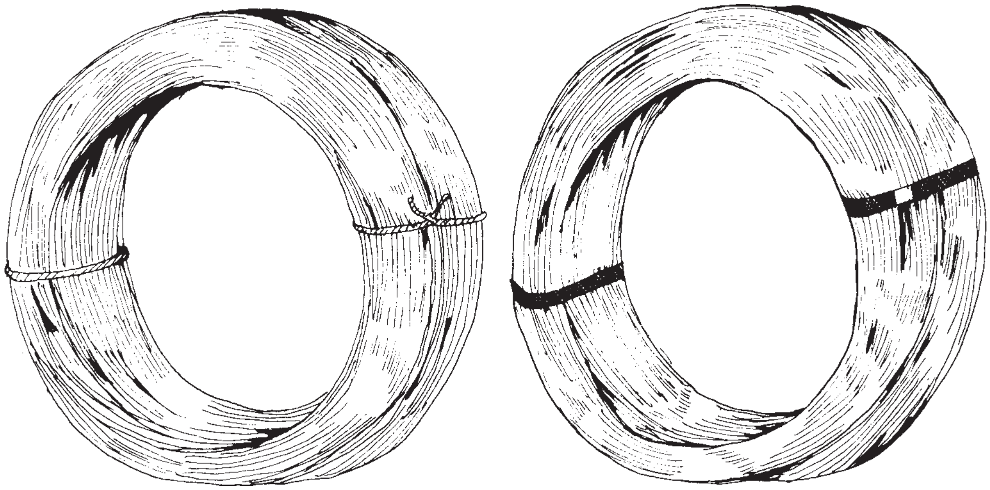

FIG. 11 Securement of Hot-Rolled Rods in Individual Coils

diameters, weights, and coil sizes are established. Limitations for coil sizes are controlled by manufacturing practices and other factors.

9.1.4 The purchaser should give careful consideration to marking, packaging, and loading requirements when ordering, and if in question about a suitable method, should consult with the manufacturer. Consultation is usually essential to develop mutually satisfactory methods for packaging of specific products.

9.2 *Product Grades*:

9.2.1 Hot-rolled rods (all grades).

9.2.2 Merchant wire products.

9.2.3 Carbon, alloy, and stainless steel wire (in coils).

9.2.4 Carbon, alloy, and stainless steel wire (straightened and cut).

9.3 *Marking*:

9.3.1 *Hot-Rolled Rods in Coils*—It is normal practice to tag each coil with the following information:

9.3.1.1 Producer's name, brand, or trademark,

9.3.1.2 Grade, product identification or type (stainless steel only),

9.3.1.3 Size,

9.3.1.4 Heat number,

9.3.1.5 Customer's name, and

9.3.1.6 Customer's order number.

(1) When identification colors are specified, marking practice shall be limited to paint striping coil with one color.

9.3.2 *Merchant Wire Products*—It is normal practice to identify each package with the following information, as applicable:

9.3.2.1 Producer's name, brand, or trademark,

9.3.2.2 Product name:

(1) Design or construction

(2) Style

9.3.2.3 Size,

9.3.2.4 Type or class of coating,

9.3.2.5 Finish,

9.3.2.6 Length,

9.3.2.7 Width and mesh, and

9.3.2.8 Height.

9.3.3 *Carbon, Alloy, and Stainless Steel Wire*—It is normal practice to identify each coil or package with the following information:

9.3.3.1 Customer's name,

9.3.3.2 Customer's order number,

9.3.3.3 Producer's name, brand, or trademark,

9.3.3.4 Grade, product identification or type (stainless steel only),

9.3.3.5 Size,

9.3.3.6 Heat number,

9.3.3.7 Quality (when applicable),

9.3.3.8 Finish, and

9.3.3.9 Weight (except coil).

When identification colors are specified, marking practice shall be limited to paint striping coil, one end of bundle or lift with one color.

9.4 *Packaging*:

9.4.1 *Hot-Rolled Rods in Coils* are shipped as individual coils or in coil groups. Securement of individual coils is with a minimum of two twisted wire ties, or tensioned flat bands (Fig. 11). Coil groups are secured with a minimum of two tensioned flat bands (Fig. 12).

9.4.1.1 *Protective Coatings*—It is not standard practice to apply protective coatings to hot-rolled rods, as the product is generally intended for further processing.

9.4.2 *Merchant Wire Products* are finished products sold through distributors or merchandizers and are primarily intended for agricultural, building and home consumption. These products are packaged in various ways depending upon the end use as shown in Table 2 and Figs. 13-26.

9.4.3 *Carbon, Alloy, and Stainless Steel Wire in Coils*—Wire is among the most highly finished products of the steel industry. Packaging, marking, and preservation methods are very important and the purchaser should give careful consideration to these requirements when ordering. Wire is drawn from hot-rolled rods. The choice of the wire drawing block diameter for a given wire size varies from manufacturer-to-manufacturer and is dependent upon the equipment in the plants and the buyer's uncoiling equipment. Wire is commonly

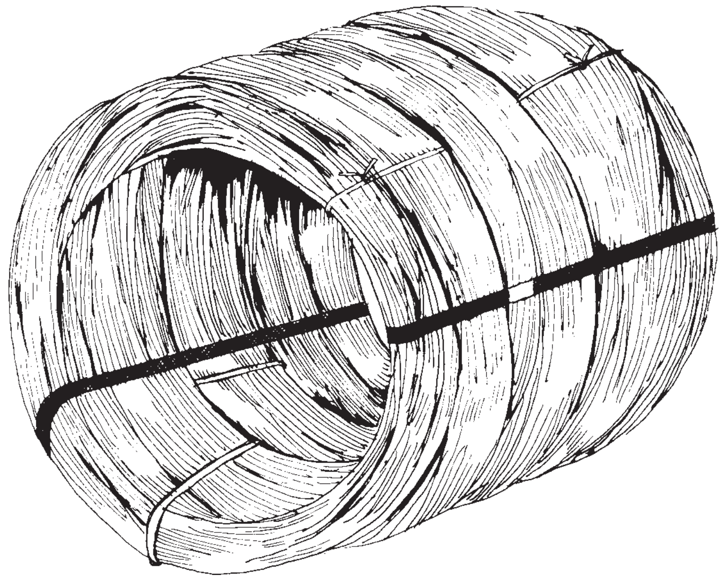

FIG. 12 Securement of Hot-Rolled Rods in Coil Group

produced in catchweight coils of one single length and generally wound in a counterclockwise direction. For special requirements, wire may also be furnished in exact weight coils, exact length coils, or straightened and cut lengths. Carbon, alloy, and stainless steel wire in coils may be packaged as shown in Table 3 and Figs. 27-37. When protection is necessary it should be specified, depending on finish, end use, type of package, mode of transportation, etc. The following types of protection are available when specified:

Package	Protection
Single coil	Spiral wrap(s) up to approximate 600-lb (272-kg) maximum weight. Protection of heavier coils should be negotiated with manufacturer
Coil on carrier	Shroud
Reel-less coil	Shroud
Wood rack	Shroud
Reel	Wrap(s) between flanges
Container	Liner or shroud, depending on type of package

NOTE 1—If special finishes require additional protection, negotiate with manufacturer.

9.4.3.1 *Protective Coating*—Depending upon finish, end use, and shipping or storage conditions, oiling may be specified. The use of specified brands of oil involves special handling and interferes with normal processing. Spray oiling of packages may be helpful but affords inadequate protection under normal conditions. Shipment should be in closed equipment.

9.4.4 *Carbon, Alloy, and Stainless Steel Wire, Straightened and Cut Lengths,* is packed in containers, bundles, or lifts as shown in Table 4 and Figs. 38-47.

9.4.4.1 *Protective Coatings*—Oiling of straightened and cut length wire requires additional handling and material. Flat wire is generally oiled for protection in transit. The use of special brands of oil involves excessive inventory of oil and disrupts the normal manufacturing process. Spray oiling of packages may be helpful but affords inadequate protection under some conditions.

9.5 *Loading*—Hot-rolled wire rods are regularly shipped in open-top equipment except material that has had special treatment, such as cleaning and coating or oiling. Such material is generally loaded in closed equipment and may require additional handling and material. Due to the nature and high finish of steel wire and wire products, they are normally shipped in closed equipment. Special rail equipment, such as DF (damage free), compartment, and insulated cars, are suitable and can be used for wire products.

10. Tubular Products

10.1 Tubular products can be used in the as-shipped condition or further processed into a finished product. The end use directly affects the extent and types of packaging and marking required.

10.2 *Product Grades*:

10.2.1 Mechanical tubing.

10.2.2 Pressure tubing.

10.2.3 EMT conduit.

10.2.4 Rigid conduit.

10.2.5 Standard pipe.

10.2.6 Line pipe.

10.2.7 Oil country goods.

10.2.8 Couplings and fittings.

10.2.9 Stainless steel tubing and pipe.

10.3 *Marking*—It is normal practice to identify each piece of large diameter steel pipe or tubing shipped loose, or each secured lift or package of smaller sizes with the following information:

(1) Producer's name, brand, or trademark.

NOTE 2—The above practice is subject to modification as to standard specifications if applicable.

10.4 *Packaging*:

10.4.1 *Mechanical and Pressure Tubing*— This product is shipped loose or in packages (secured lifts) up to 10 000 lb (454 kg). The type of package normally depends on the length

TABLE 2 Packaging Merchant Wire Products

Bale ties (3 to 20-ft (0.91 to 6.10-m) lengths)	Ends protected, secured with spiral tie wire the entire length of the bundle (Fig. 13).
	Size, gage — Ties per Bundle
	11 — 125
	12, 13, and 14 — 250
	14½, 15, 15½, 16, and 16½ — 500
Baling wire:	
6500-ft (1981-m) minimum length coil (100 lb (45.4 kg) approximate weight)	One coil in self-dispensing corrugated carton (Fig. 14).
3150-ft (960-m) minimum length coil (48.5 lb (22 kg) approximate weight)	Two coils in corrugated box. Note—Packaging must comply with ASAE Standard S 229 (latest revision).
Barbed wire	80-rod spool, secured with wire ties (Fig. 15).
Fence and netting	In rolls secured with wire ties (Fig. 16).
Fence panels	Ten sheets per bundle, inverted; five bundles per lift (Fig. 17). Bundles secured at the four corners with wire ties. Lift secured in the four corners with rod ties.
Fence posts	Five posts per bundle, 40 or 50 bundles per lift (manufacturer's option), secured (Fig. 18 and Fig. 19). Bundle is secured with minimum of two flat bands. Lift is secured with minimum of two flat bands.
Fence wire	150-lb (68-kg) catchweight coil secured with four wire ties (Fig. 20).
Fence assemblies/accessories:	
End and corner posts	Secured into a set.
Brace, complete with bolts	Five braces per bundle.
Stretchers and tools	Single unit.
Stays	100 per bundle, secured with a minimum of three ties.
Fasteners (clamps)	25 or 50 fasteners in a bag; 1000 or 2500 fasteners in a shipping bag or container (manufacturer's option).
Gates, complete with screws, fittings, and latches	Single unit.
Lath-tie wire	One 25-lb (11-kg) bundle in corrugated box (Fig. 24).
Merchant quality wire	One or more pieces of wire in a 100-lb (45-kg) coil secured with a minimum of three wire ties or flat bands (Fig. 20). 100-lb coil group secured with a minimum of three wire ties or flat bands segregated in increments of 10 or 25 lb (4.5 or 11 kg), each secured with three wire ties or flat bands Fig. 20). When specified, two or more 100-lb coils may be combined into coil groups secured with a minimum of three wire ties or flat bands (Fig. 20).
Nails, brads, staples, spikes:	
Bulk	50-lb (22-kg) corrugated box (Fig. 21).
Packaged	1 and 5-lb (0.5 and 2-kg) boxes, packed in 50-lb shipping containers (Fig. 22 and Fig. 23).
Reinforcing bar tie wire	Twenty, approximate 4-lb (1.8-kg) coils in corrugated box (Fig. 25).

The following items may be furnished on pallets: baling wire, barbed wire, lath-tie wire, netting, nails, brads, staples and spikes, and reinforcing bar tie wire (Fig. 26).

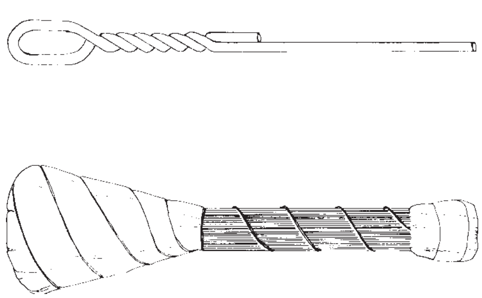

FIG. 13 Bale Ties

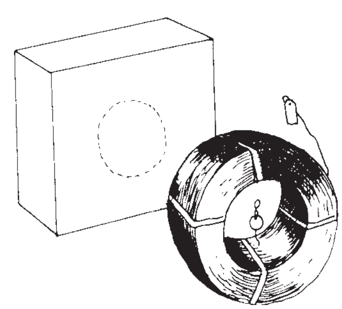

FIG. 14 Coil of Baling Wire and Self-Dispensing Carton

and surface quality of the tubing, the user handling facilities, and the method of storage. Thin-wall, polished, or bright finish tubing subject to possible damage during transit is furnished in wrapped packages, frame packages, or boxes. All packages are secured with tension ties. See Figs. 48-51 for types of packages. The number of ties are shown as follows:

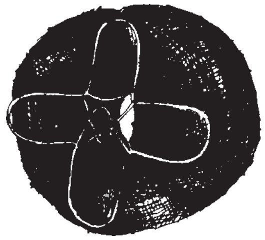
FIG. 15 Spool of Barbed Wire

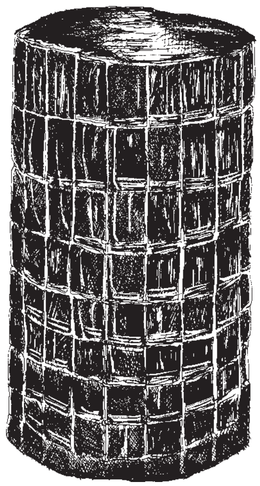
FIG. 16 Roll of Fence/Netting

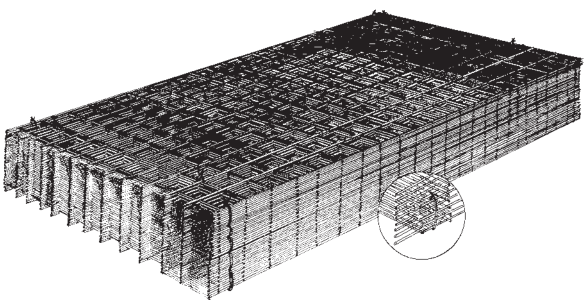
FIG. 17 Secured Lift of Fence Panels


FIG. 18 5-Post Bundle

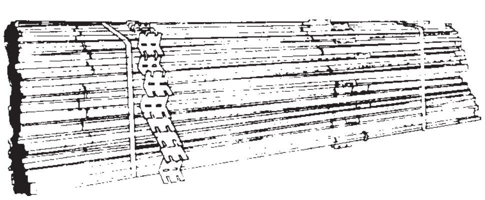
FIG. 19 Secured Lift of 5-Post Bundles

Length, ft (m)	Minimum Number of Ties
Up to (3.05), incl	2
Over 10 to 15 (3.05 to 4.57), incl	3
Over 15 to 22 (4.57 to 6.71), incl	4
Over 22 to 33 (6.71 to 10.06), incl	5
Over 33 (10.06)	6

NOTE 3—Sub-bundles are used for EMT conduit (10.4.2), rigid conduit (10.4.3), and standard pipe (10.4.4).

10.4.2 *EMT Conduit*—This product is normally shipped in packages weighing 2000 lb (907 kg) or more. All EMT conduit of 2-in. nominal diameter and smaller is sub-bundled as listed in the following table. Before it is packaged, all sub-bundles are secured with either bands or tape. All packages are secured with tension ties. See 10.4.1 for number of ties.

Nominal Size, in.	Pieces	ft (m)	Weight, lb (kg)
½	10	100 (30.5)	32 (14.5)
¾	10	100 (30.5)	49 (22.2)
1	10	100 (30.5)	71 (32.2)
1¼	5	50 (15.2)	50 (22.7)
1½	5	50 (15.2)	59 (26.8)
2	3	30 (9.1)	45 (20.4)

10.4.3 *Rigid Conduit*—This product is normally shipped in packages weighing 2000 lb (907 kg) or more. All rigid conduit of 1½ -in. nominal diameter and smaller is sub-bundled as in the following table. Before it is packaged, all sub-bundles are secured with either bands or tape. All packages are secured with tension ties. See 10.4.1 for number of ties.

Nominal Size, in.	Pieces	ft (m)	Weight, lb (kg)
½	10	100 (30.5)	79 (35.8)
¾	5	50 (15.2)	53 (24.0)
1	5	50 (15.2)	77 (34.9)
1¼	3	30 (9.1)	60 (27.2)
1½	3	30 (9.1)	75 (34.0)

10.4.4 *Standard Pipe, Line Pipe, and Oil Country Goods*—These products in sizes 1½ in. nominal diameter and smaller may be shipped in sub-bundles as shown in Table 5 or in larger lifts as requested. Sub-bundles are secured with soft annealed wire, tape or secured with tension ties. A minimum of two ties are used for lengths 22 ft (6.71 m) or less and a minimum of three ties for lengths over 22 ft. Sub-bundles may be shipped in packages (secured lifts) of up to 10 000 lb (4540 kg). Larger sizes are shipped loose. Thread protectors are used as indicated in Table 6.

10.4.4.1 *Protective Coatings*—Standard pipe, line pipe, and oil country goods are normally protected with a varnish-type coating (see 4.6.4). The purchaser may order the pipe shipped bare or with other coatings.

10.4.5 *Couplings and Fittings*:

10.4.5.1 *Conduit Couplings and Fittings*— These products are generally shipped on wires, in burlap sacks, or corrugated fiberboard cartons, dependent upon quantities. The weight of a carton generally does not exceed 200 lb (91 kg).

10.4.5.2 *Pipe Couplings*—These are generally shipped in either burlap sacks or wooden boxes, dependent upon quantities. The weight of a wooden box generally does not exceed 600 lb (272 kg).

10.4.5.3 *Pipe Fittings*—These are generally shipped loose, in burlap sacks, in wooden boxes, in corrugated fiberboard cartons, on pallets, and by other acceptable means at the option of the manufacturer.

10.4.6 *Stainless Steel Tubular Products*:

10.4.6.1 Stainless steel tubular products are variously packaged according to product, finish, size, and method of shipment. Stainless steel tubular products are pipe, pressure tubing, mechanical tubing, and structural tubing (including ornamental). Finishes are as-produced (welded or seamless), annealed

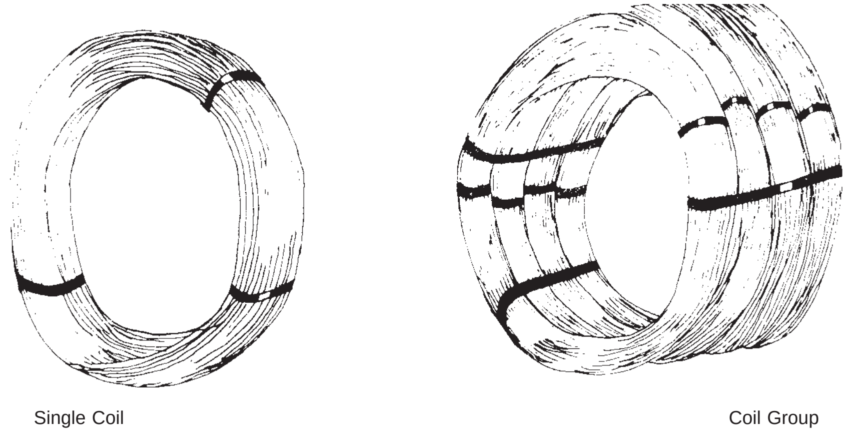

FIG. 20 Coils of Merchant Quality Wire

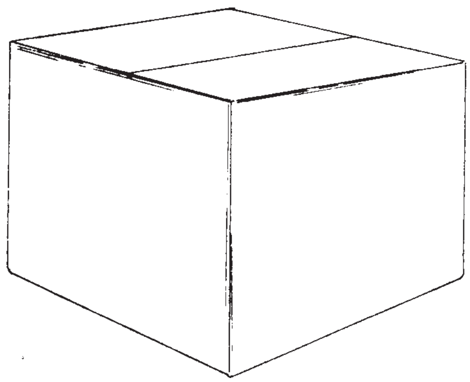

FIG. 21 Corrugated Box for 50-lb Nails

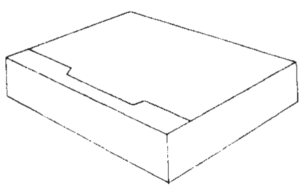

FIG. 22 Box for 1-lb and 5-lb Nails

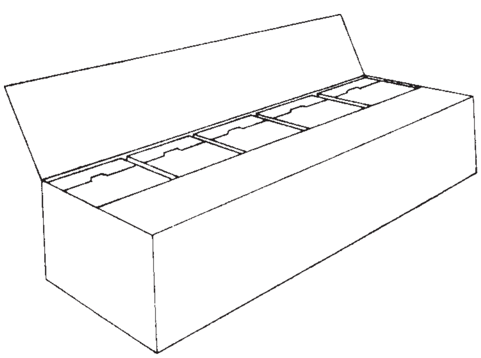

FIG. 23 Shipping Container for Packaged Nails

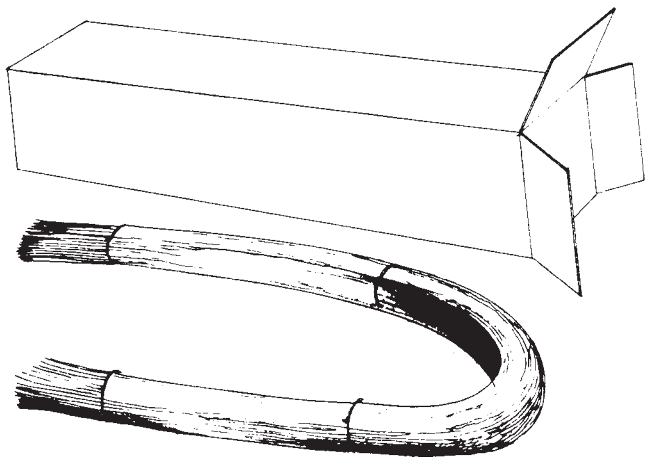

FIG. 24 Bundle of Wire in Corrugated Box

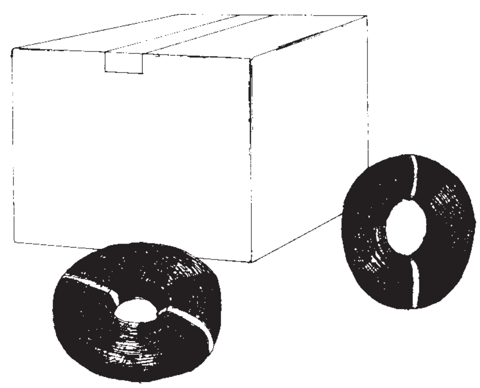

FIG. 25 Coils of Wire in Corrugated Box

and pickled, cold finished, ground and polished, and ornamental (including stainless clad). Due to the many sizes, grades, and finishes produced, the purchaser should give careful attention to the packaging, marking, and loading methods when ordering: if in doubt about a suitable method, the purchaser should consult with the supplier.

10.4.6.2 Stainless steel tubular products are packaged in bundles, boxes, or protective containers. Tubes over 6 in. in outside diameter may be shipped loose. Packages may be wrapped or bare. Length, outside diameter, wall, finish, and method of shipment will determine the most suitable packaging method. Polished tubing is always packed in boxes or containers of wood or other suitable material.

10.4.6.3 *Bundles*—If tubing is shipped in such quantities that a risk of its being bent, crushed, or distorted from handling exists, the bundle may require additional support. Bundles are

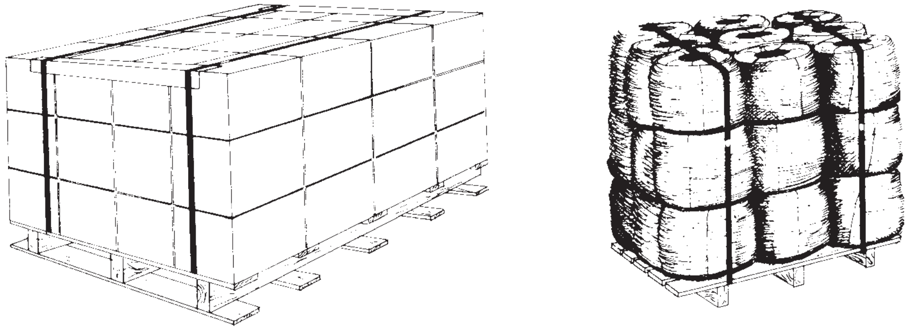

FIG. 26 Typical Palletizing

TABLE 3 Packaging Carbon, Alloy, and Stainless Steel Wire in Coils

Single coil	Secured with a minimum of two ties (Fig. 27).
Coil group (16 in. (406 mm) inside diameter and larger)	Individually tied coils secured into a unit with minimum of two tensioned flat bands (Fig. 28).
Coil carrier^{A}	Single or multiple coils on carrier; normally not secured to carrier (Fig. 29).
Reel-less coil	Approximate 600 to 1000-lb (272 to 474-kg) coil wound on a fiber core and secured with minimum of three tensioned flat bands; pack eye vertical on wood pallet (Fig. 30 or Fig. 32).
Wood rack	Small single coils secured with minimum of two ties nested in rack. Approximate maximum weight 2000 lb (907 kg) (Fig. 31).
Fiber drum	Small single coils secured with a minimum of two ties, nested in drum; or a single coil laid loose in drum. Maximum diameter of drum 23 in. (584 mm). Approximate maximum weight 550 lb (249 kg) (Fig. 33 or Fig. 34). Available loose; or palletized on wood pallets, to improve handling (see Fig. 36).
Pay-off drum	Single coil laid in drum with a fiber core. Core diameters: 11, 11½ , 13, or 16 in. (279, 292, 330, or 406 mm). Maximum diameter of drum 23 in. (584 mm). Approximate maximum weight 550 lb (249 kg) (Fig. 35). Available loose; or palletized on wood pallets, to improve handling (see Fig. 36).
Reel	Single or multiple lengths wound on a reel. Reel size and weight vary by product and manufacturer (Fig. 37).

^{A} List of commonly used sizes of coil carriers:

Arbor	Base	Height	Tube Diameter and Gage	Identification
11	23	35	1 × 16	pink
*13	23	35	1 × 16	orange
13	32	46	1¼ × 13	purple
*15	32	46	1¼ × 13	green
*16[n|]P	36	48	1¼ × 13	yellow
*18½	37	46	1¼ × 13	red
20½	34	46	1¼ × 13	white
22½	42	46	1¼ × 13	aluminum
*22½	42	46	1⅝ × 13	blue
*26	50	50	1⅝ × 13	brown
*30	50	50	1⅝ × 13	black

*Preferred sizes.

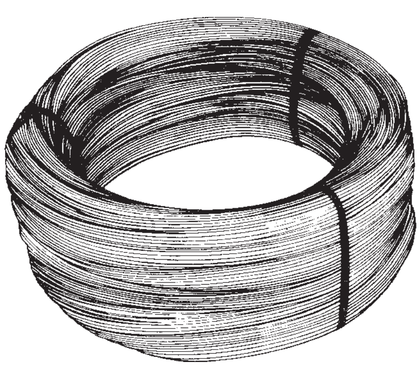

FIG. 27 Single Coil, Bare

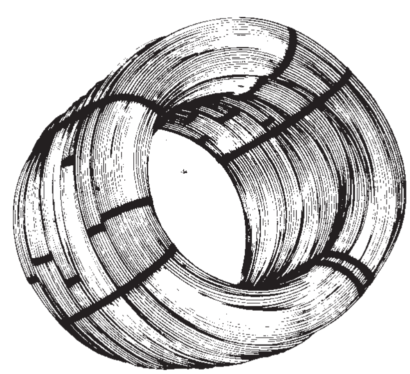

FIG. 28 Coil Group, Bare

normally secured with flat steel bands but other suitable materials may be used. The amount of securement required is dependent upon length and weight of bundle.

10.4.6.4 *Containers*—Special finishes, quantities ordered, methods of transportation, or other factors may require special containers such as fiberboard or clipboard tubes, fiberboard boxes, wooden boxes or crates, or similar containers.

10.5 *Weather Protection*—Wrapping, shrouding, or covering pipe involves additional labor and material. However,

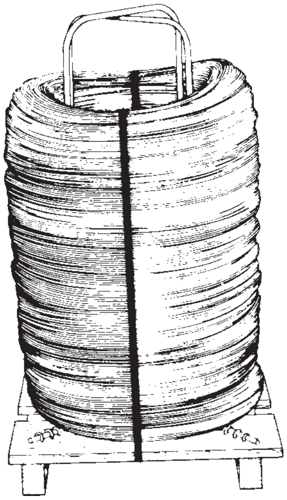

FIG. 29 Single Coil, Bare on Coil Carrier

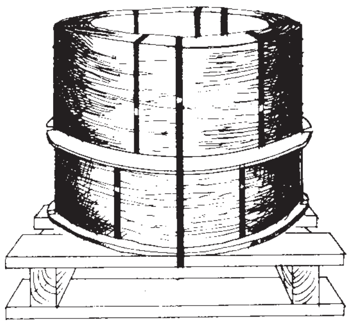

FIG. 30 Reel-less Coils

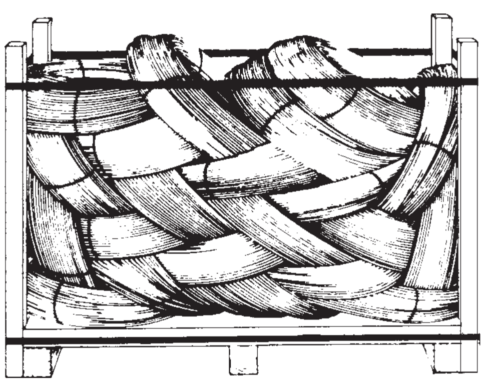

FIG. 31 Coils Nested in Wood Rack

when outside diameter or inside diameter surfaces are critical, shrouding of rail shipments and tarping of trucks is normal practice. Some amount of dirt and oxidation may be expected on black or galvanized pipe and tubes noncoated, or, when coated with nondrying coating, regardless of the type of protection specified.

10.6 *Loading*—Certain steel tubular products are regularly shipped unprotected in open top-cars. It is common practice to load pipe nested without separators, except for external upset pipe and tubing. Consideration should be given to using wood-lined, high-end, bulkheaded, gondola cars for added protection. Securing or separating pipe into lifts, separating sizes and quantities, requires additional handling and material. Loading tubular products in closed cars or closed trucks requires additional handling. Loading small outside diameter pipe on flat cars requires additional labor and material.

11. Plates

11.1 *Product Grades*:

11.1.1 Carbon, high-strength low-alloy, and alloy steel plates, cut length.

11.1.2 Carbon and alloy steel plate in coils.

11.1.3 Stainless steel plates.

11.1.4 Floor plates.

11.2 *Marking*—It is normal practice to identify each piece, lift, or coil with those requirements as specified in applicable specifications (ASTM, ASME, etc.).

11.3 *Packaging and Loading*:

11.3.1 It is regular practice to load carbon, high-strength low-alloy, and alloy steel plates unprotected in open-top equipment. When specified, loading in closed cars requires additional labor and handling. Carbon, high-strength low-alloy, and alloy steel plates are regularly loaded in unsecured lifts. Loading plates in lifts weighing less than 5 tons (4.5 Mg) involves additional labor and handling. The method used to maintain the unity of unsecured lifts is best determined by the shipper's experience. An example of a suitable method is the staggering of lifts. Segregation of sizes and items involves additional handling, often causes congestion in the manufacturer's plant, and may retard production. Such segregation is not considered feasible. The use of special or particular methods of loading or blocking and specifying the use of bands and wire ties to secure lifts disrupts the normal packaging and loading procedures. This requires additional labor and materials.

11.3.2 *Carbon and Alloy Steel Plates in Coils* are secured with a minimum of either one circumferential tie and one eye tie or with two eye ties.

11.3.3 *Stainless Steel Plates*—Packaging requirements of stainless steel plates are determined by the method of transportation, the finish specified, and the dimensions of the plates. Stainless steel hot-rolled and hot-rolled annealed plates are shipped loose, or when specified, in secured lifts and are loaded in open-top equipment. When processed beyond the as-rolled or annealed condition, such as by pickling or blast cleaning, the plates may also be shrouded or tarped if specified on the order or contract. Cold-rolled stainless steel plates may require greater protection such as wrapping or shrouding and the use of skids or platforms. Polished stainless steel plates are boxed when shipped in small quantities. Larger quantities are packaged on skids or platforms and are paper wrapped and may have additional protection when necessary.

11.3.4 *Floor Plates* are handled in the same manner as carbon and alloy steel plates.

12. Sheets and Strip

12.1 Sheets and strip, in cut lengths, coils, and circles, are among the most highly finished products of the steel industry. Because of their nature and the exacting uses to which such products are put, the marking, packaging, and loading methods are very important. The many sizes, grades, and finishes produced require various methods of packaging and loading,

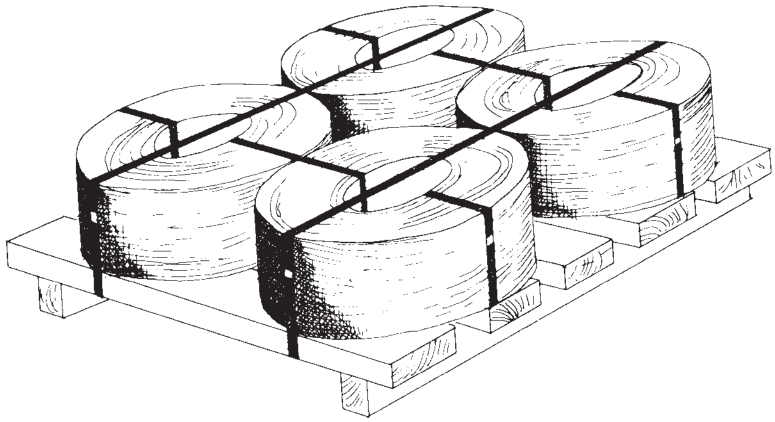

FIG. 32 Reel-less Coils

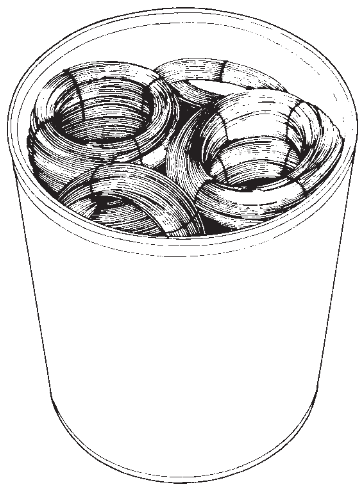

FIG. 33 Coils Nested in Fiber Drum

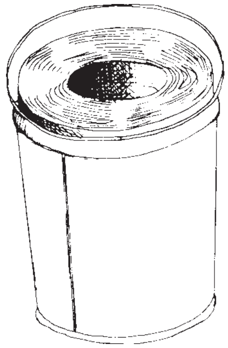

FIG. 34 Coil in Fiber Drum

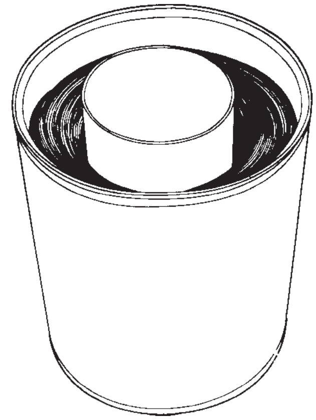

FIG. 35 Single Length Coil in Pay-Off Drum

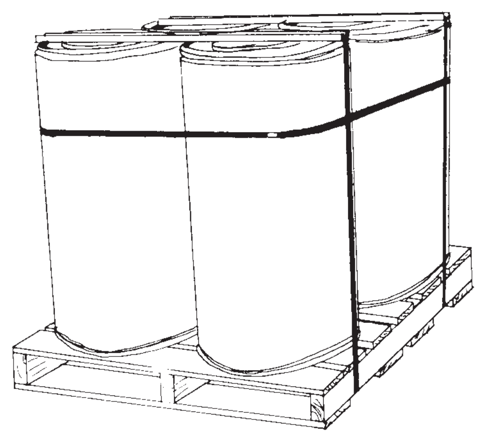

FIG. 36 Palletized Drums

along with surface and weather protection. The methods exemplified in this section recognize these general requirements, the end use of the material, the quantity involved, and the methods of transportation. The purchaser should give careful consideration to the marking, packaging, and loading requirements when ordering and, if in question, about a suitable method, should consult with the manufacturer.

12.1.1 *Suitable Lifts*—In order to facilitate handling, the manufacturer generally prepares these products into lifts or packages so that various mechanical handling equipment can be utilized to advantage. The maximum acceptable package weight should be specified whenever possible, because the heavier packages withstand transportation hazards better and result in greater economy for both the manufacturer and the purchaser. The recommended minimum weight for single lift packages is 10 000 lb (4.5 Mg). Lifts lighter than 10 000 lb require additional labor, material, and handling.

12.1.2 *Skid Arrangements and Platforms*—Figs. 52-59 show packages on skids only, but platforms may be used when required. Suitable arrangements of skids and platforms are covered in 12.5.

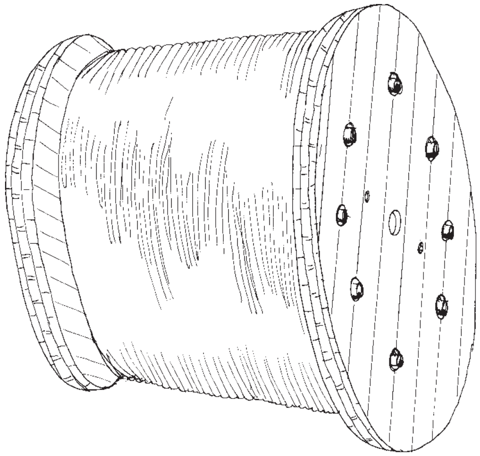

FIG. 37 Wire on Reel

12.2 *Product Grades*:

12.2.1 Carbon steels.

12.2.2 Alloy steels.

12.2.3 Electrical steels.

12.2.4 Metallic coated (except in mill products).

12.2.5 Nonmetallic coated.

12.2.6 Painted.

12.2.7 Stainless steels.

12.3 *Marking*—It is normal practice to identify each coil, group of coils, or lift of cut lengths with the following information:

12.3.1 Producer's name, brand, or trademark,

12.3.2 Width and gage or thickness,

12.3.3 Product type,

12.3.4 Weight (except strip, coil),

12.3.5 Customer's name, and

12.3.6 Customer's order number.

Stainless steel coils and cut lengths are also identified with the following:

12.3.7 Finish, and

12.3.8 Heat number or coil number.

12.4 *Packaging*:

12.4.1 *Carbon Steel Sheets, Cut Lengths*:

12.4.1.1 *Bare*—Fig. 60 and Fig. 61 illustrate suitable methods of packaging carbon steel sheets in unsecured lift and secured lift, bare. Hot-rolled carbon steel sheets, not pickled, in heavier gages can be shipped in unsecured lifts as illustrated by Fig. 60 or in secured lifts as illustrated by Fig. 61.

12.4.1.2 *Bare on Skids*—Fig. 52 and Fig. 53 illustrate suitable methods of packaging bare unwrapped carbon steel sheet on lengthwise and crosswise skids for handling with mechanical equipment. When protection of surface is important, packaging bare as illustrated by these methods is not recommended and, when specified, the responsibility for damage due to inadequate protection rests with the purchaser. The customary weight of this package is 10 000 lb (4.5 Mg) or more. Lengthwise skids are not used on sheets over 192 in. (4.88 m) long or less than 22 in. (559 mm) wide.

12.4.1.3 *Covered*—Fig. 54 illustrates a suitable method for covered sheet packages. The bottom of the package is not covered. Sheets lighter than 11 to 16 gage (2.30 to 1.29 mm), inclusive, for shipment in open-top equipment may be covered as illustrated by this figure, which requires additional labor and material. This type of packaging is not used for highly finished sheets for shipment in open-top equipment.

12.4.1.4 *Wrapped*—Fig. 55 illustrates a suitable method of wrapping sheet packages. Hot-rolled pickled, and other more highly finished sheets, for shipment in open-top equipment may be wrapped as illustrated by this figure.

12.4.1.5 *Multiple Lift*—Fig. 56 illustrates a method of packaging two or more smaller lifts into a secured lift. This method, because of the higher center of gravity of the unit and a tendency for the wood separators to mark the steel, is less desirable than the conventional single lift of 10 000 lb (4.5 Mg). Such packaging requires additional labor and materials. Separators are usually from 1 to 2 in. (25 to 51 mm) in thickness and from 2 to 4 in. (51 to 102 mm) wide, aligned with the skids, and extending the full dimension of the sheets. The individual lift weight in this type of package is generally not less than 2000 lb (907 kg), and the total weight of the multiple lift package is usually not less than 10 000 lb. The individual lifts are not tied, covered, or wrapped. Fig. 56 shows lengthwise skids and separators, but crosswise skids and separators may be used.

12.4.1.6 *Short-Length or Narrow-Width Sheets, Crosswise*—Fig. 57 illustrates a suitable method of packaging short length or narrow width sheets arranged crosswise, side by side, into secured lifts. Minimum weight of secured lift for such package is 10 000 lb (4.5 Mg). This package is recommended for short sheets 48 in. (1.22 m) or less in length or narrow sheets under 22 in. (559 mm) in width. Suitable vertical separators between piles are used when required. When handled as a unit lift, this package should be handled with a sheet lifter. Fig. 57 shows material piled on skids. Platforms may also be used when required; however, such packaging requires additional labor and material. Fig. 57 also shows a method of wrapping such a package when protection of steel in open-top equipment requires it to be fully wrapped.

12.4.1.7 *Short-Length Sheets, Lengthwise, End to End*—Fig. 58 illustrates a suitable method of packaging short-length sheets arranged lengthwise end to end into secured lifts. This package is generally not used for sheets under 22 in. (559 mm) in width; otherwise, the method of packaging is similar to that shown for short length or narrow width sheets, crosswise, Fig. 57. When handled as a unit lift, this package should be handled with a sheet lifter. Fig. 59 illustrates a suitable method of packaging narrow long sheets side by side.

12.4.1.8 *Protective Materials*—Hot-rolled pickled and better grades may require protection from contact with separator or skid lumber. Wrapping sheets with more than one layer of paper requires additional labor and materials. On highly finished sheets, protection against band seal damage is recommended. Protecting sheets with metal wrapping, or the use of metal protector sheets on top or bottom, or both, of lift or package involves additional labor and material.

12.4.1.9 *Protective Coatings*—Oiling to customers' specifications requires additional labor and material.

12.4.1.10 *Weather Protection*:

TABLE 4 Packaging Table for Carbon, Alloy, and Stainless Steel Wire, Straightened and Cut Lengths[A]

Length, in. (mm)	Package	Approximate Weight, lb (kg) Bundle/Lift	Approximate Weight, lb (kg) Package
12 (305) and under	loose in corrugated box (Fig. 38)	...	125 (57) max
Over 12 to 36 (305 to 914), incl	loose in container (Fig. 47)	...	1500 to 1800 (680 to 816)
Over 12 to 18 (305 to 457), incl	hand bundles	25 to 50 (11 to 23)	...
Over 18 to 36 (457 to 914), incl	hand bundles	50 to 100 (23 to 45)	...
	in containers (Fig. 47)	...	1500 to 1800 (680 to 816)
	on skids	...	2000 (907)
	on platform (Fig. 44)	...	2000 (907)
Over 36 (914)	hand bundles (Fig. 39)		
	loose	100 to 200 (45 to 91)	...
	secured lifts (Fig. 43)	4000 to 6000 (1814 to 2722)	...
Over 36 to 96 (914 to 2438)	secured lift (Fig. 42)	2000 to 4000 (907 to 1814)	...
Over 96 (2438)	secured lift	4000 to 6000 (1814 to 2722)	...

Securement—The number of bands or wire ties depends upon the length and weight of the lift or bundle, or both, as follows:

Length, ft (m)	Number of Ties
8 (2.44) and under	2
Over 8 to 16 (2.44 to 4.88), incl	3
Over 16 to 20 (4.88 to 6.10), incl	4
Over 20 (6.10)	5

Protection[A]—Where protection is required, wire may be packaged as follows:

Package	Protection
Hand bundles	Ends wrapped (Fig. 40)
Hand bundles	Wrapped entire length (Fig. 41)
Lifts	Shrouded (Fig. 45)
Lifts	Wrapped (Fig. 46)
Loose or hand bundles	Special containers constructed of fiberboard, chipboard, wood, or other suitable material. Containers are to be lined when required (Fig. 47).

[A] Some manufacturers determine type of packaging and protection by gage and other factors, and these should be considered in ordering.

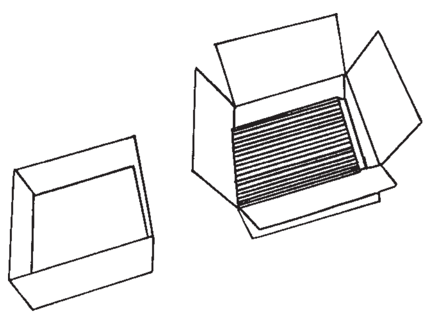

FIG. 38 Short Lengths of Straightened and Cut Wire in Corrugated Box

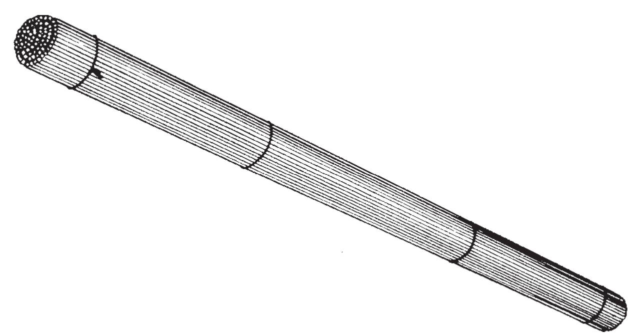

FIG. 39 Hand Bundle of Wire, Bare

(1) Open-Top Equipment, General—Experience has shown that the amount of weather protection required for shipping sheets in open-top equipment depends upon the quality, size, and method of transportation. Hot-rolled sheets, due to their nature, are not generally protected from the weather when loaded in open-top equipment. Hot-rolled pickled and more highly finished sheets are regularly wrapped and shrouded when loaded on open-top equipment. Such wrapping and shrouding requires additional labor and material. Truck tarpaulins are considered to be the equivalent of waterproof paper shrouding.

(2) Shrouded Package Open-Top Equipment—Fig. 62 and Fig. 63 illustrate suitable methods of shrouding lifts of cut-length sheets for shipment in open-top equipment.

(3) Covered or Closed Equipment—General—While this type of equipment is recommended for rail and affords better protection from the elements, covering, wrapping, or shrouding of sheets may be required for preservation of the surface. Such protection, when specified, requires additional labor and material.

12.4.2 *Carbon Steel Sheets, Coils*:

12.4.2.1 *General*—All coil weights are subject to mill manufacturing limits. When individual coil weights are required, narrow sheet coils are generally weighed in groups and the weight of the group averaged over the number of coils in the group. This average is not intended to be the actual weight of each individual coil of the group. Weighing such coils individually, recording, and marking the weight of each coil requires additional time and handling. Individual coils are usually secured with one to four flat steel bands. Hot-rolled coils are regularly shipped in the as-rolled condition, unprotected, in open-top equipment. It is not standard practice to ship

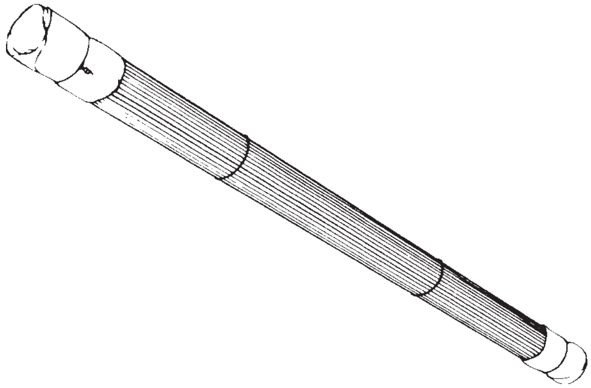

FIG. 40 Hand Bundle of Wire, Ends Wrapped

FIG. 41 Hand Bundle of Wire, Wrapped Entire Length

hot-rolled coils on platforms. Hot-rolled pickled or other highly finished sheet coils may be packaged on platforms when required. However, the use of platforms requires additional labor and material. Supporting coils with special cores, or placing coils on spools, requires additional labor and material. Wrapping narrow coils individually requires additional labor and material.

12.4.2.2 *Bare, Unwrapped, Individual Coils*—Fig. 64 illustrates a suitable method of packaging individual hot-rolled sheet coil in the as-rolled condition. Fig. 65 illustrates a method of packaging often used on more highly finished coils.

12.4.2.3 *Bare, Unwrapped, Coil Group Package*—Fig. 66 illustrates a suitable method of packaging two or more narrow sheet coils into a coil group package. Securing sheet coils into specified groups requires additional labor and material.

12.4.2.4 *Coils, Bare Unwrapped, on Platform*—Fig. 67 illustrates a suitable method of packaging bare unwrapped sheet coils on skeleton platform with the eye of the coils vertical. The use of separators between coils requires additional labor and material.

12.4.2.5 *Wrapped Individual Coil*—Fig. 68 illustrates a suitably wrapped individual sheet coil with eye of the coil horizontal. Wrapping coils requires additional labor and material.

12.4.2.6 *Wrapped Individual Coil on Cradle Platform*—Fig. 69 illustrates a suitably wrapped individual coil on cradle platform with the eye of the coil horizontal.

12.4.2.7 *Wrapped Individual Coil on Platform*—Fig. 70 illustrates a suitably wrapped individual coil on platform with the eye of the coil vertical.

12.4.2.8 *Surface Protection*:

(1) Oiling—Oiling coils to customer's specifications requires additional labor and material.

12.4.3 *Circles*:

12.4.3.1 *General*—Fig. 71 illustrates suitably wrapped or covered sheet circles on skeleton platform. Circles 17 in. (432 mm) and over in diameter are packaged single pile on square or round platforms, or on crossed skids. To avoid top heaviness, the maximum height of the single pile package should not exceed the diameter of the circle. Circles under 17 in. in diameter may be packaged in several piles on square or rectangular platforms.

12.4.3.2 *Weather Protection*:

(1) Hot-rolled pickled and more highly finished sheet coils are regularly wrapped and shrouded when loaded in open-top equipment. Such wrapping and shrouding requires additional labor and material. Truck tarpaulins are considered to be the equivalent of waterproof paper shrouding.

(2) Covered or Closed Equipment, General—While this type of equipment affords better protection from the elements, covering, wrapping, or shrouding of sheets may be required for preservation of the surface. Such protection, when specified, requires additional labor and material.

12.4.3.3 *Loading*:

(1) Open-Top Equipment, General—Hot-rolled sheet coils, due to their nature, are not generally protected from the weather when loaded in open-top equipment.

12.4.4 *Stainless Steel Sheets, Cut Lengths*:

12.4.4.1 *General*—The minimum net weight for conventional single-lift packages of stainless sheets depends on the type of package specified. Small amounts regardless of finish are regularly packaged in boxes.

12.4.4.2 *Cut Lengths, Bare*—Fig. 52 and Fig. 53 illustrate suitable methods of packaging bare, unwrapped, stainless steel sheets on lengthwise and crosswise skids. The figures show the package on skids only, but skeleton deck platforms are also used when required. The recommended weight for this type package is 5000 lb (2268 kg) or more. Finishes and gages generally confined to this type of package are:

(1) No. 1 Finish, 0.0418 in. (1.062 mm) and thicker, on skids.

(2) No. 1 Finish, under 0.0418 in. (1.062 mm), on skeleton platforms.

When protection of surface is important, packaging bare, as illustrated by these methods, is not recommended. Suitable arrangements of skids and platforms are shown by Fig. 52 to 60 and Table 7 and Table 8.

12.4.4.3 *Cut Lengths, Wrapped*—Fig. 72 and Fig. 73 illustrate suitably wrapped stainless steel sheets on lengthwise and crosswise skids. The illustrations show the package on skids only, but skeleton deck platforms are also used when required. Skeleton deck platforms may have either lengthwise or crosswise runners. The customary weight of this type package is 5000 lb (2268 kg) or more. Finishes and gages generally confined to this type of package are:

(1) No. 1 Finish, 0.0418 in. (1.062 mm) and thicker, on skids.

(2) No. 1 Finish, under 0.0418 in. (1.062 mm) on skeleton platforms.

When protection of surface is important, wrapped packages, as illustrated by these methods, are not recommended. Suitable arrangements of skids and platforms are shown in Fig. 52 to 60 and Table 7 and Table 8.

12.4.4.4 *Cut Lengths, Fully Enclosed Packages 5000 lb (2268 kg) and Heavier*—Fig. 74 illustrates a suitable method of packaging steel sheets in a fully enclosed package on a skeleton platform, using wood materials. Other materials used

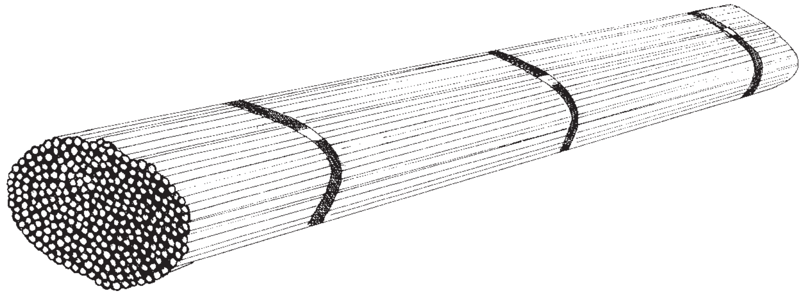

FIG. 42 Secured Lift of Wire, Bare

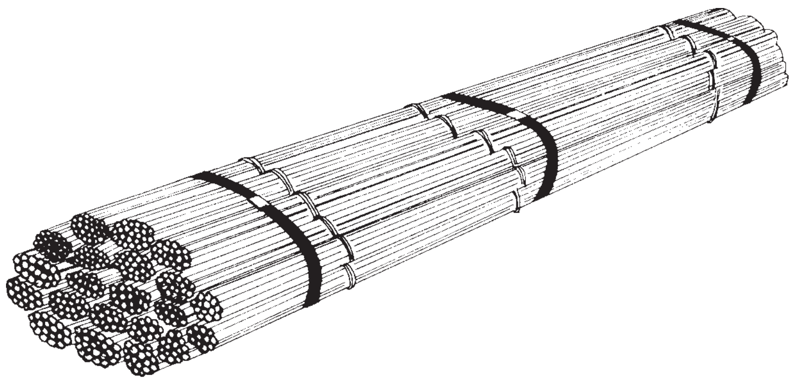

FIG. 43 Secured Lift of Hand Bundles of Wire, Bare

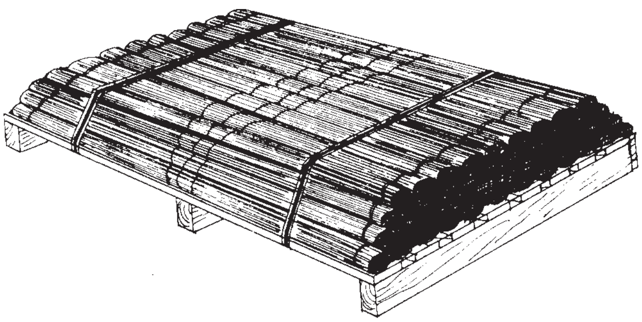

FIG. 44 Hand Bundles of Wire, Secured to Skids or Platforms

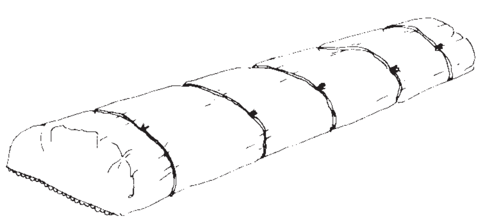

FIG. 45 Shrouded Lift of Wire

are hardboard, composition board, fiberboard, plywood, angles and channels, depending on the materials available, the type of package, and the discretion of the shipper. This package is designed for lifts 5000 lb and over, and is recommended for maximum protection of all domestic shipments of all gages and finishes. Sideboards are not usually needed if material is less than 1 in. (25 mm) piling height.

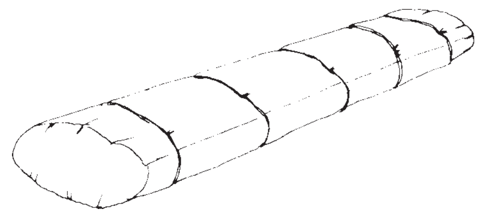

FIG. 46 Wrapped Lift of Wire

12.4.4.5 *Cut Lengths, Boxed*—Fig. 75 illustrates a suitable method of packaging steel sheets in a wooden box of suitable solid protective material to provide an entirely closed flat container. This type container is designed for maximum protection of small quantities of all grades, gages, and finishes.

12.4.4.6 *Surface Protection*:

(1) Protective Coverings—The usual method of protecting surfaces is to interleave with nonabrasive antitarnish paper. Protection of surfaces by means of gluing or pasting paper or otherwise applying protective coverings requires additional labor and material. Protecting sheets with metal wrapping or the use of metal protector sheets on top or bottom, or both, of lift or package requires additional labor and material.

12.4.5 *Stainless Steel Sheets, Coils*:

12.4.5.1 *Bare Unwrapped Individual Coil*—Fig. 64 illustrates a suitable method of packaging individual stainless steel hot-rolled sheet coil in the as-rolled condition. This type of packaging is confined to hot-rolled or hot-rolled annealed material.

12.4.5.2 *Wrapped Individual Coil*—Fig. 68 illustrates a suitable method of packaging fully wrapped individual stainless steel sheet coil with eye of coil horizontal. This type of

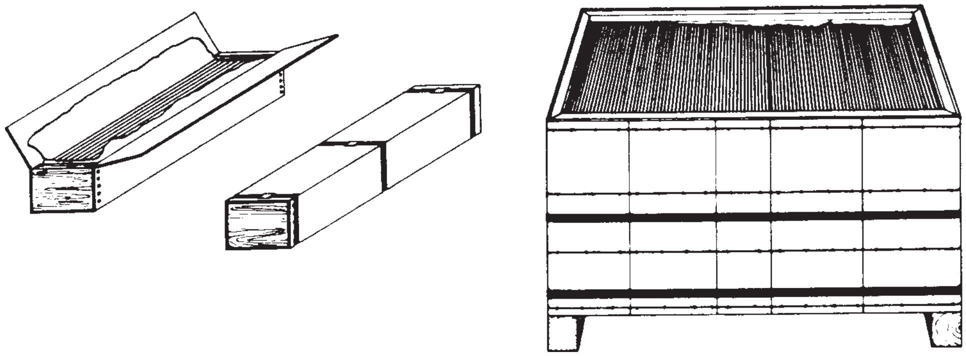

FIG. 47 Loose or Hand Bundles of Wire in Containers

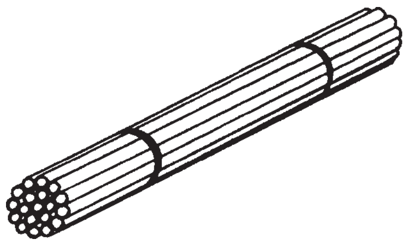

FIG. 48 Secured Lift

packaging is not recommended for light gage material or for any material when protection of the surface is important. Stainless steel coils, No. 1 Finish, 0.062 in. (1.57 mm) and thicker, are generally confined to this type of package. For thinner gages, platforms are recommended.

12.4.5.3 *Bare Individual Coil on Cradle Platform*—Fig. 76 illustrates a suitable method of packaging bare, unwrapped, individual stainless steel sheet coil on cradle platform with the eye of the coil horizontal. This method of packaging provides adequate protection for most grades and gages, when surface protection is not important.

12.4.5.4 *Wrapped Individual Coil on Cradle Platform*—Fig. 69 illustrates a suitable method of packaging a wrapped individual stainless steel coil on a cradle platform with the eye of the coil horizontal. This method of packaging is recommended for practically all domestic usage and for most finishes and gages. Gages and finishes requiring additional protection should be boxed.

12.4.5.5 *Bare Individual Coil on Platform*—Fig. 77 illustrates a suitable method of packaging bare unwrapped individual sheet coil on platform with the eye of the coil vertical. This method of packaging provides adequate protection for most grades and gages, when surface protection is not important.

12.4.5.6 *Wrapped Individual Coil on Platform*—Fig. 70 illustrates a suitably wrapped individual stainless steel coil on platform with the eye of the coil vertical. This method of packaging provides adequate protection for most grades and gages.

12.4.5.7 *Boxed on Platform with Eye of Coil Vertical*—Fig. 78 illustrates a suitable method of packaging individual sheet coil or group of sheet coils in solid box, on platform, with the eye of the coil vertical. This type of package, an entirely enclosed container made of suitable solid material, is recommended for maximum protection of all finishes and gages.

12.4.5.8 *Surface Protection*:

(1) Protective Coatings—The usual method of protecting surfaces is to interleave with nonabrasive antitarnish paper. Protection of surfaces by means of gluing or pasting paper, or otherwise applying protective coverings, requires additional labor and material. Spiral wrapping is not applied to stainless steel sheet coils. The use of metal protective wrapping on coils requires additional labor and material.

12.4.6 *Stainless Steel Sheets, Circles*:

12.4.6.1 *Circles, Bare Unwrapped Single Pile on Platform*—Fig. 79 illustrates a suitable method of packaging a single pile of bare stainless steel sheet circles on skeleton platform. This type of packaging is generally confined to No. 1 Finishes 0.062 in. (1.57 mm) and thicker. This package is not recommended for light gage material or for any material when protection of surface is important.

12.4.6.2 *Circles, Wrapped Single Pile on Platform*—Fig. 71 illustrates a suitable method of packaging wrapped stainless steel sheet circles on skeleton platform. This type of package is generally recommended for practically all domestic usage, for all gages and finishes.

12.4.6.3 *Circles, Multiple Piles on Platform, Covered with Corrugated Fiberboard*—Fig. 80 illustrates a typical method of packaging multiple piles of stainless steel circles on platforms, covered with corrugated fiberboard. This type of package is generally recommended for practically all domestic usage and for all gages and finishes in lots of 2000 lb (907 kg) or more. Quantities less than 2000 lb should be packaged in individual piles or in boxes.

12.4.6.4 *Boxes Wrapped Multiple Piles of Circles on Platform*—Fig. 81 illustrates a suitable method of packaging multiple piles of stainless steel sheet circles in a box on a solid deck platform.

12.4.6.5 *Surface Protection*:

(1) Protective Coverings—The usual method of protecting surfaces is to interleave with nonabrasive antitarnish paper. Protection of surfaces by means of gluing or pasting paper, or otherwise applying protective coverings, requires additional labor and material.

12.4.6.6 *Loading*—Due to the nature of stainless products, shipment in covered or closed equipment is recommended. If shipped in open-top equipment, shrouding of the package or load is recommended.

12.4.7 *Carbon Steel Strip, Cut Lengths*:

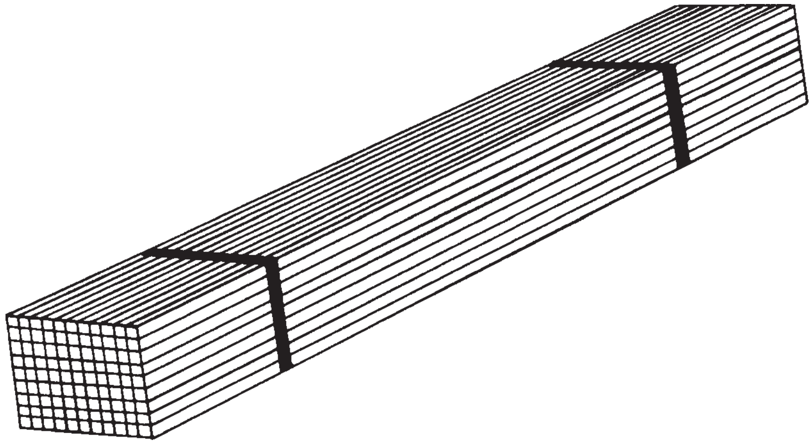

FIG. 49 Rectangular Package

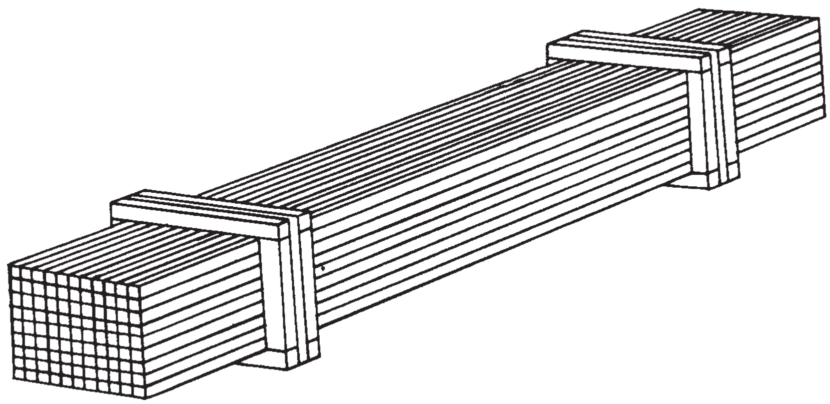

FIG. 50 Frame Package

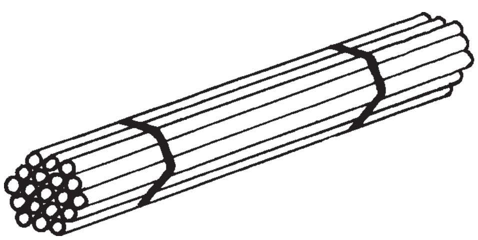

FIG. 51 Hexagonal Package

12.4.7.1 *Bare Oval Lift*—Fig. 3 illustrates a suitable method of packaging narrow hot-rolled steel strip, 5 in. (127 mm) or less in width, into conventional oval lifts.

12.4.7.2 *Secured Lift, Strip Lengthwise*—Fig. 59 illustrates a suitable method of packaging narrow steel strip piled lengthwise on crosswide skids, in multiple rows, into secured lift. The illustration shows material piled on skids, but skeleton platforms are also used when required. Such packaging requires additonal labor and material. Light-gage reinforcing shields or channels are used to maintain alignment of strip in the piles. Fig. 59 also shows the method of wrapping packages when protection of steel is required for shipping in open-top equipment.

12.4.7.3 *Surface Protection*:

(1) Oiling—Oiling to customer's specifications requires additional labor and material.

TABLE 5 Pieces, Feet, and Weight per Sub-bundle for Standard Pipe, Line Pipe, and Oil Country Goods[A]

Nominal Size, in.	Pieces	ft (m)	Weight, lb (kg)
1⁄8	30	630 (192)	151 (69)
1⁄4	24	504 (154)	212 (96)
3⁄8	18	378 (115)	215 (98)
1⁄2	12	252 (77)	214 (97)
3⁄4	7	147 (45)	166 (75)
1	5	105 (32)	176 (80)
1 1⁄4	3	63 (19)	144 (65)
1 1⁄2	3	63 (19)	172 (78)
Extra Strong Pipe:			
1⁄8	30	630 (192)	195 (89)
1⁄4	24	504 (154)	272 (123)
3⁄8	18	378 (115)	280 (127)
1⁄2	12	252 (77)	275 (125)
3⁄4	7	147 (45)	216 (98)
1	5	105 (32)	228 (104)
1 1⁄4	3	63 (19)	189 (86)
1 1⁄2	3	63 (19)	229 (104)
Double Extra Strong Pipe:			
1⁄2	7	147 (45)	251 (114)
3⁄4	5	105 (32)	256 (116)
1	3	63 (19)	230 (104)
1 1⁄4	3	63 (19)	328 (149)
1 1⁄2	3	63 (19)	404 (184)

[A] Other bundling practices may be available, subject to agreement between the purchaser and the manufacturer.

TABLE 6 Thread Protection for Standard Pipe, Line Pipe, and Oil Country Goods

Types of Pipe	Nominal Size		
	1½ in. and Smaller	2 to 3½ in., incl	4 in. and Over
Standard pipe	none	none	threads protected[A]
Standard pipe, reamed and drifted	none	threads protected[A]	threads protected[A]
Line pipe	threads protected[B]	threads protected[A]	threads protected[A]
Oil country pipe	threads protected[C]	threads protected[D]	threads protected[D]

[A] Thread protectors are used on pipe threads not protected by a coupling.
[B] Either burlap cloth or waterproof paper is used to wrap the ends of sub-bundles or lifts, or thread protectors are used to protect exposed threads.
[C] Burlap cloth or waterproof paper is used to wrap the end of sub-bundles or lifts to protect the exposed threads.
[D] Thread protectors are used on pipe threads not protected by a coupling. The exposed coupling threads are protected with either a protective coating or thread protectors.

(2) Protective Coverings—Wrapping strip with more than one layer of paper has been found unnecessary for satisfactory delivery.

12.4.7.4 *Loading*:

(1) Open-Top Equipment, General—Hot-rolled strip, due to its nature, is not protected from the weather when loaded in open-top equipment. It is recommended that hot-rolled pickled and more highly finished strip be covered or shrouded when loaded in open-top equipment. When specified, such protection requires additional labor and material. Truck tarpaulins are considered to be the equivalent of waterproof paper shrouding.

(2) Covered or Closed Equipment, General—While this type of equipment affords better protection from the elements, covering, wrapping, or shrouding of strip may be required for preservation of the surface. Such protection, when specified, requires additional labor and material.

12.4.8 *Carbon Steel Strip, Coils*:

12.4.8.1 *General*—All coil weights are subject to mill manufacturing limits. When individual coil weights are required, coils are generally weighed in groups, and the weight of the group averaged over the number of coils in the group. This average is not intended to be the actual weight of each individual coil of the group. Weighing coils individually, recording, and marking the weight of each coil require additional time and handling. Individual coils are usually secured with one to four flat steel bands. Hot-rolled coils are regularly shipped in the as-rolled condition, unprotected, in open-top equipment. It is not regular practice to ship hot-rolled coils on platforms. When specified, the use of platforms requires additional labor and material. Supporting coils with special cores or placing coils on spools requires additional labor and material.

12.4.8.2 *Individual Narrow Strip Coils*—Fig. 82, Fig. 83, and Fig. 84 illustrate suitable methods of packaging individual narrow-strip coils.

12.4.8.3 *Bare Unwrapped Coil Group Package*—Fig. 85 illustrates a suitable method of packaging narrow-strip coils into a coil group package. Banding coils into coil group package requires additional labor and material.

12.4.8.4 *Coils on Platforms*—Fig. 86 illustrates a suitable method of packaging narrow-strip coils on skeleton platform with the eye of the coils vertical. The illustration shows the package on skeleton platform. Placing individual coils or stacking coils on platforms requires additional labor and material. Separators between coils decrease the security of the package, and requires additional labor and material.

12.4.8.5 *Coils Wrapped*—Fig. 87 illustrates suitably wrapped individual strip coils or groups of coils. Wrapping individual coils or wrapping or shrouding coil group packages requires additional labor and material.

12.4.8.6 *Bare Coils in Container*—Fig. 88 illustrates a suitable method of packaging narrow-strip coils in a container with the eye of the coils vertical. This type of package is an entirely enclosed container made of suitable solid materials, and is designed for maximum protection of all finishes and gages.

12.4.8.7 *Surface Protection*:

(1) Oiling—Oiling coils to customer's specifications requires additional labor and material.

(2) Protective Coverings—Wrapping coils requires additional labor and material. Wrapping individual coils or groups of coils with more than one layer of paper has been found unnecessary for satisfactory delivery. The use of metal protective wrapping on coils requires additional labor and material.

12.4.8.8 *Loading*:

(1) Open-Top Equipment, General—Hot-rolled strip coils, due to their nature, are not generally protected from the weather when loaded in open-top equipment. It is recommended that hot-rolled pickled and more highly finished strip coils be wrapped or shrouded when loaded in open-top equipment. Truck tarpaulins are considered to be the equivalent of waterproof paper shrouding.

(2) Closed Equipment, General—While this type of equipment affords better protection from the elements, wrapping or shrouding of strip may be required for preservation of the surface. Such protection, when specified, requires additional labor and material.

12.4.9 *Stainless Steel Strip, Cut Lengths*:

12.4.9.1 *Cut Lengths, Bare*—Fig. 89 and Fig. 90 illustrate suitable methods of packaging bare unwrapped stainless steel strip on crosswise skids or platforms. The recommended weight of this type package is 5000 lb (2268 kg) or more. Finishes and gages generally confined to this type of package are:

(1) No. 1 Finish, 0.0418 in. (1.062 mm) and thicker, on skids.

(2) No. 1 Finish, under 0.0418 in. (1.062 mm), on skeleton platforms.

When protection of surface is important, packaging bare, as illustrated by these methods, is not recommended. Suitable arrangement of skids and platforms is described in 12.5.

12.4.9.2 *Cut Lengths, Wrapped*—Fig. 59 and Fig. 91 illustrate suitably wrapped stainless steel strip on crosswise skids or platforms. Platforms may have either lengthwise or crosswise runners. The recommended weight of this type package is 5000 lb (2268 kg) or more. Finishes and gages generally confined to this type of package are:

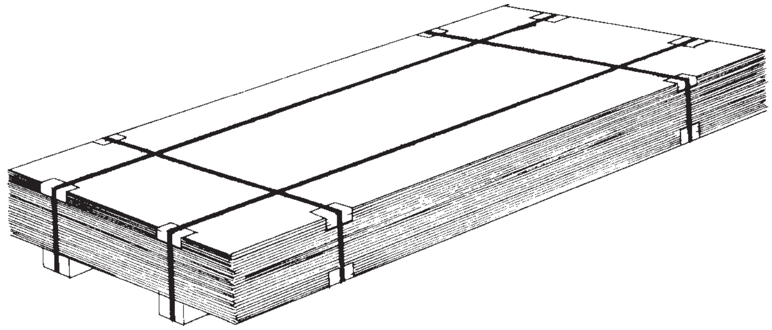

FIG. 52 Bare Package on Lengthwise Skids

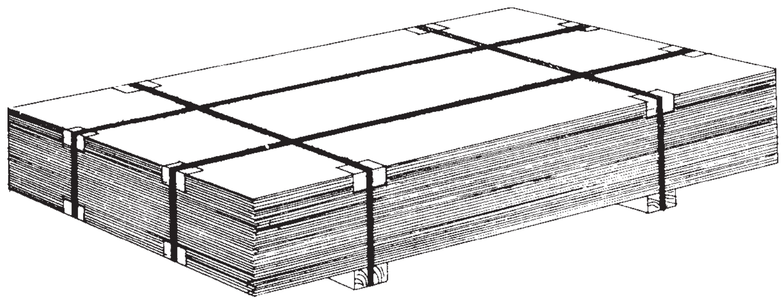

FIG. 53 Bare Package on Crosswise Skids

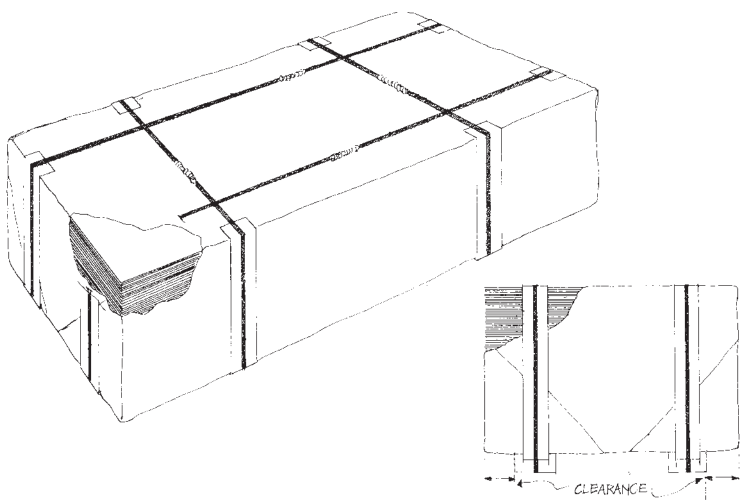

FIG. 54 Covered Package on Skids

(1) No. 1 Finish, 0.0418 in. (1.062 mm) and thicker, on skids.

(2) No. 1 Finish, under 0.0418 in. (1.062 mm), on skeleton platforms.

When protection of surface is important, packages wrapped, as illustrated by these methods, are not recommended. Suitable arrangement of skids and platforms is shown in 12.5.

12.4.9.3 *Cut Lengths, Fully Enclosed Package 5000 lb (2268 kg) and Heavier*—Fig. 92 illustrates a suitable method of packaging stainless steel strip in a fully enclosed package on a platform using wood materials. Other materials generally used are hardboard, composition board, fiberboard, plywood, angles and channels, depending on the materials available, the type of package, and the discretion of the shipper. This package is designed for lifts 5000 lb (2268 kg) and over, and is recommended for maximum protection of all domestic shipments of all gages and finishes. Sideboards are not usually needed if material is less than 1 in. (25 mm) piling height.

12.4.9.4 *Cut Lengths Boxed*—Fig. 75 illustrates a suitable method of packaging stainless steel strip in a box of suitable solid protective material, lined or unlined, to provide an entirely closed flat container. This type container is designed for maximum protection of small quantities of all grades, gages, and finishes. Boxes are designed for packaging quantities of less than 5000 lb (2268 kg). Placing boxes on runners or platforms requires additional labor and material.

12.4.9.5 *Surface Protection*:

(1) *Protective Coverings*—The usual method of protecting surfaces is to interleave with nonabrasive antitarnish paper. Protection of surfaces by means of gluing or pasting paper, or

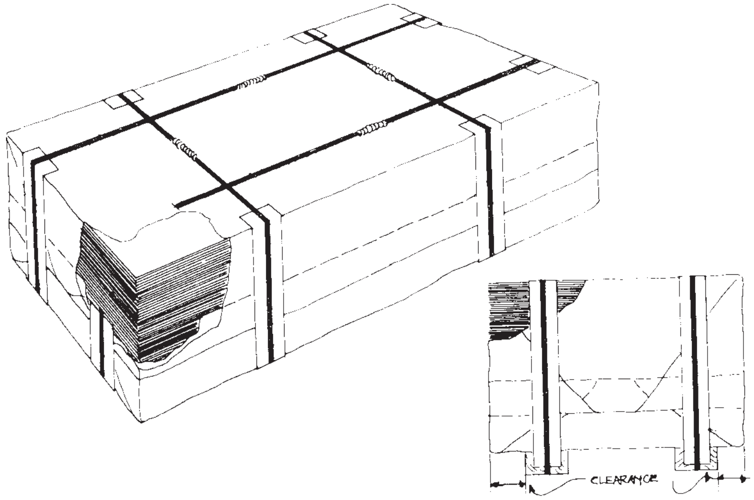

FIG. 55 Wrapped Package on Skids

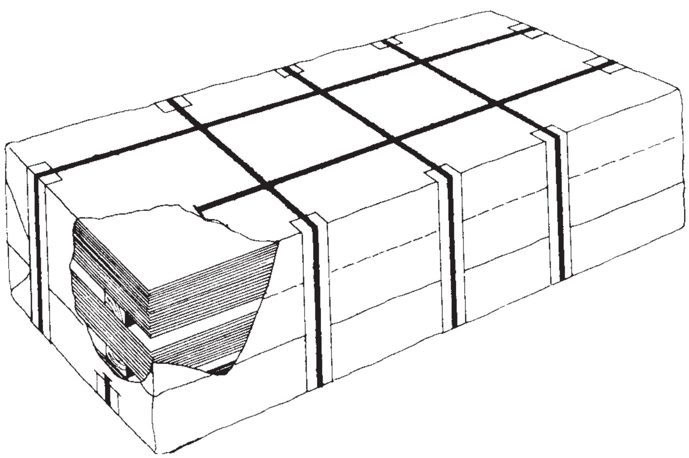

FIG. 56 Multiple-Lift Package on Skids

otherwise applying protective coverings, requires additional labor and material. Protecting stainless steel strip with metal wrapping or using metal protector sheets on top or bottom, or both, of lift or package requires additional labor and material.

12.4.9.6 *Loading*—Due to the nature of stainless products, shipment in covered or closed equipment is recommended. If shipped in open-top equipment, shrouding of the package or load is recommended.

12.4.10 *Stainless Steel Strip, Coils*:

12.4.10.1 *Bare Unwrapped Individual Coils*—Fig. 64 illustrates a suitable method of packaging individual hot-rolled stainless steel strip coil in the as-rolled condition. This type of packaging is generally confined to hot-rolled or hot-rolled annealed material.

12.4.10.2 *Coils on Platform*—Fig. 93 illustrates a suitable method of packaging narrow stainless steel strip coils on skeleton platform with eye of the coils vertical. Placing individual coils or stacking coils on platforms requires additional labor and material. Separators between coils decreases the security of the package, and requires additional labor and material. This method of packaging is considered to be adequate for practically all domestic shipments of most gages and finishes. Material requiring maximum protection should be boxed.

12.4.10.3 *Coils, Fully Wrapped*—Fig. 87 illustrates a suitably wrapped individual stainless steel strip coil or group of coils. This method of packaging is not recommended for light-gage material nor for any material when protection of surface is important. Wrapping individual coils or wrapping, covering, or shrouding coil group packages requires additional labor and material.

12.4.10.4 *Coils in a Container*—Fig. 88 illustrates a suitable method of packaging narrow stainless steel strip coils in a container with the eye of the coils vertical. This type of package is an entirely enclosed container made of suitable solid material, and is recommended for maximum protection of all finishes and gages.

12.4.10.5 *Coils, Boxed on Platform with Eye of Coils Vertical*—Fig. 78 illustrates a suitable method of packaging individual stainless steel strip coils or group of strip coils in solid box on platform with the eye of the coils vertical.

12.4.10.6 *Surface Protection*:

(1) Protective Coverings—The usual method of protecting surfaces is to interleave with nonabrasive antitarnish paper. Protection of surfaces by means of gluing or pasting paper, or otherwise applying protective coverings, requires additional labor and material. Protecting stainless steel coils with metal wrapping requires additional labor and material.

12.4.10.7 *Loading*—Due to the nature of stainless products, shipment in covered or closed equipment is recommended. If shipped in open-top equipment, shrouding of the package or load is recommended.

12.5 *Skid Arrangements and Platforms*:

12.5.1 *Skid Arrangements*—All skids shall be made of sound lumber of commercial sizes not less than 3 in. (76 mm) in width nor more than 4 in. (102 mm) in height. The overall length of skids shall be approximately equal to the full dimension of the package along the direction in which they are used. The number of skids required on packages using skids parallel to their lengthwise direction are shown in Table 7. The number of skids required on packages using skids parallel to

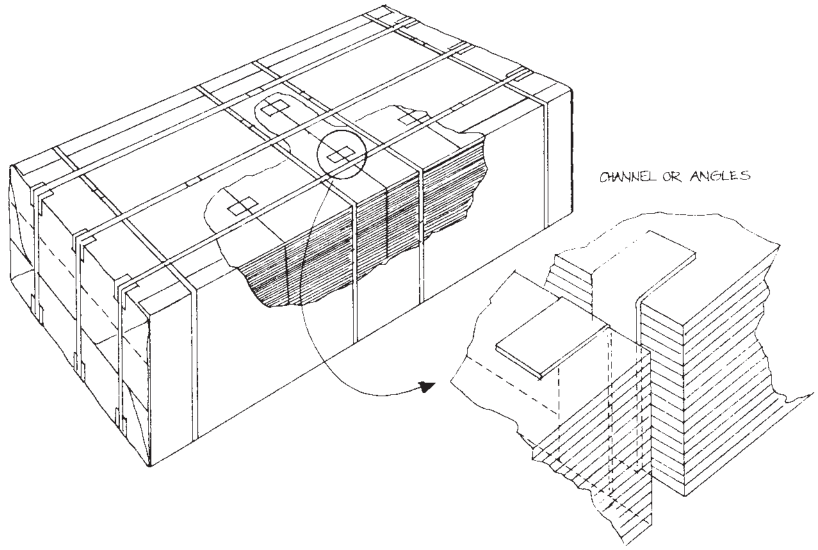

FIG. 57 Suitable Package for Short-Length or Narrow-Width Sheets on Skids

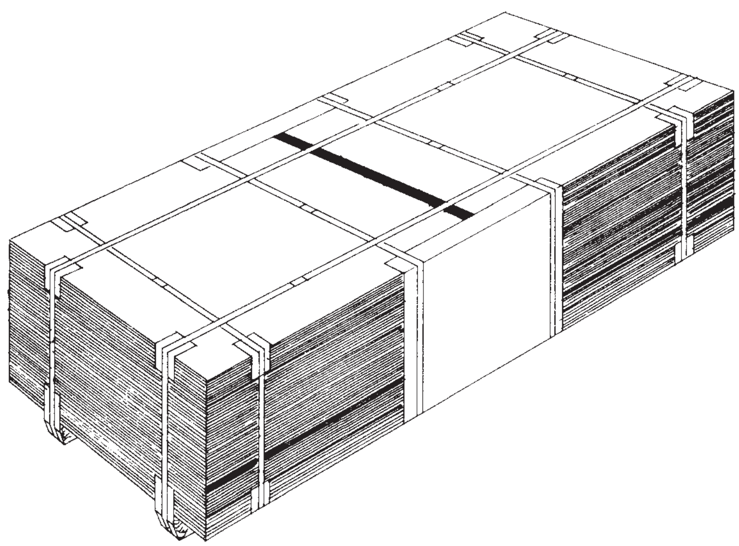

FIG. 58 Suitable Package for Short-Length Sheets Lengthwise, End to End, on Skids

their crosswise direction are shown in Table 8. Fig. 52 to Fig. 59 illustrate typical packaging of cut length sheets on skids.

12.5.2 *Platforms for Cut Lengths*—Structures consisting of deckboards and runners. The arrangements shown in Fig. 94 are often used for packaging of wide sheets of light gage or for packaging long, narrow sheets and strip of any gage piled side by side on one platform. Deckboards shall be equal in length to full width or length of the unit and shall have a minimum thickness of 1 in. (25 mm). Deckboards may be nailed to the runners. The minimum number of deckboards shall be the same as the number of lengthwise or crosswise skids shown in Table 7 and Table 8. Illustrations are general and actual construction may vary among producers.

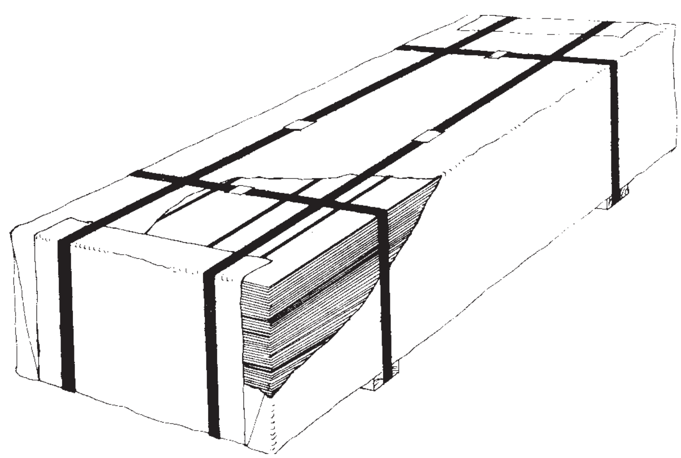

FIG. 59 Suitable Package for Narrow Long Sheets Side by Side, on Skids

13. Tin Mill Products

13.1 Tin mill products are among the most highly finished products of the steel industry; and marking, packaging, and loading methods are very important. The purchaser should give

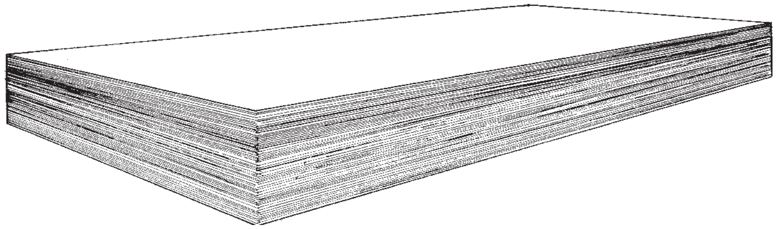

FIG. 60 Suitable Method of Packaging Carbon Steel Sheets in Unsecured Lift, Bare

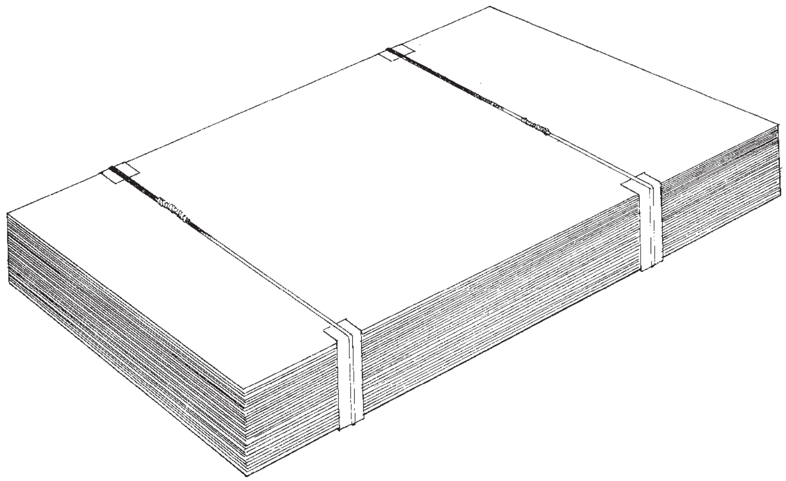

FIG. 61 Suitable Method of Packaging Carbon Steel Sheets in Secured Lift, Bare

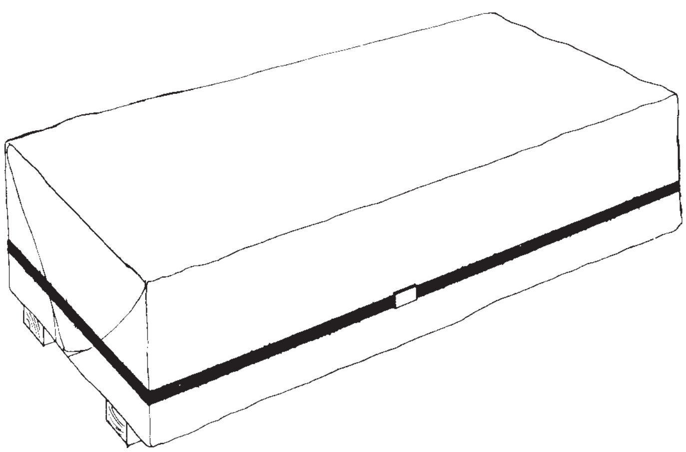

FIG. 62 Suitable Shrouded Package of Cut-Length Sheets, Banded

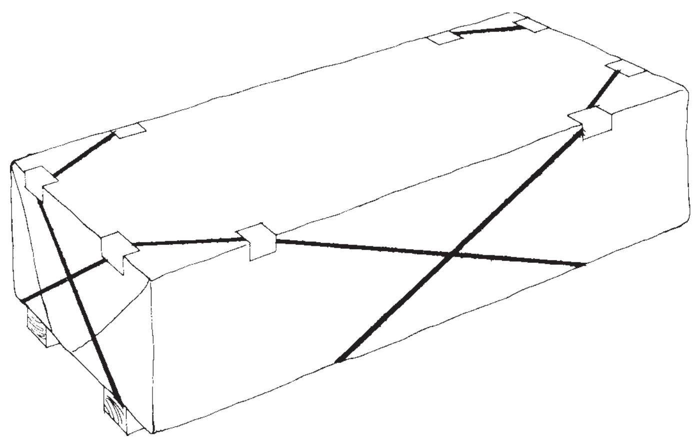

FIG. 63 Suitable Shrouded Package of Cut-Length Sheets, Wired

careful attention to these requirements when ordering and, if in question about a suitable method, should consult with the manufacturer.

13.2 *Product Grades*:

13.2.1 Tin plate.

13.2.2 Black plate.

13.2.3 Electrolytic chromium-coated steel (tin-free steel).

13.3 *Marking*:

13.3.1 *Cut Lengths*— Packages of cut length tin plate are identified with the following:

(1) Producer's name, brand, or trademark,
(2) Basis weight,
(3) Size,
(4) Type,
(5) Temper,
(6) Coating weight (when applicable),
(7) Product classification,
(8) Surface treatment (when applicable), and
(9) Differential markings (when applicable).

13.3.2 *Coils*—It is normal practice to identify each coil package with the following information:

(1) Producer's name, brand, or trademark,
(2) Width,
(3) Basis weight,
(4) Type,
(5) Temper,
(6) Coating weight (when applicable),
(7) Coil number,

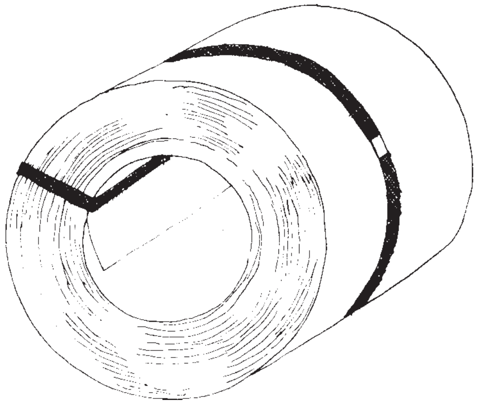

FIG. 64 Suitable Method of Packaging Individual Hot-Rolled Sheet or Strip Coil in the As-Rolled Condition

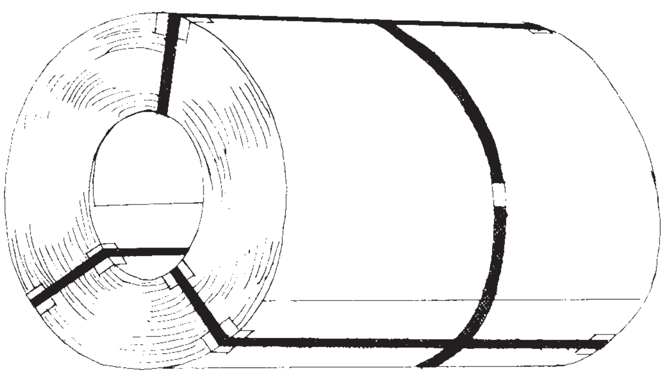

FIG. 65 Suitable Packaging of Highly Finished Individual Coil

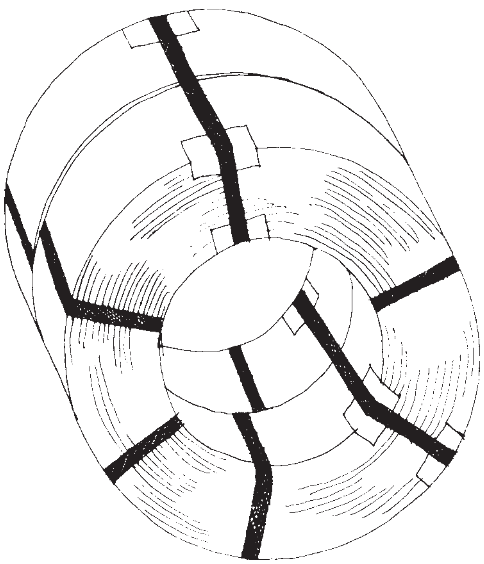

FIG. 66 Suitable Packaging of Two or More Narrow Sheet Coils into a Coil Group Package

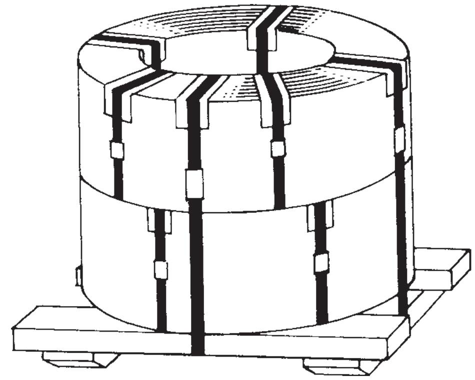

FIG. 67 Suitable Packaging of Bare Unwrapped Sheet Coils on Skeleton Platform with the Eye of the Coils Vertical

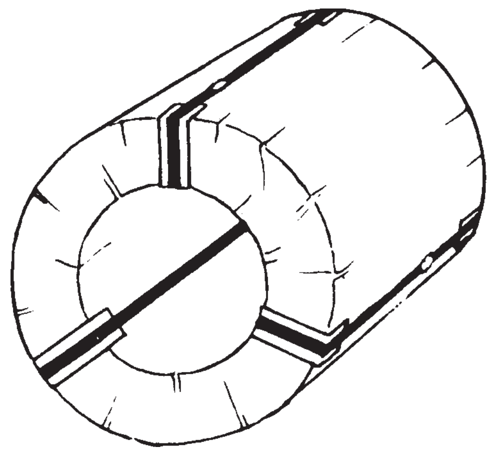

FIG. 68 Suitably Wrapped Individual Sheet Coil with Eye of the Coil Horizontal

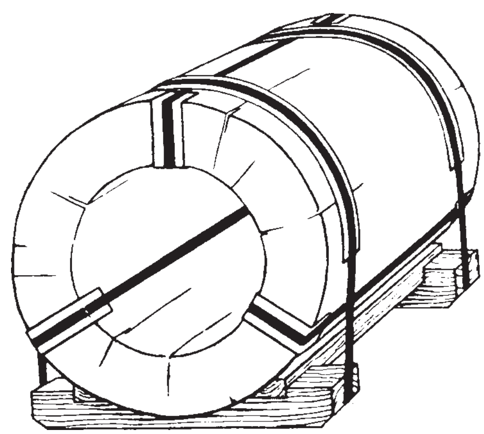

FIG. 69 Suitably Wrapped Individual Coil on Cradle Platform with the Eye of the Coil Horizontal

(8) Lineal feet,
(9) Weight,
(10) Product classification,
(11) Differential markings (when applicable), and
(12) Surface treatment (when applicable).

13.4 *Packaging*:

13.4.1 *Cut Lengths*— Most tin mill products in cut lengths are shipped in multiple-package units secured to platforms. Such units consist of 10, 12, 15, or more packages, containing 112 sheets per package. The amount of protection and securement may vary with the method of transportation, the ultimate destination, and the experience of the shipper. The components of a typical package unit are as follows:

(1) Standard platform with two or three runners.

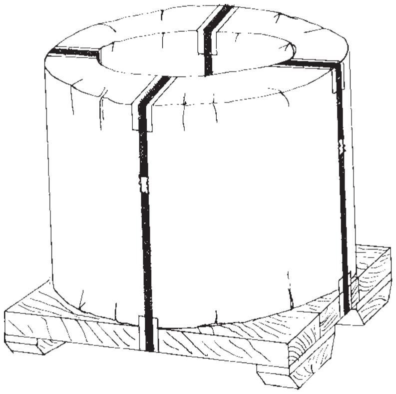

FIG. 70 Suitably Wrapped Individual Coil on Platform with the Eye of the Coil Vertical

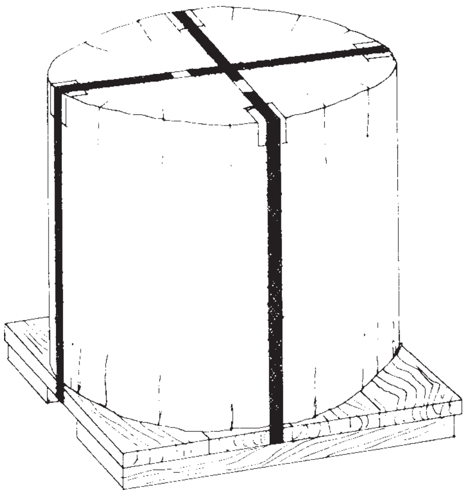

FIG. 71 Suitably Wrapped or Covered Package of Sheet Circles on Skeleton Platform

TABLE 7 Number of Lengthwise Skids for Sheet Steel Packages[A]

Sheet Gage (in.) (mm)	Use 2 Skids, in. (mm)	Use 3 Skids, in. (mm)	Use 4 Skids, in. (mm)
28 to 24 (0.0149 to 0.0239) (0.378 to 0.607)	22 to 36 (559 to 914) wide	36 to 56 (1422) wide	56 to 75 (1905) wide
Under 24 to 20 (0.0239 to 0.0359) (0.607 to 0.912)	22 to 42 (559 to 1067) wide	42 to 68 (1727) wide	68 to 96 (2438) wide
Under 20 to 16 (0.0359 to 0.0598) (0.912 to 1.519)	22 to 50 (559 to 1270) wide	50 to 84 (2134) wide	Over 84 wide
Under 16 to 12 (0.0598 to 0.1046) (1.519 to 2.657)	all widths		

[A] Lengthwise skids are not used on sheets over 192 in. (4877 mm) long or less than 22 in. (559 mm) wide.

(2) Protection on top of platform when required.
(3) Paper lining when specified or required.
(4) Edge protectors under ties.
(5) Wire or flat band ties.
(6) Fiberboard covering.

Regardless of which type of ties are shown in the illustrations, either flat bands or wires may be used. Fig. 95 illustrates a suitable method of packaging cut-length tin mill products in a multiple-package unit. This package has fiber-board covering. Edge protectors are used under ties. Ties may be bands or wire. Modifications may be made for units shipped to certain points. Standard platforms used for tin mill products are illustrated by Fig. 96 and Fig. 97. The illustrations show platforms with only two runners, but three runners are used when required. The two-runner platform is regularly used for sheets up to 30 in. (762 mm) maximum length. The third runner, when used, is placed midway between the two outside runners. Decks are usually of single thickness, made from lumber dressed not lighter than 3⁄8 in. (9.5 mm) nor more than 13⁄16 in. (20.6 mm) in thickness, depending on the size and weight of the package. Deck sizes should be the same or slightly smaller than plate size, never larger. Runners are regularly made from lumber dressed to 1¾ in. (44.4 mm) in width and not less than 2 in. (50.8 mm) or more than 4 in. (101.6 mm) in height with the ends beveled. Unless otherwise specified, they are placed parallel to the short dimension of the sheet.

13.4.2 *Coils*—It is regular practice to package tin mill coils on platforms. It is not recommended that coils be shipped eye horizontal either with or without cradle platforms on those products where transit abrasion might be detrimental. Coil packages are secured with tension-tied bands. The number of ties depends upon the size and weight of the coil, and the method of handling. Edge protectors are used under all ties. Platform runners not over 6 in. (152 mm) high have been found adequate in practically all instances. Supporting coils with special cores or spools is unnecessary and requires additional labor and material. It is regular practice to paper wrap coils. (See Fig. 69 and Fig. 98.) Fiberboard covers may be used for further protection when required. Protecting coils with metal wrapping requires additional labor and material.

13.5 *Loading*—Cut length tin mill products are shipped in closed cars or by truck. Coiled tin mill products are usually shipped in covered or closed cars or by truck.

14. Castings

14.1 All castings shall be separated by class, type, and condition when packed for shipment.

14.1.1 When castings are packed into containers they shall be adequately blocked, braced, or otherwise secured to prevent their movement within the containers.

14.1.2 Finished or polished castings shall be adequately protected from mechanical damage. Where practical the castings shall be boxed. All polished or finished surfaces shall be protected with a suitable cover such as paper or plastic.

14.1.2.1 When boxing is not practical because of size or weight, the castings shall be secured on skids or pallets. Large polished or finished castings shall have the polished or finished surfaces protected with batten strips. The entire surfaces may be covered with a protective cover such as paper or plastic.

14.1.3 Rough castings unless otherwise specified may be shipped unpacked or bundled, unless by so doing the castings may be subject to damage.

14.1.3.1 Large castings weighing more than 250 lb (114 kg) may be secured on skids or pallets for convenience in handling.

TABLE 8 Number of Crosswise Skids for Sheet Steel Packages[A]

Sheet Gage (in.) (mm)	Use 2 Skids, in. (mm)	Use 3 Skids, in. (mm)	Use 4 Skids. in. (mm)	Use 5 Skids, in. (mm)	Use 6 Skids, in. (mm)
24 and lighter (0.0239) (0.607)	22 to 36 (559 to 914) long	36 to 56 (1422) long	56 to 76 (1930) long	76 to 96 (2438) long	96 to 120 (3048) long
Under 24 to 20 (0.0239 to 0.0359) (0.607 to 0.912)	22 to 42 (559 to 1067) long	42 to 68 (1727) long	68 to 96 (2438) long	96 to 122 (3099) long	122 to 149 (3785) long
Under 20 to 16 (0.0359 to 0.0598) (0.912 to 1.519)	22 to 50 (599 to 1270) long	50 to 84 (2134) long	84 to 120 (3048) long	120 to 154 (3912) long	154 to 188 (4775) long
Under 16 to 12 (0.0598 to 0.1046) (1.519 to 2.657)	22 to 72 (559 to 1829) long	72 to 120 (3048) long	120 to 164 (4166) long	164 to 208 (5283) long	208 to 253 (6426) long
Heavier than 12 (0.1046) (2.657)	22 to 82 (559 to 2083) long	86 to 146 (3708) long	146 to 206 (5232) long	206 to 266 (6756) long	266 to 327 (8306) long

[A] The arrangements shown in Fig. 52 and Fig. 53 illustrate lengthwise and crosswise skid arrangements used for packaging cut length sheets.

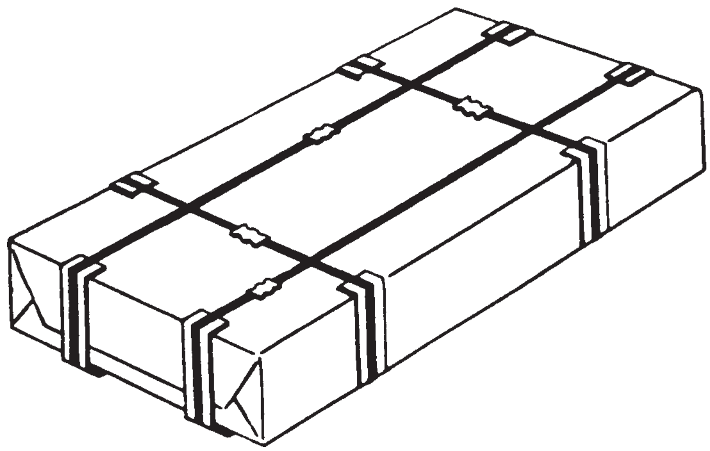

FIG. 72 Suitably Wrapped Package on Lengthwise Skids

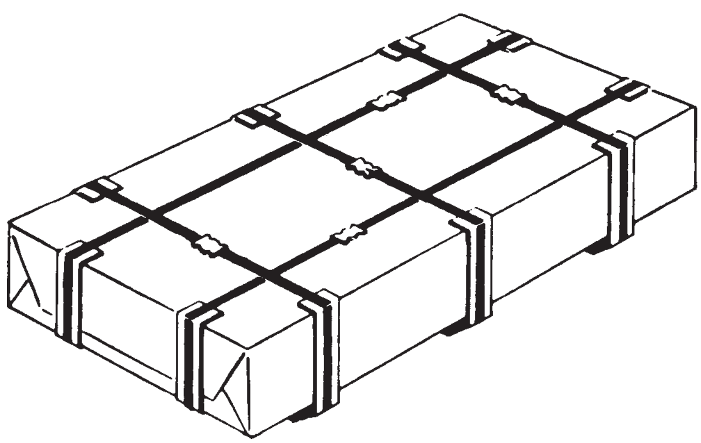

FIG. 73 Suitably Wrapped Package on Crosswise Skids

(1) When shipped on skids or pallets they may be secured by ties of soft wire or tensioned flat bands. The number of ties is at the shipper's option but must be adequate to secure the load.

14.1.4 Castings having projections that may be damaged in handling or shipping may be boxed, crated, or secured on skids or pallets with the projections adequately protected with batten strips.

14.2 Containers when used shall afford maximum protection from the normal hazards of transportation and shall be so constructed as to ensure safe delivery by common carrier.

14.3 *Marking*—It is normal practice to have the heat number, alloy type, and pattern number cast or stamped on the surface of castings. The purchase order number may be shown on a tag attached to each box, skid, pallet or loose casting.

15. Keywords

15.1 loading; marking; packaging; shipment; steel products

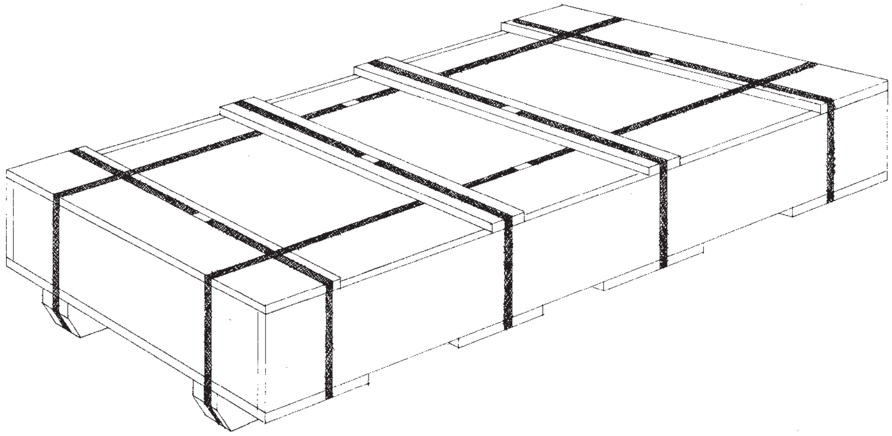

FIG. 74 Steel Sheets in a Fully Enclosed Package on a Skeleton Platform, Using Wood Materials

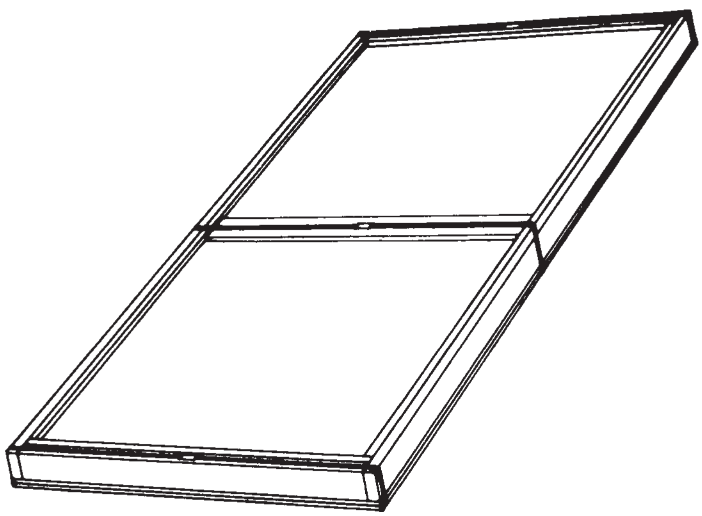

FIG. 75 Steel Sheets in a Box of Suitable Solid Protective Material

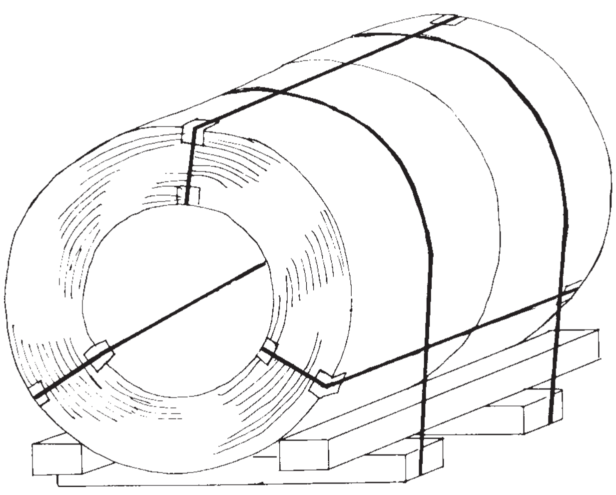

FIG. 76 Suitably Packaged Bare Unwrapped Individual Stainless Steel Sheet Coil on Cradle Platform, with the Eye of the Coil Horizontal

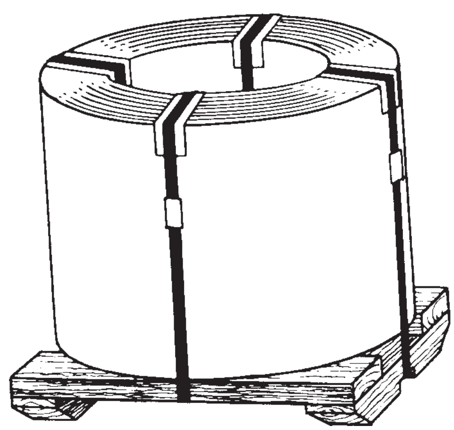

FIG. 77 Suitably Packaged Bare Unwrapped Individual Sheet Coil on Platform with the Eye of the Coil Vertical

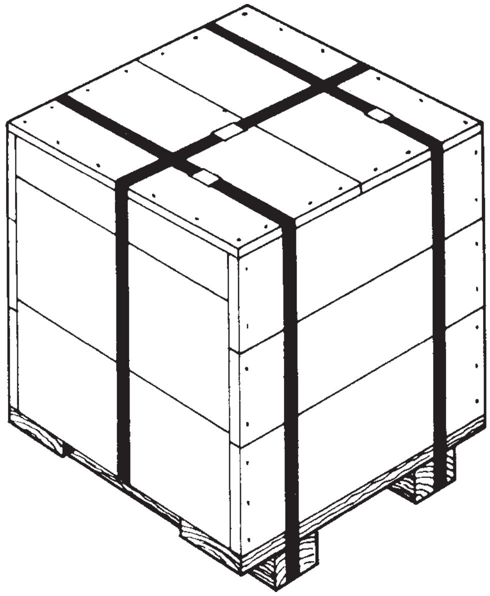

FIG. 78 Suitably Packaged Individual Sheet or Strip Coil or Group of Sheet or Strip Coils in Solid Box, on Platform with the Eye of the Coil Vertical

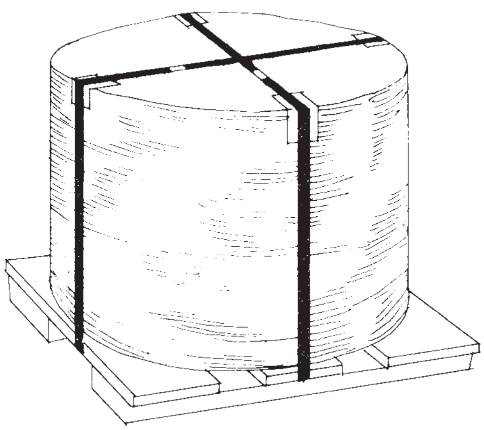

FIG. 79 Suitably Packaged Single Pile of Bare Stainless Steel Sheet Circles on Skeleton Platform

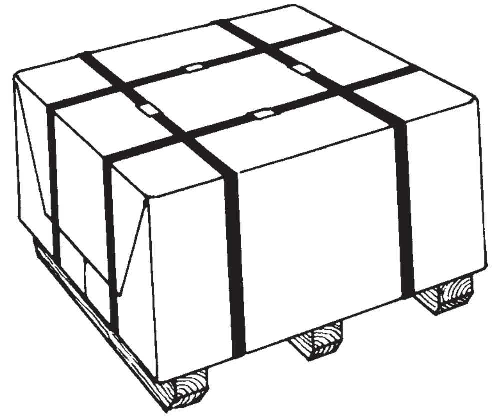

FIG. 80 Multiple Piles of Circles on Solid Platform, Covered with Corrugated Fiberboard

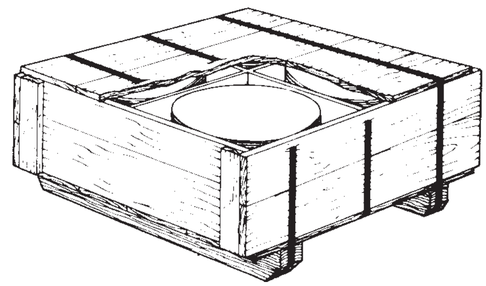

FIG. 81 Multiple Piles of Circles in Box on Solid Deck Platform

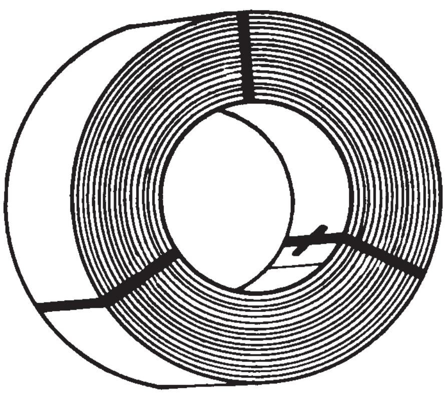

FIG. 82 Narrow Strip Coil with Flat Twist Bands

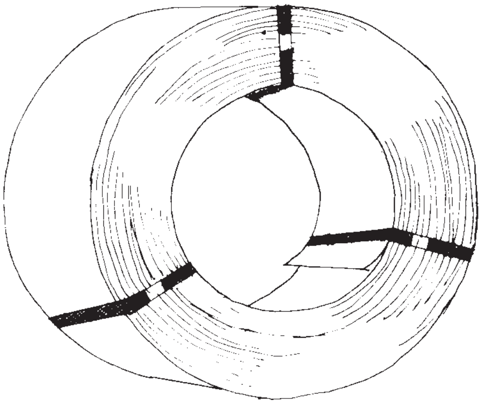

FIG. 83 Narrow Strip Coil with Machine Tension Bands

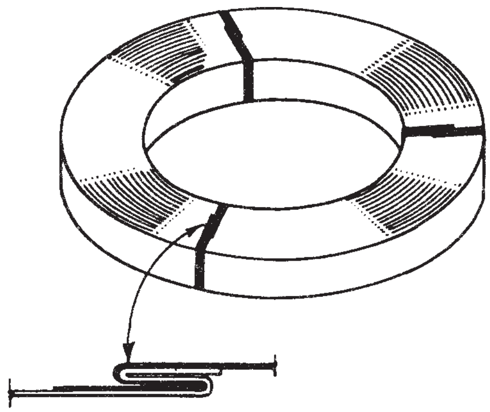

FIG. 84 Narrow Strip Coil with Knockdown or Buckle Bands

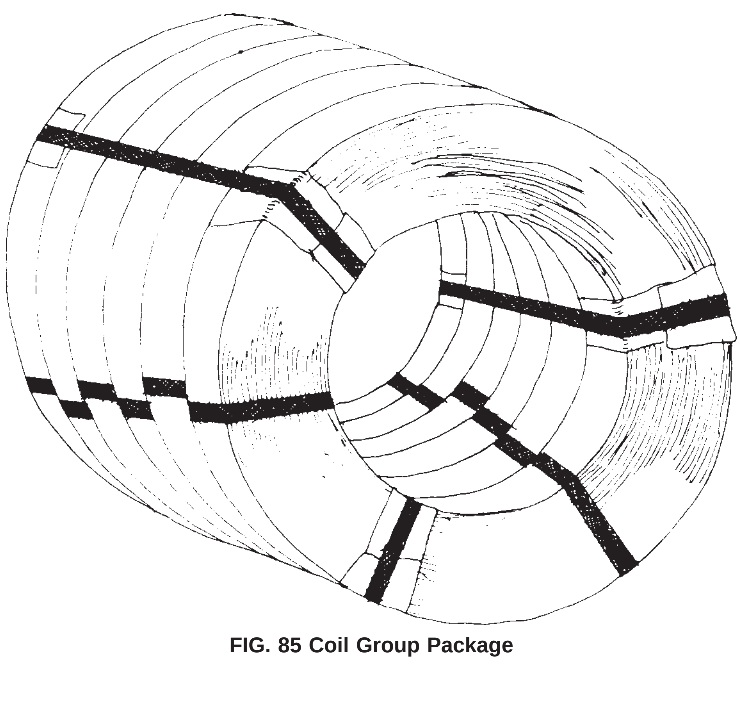

FIG. 85 Coil Group Package

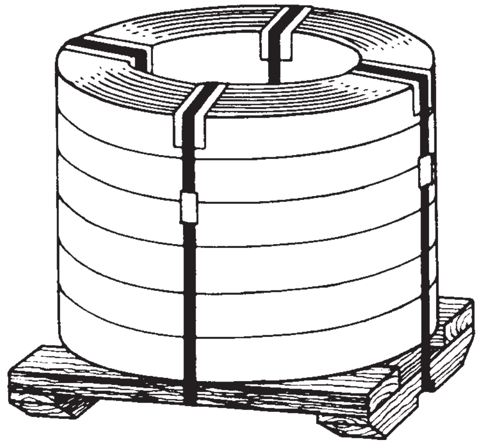

FIG. 86 Narrow-Strip Coils on Skeleton Platform with the Eye of the Coils Vertical

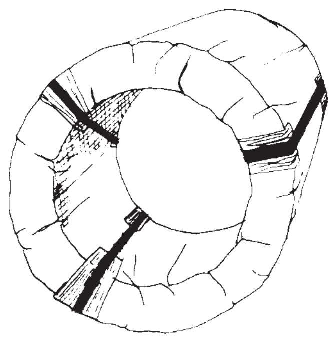

FIG. 87 Suitably Wrapped Individual Strip Coils or Groups of Coils

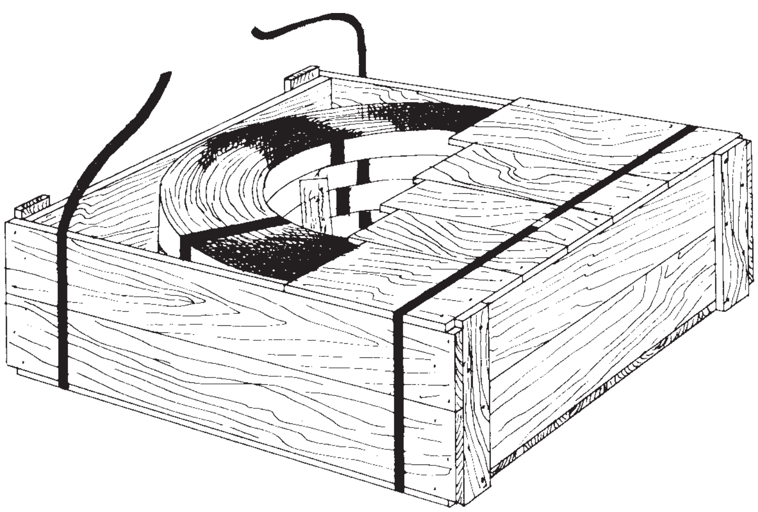

FIG. 88 Suitably Packaged Bare Narrow Strip Coils in Container

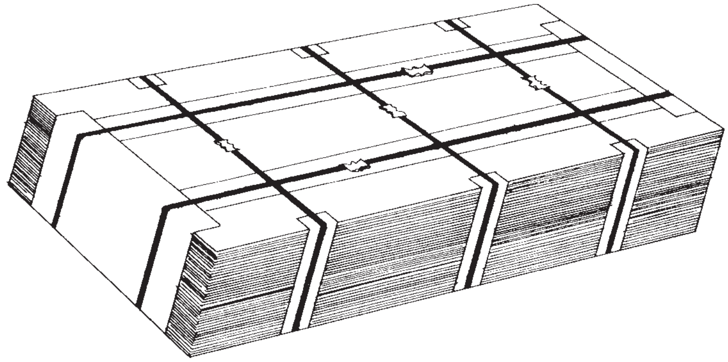

FIG. 89 Bare Package of Stainless Steel Strip on Crosswise Skids

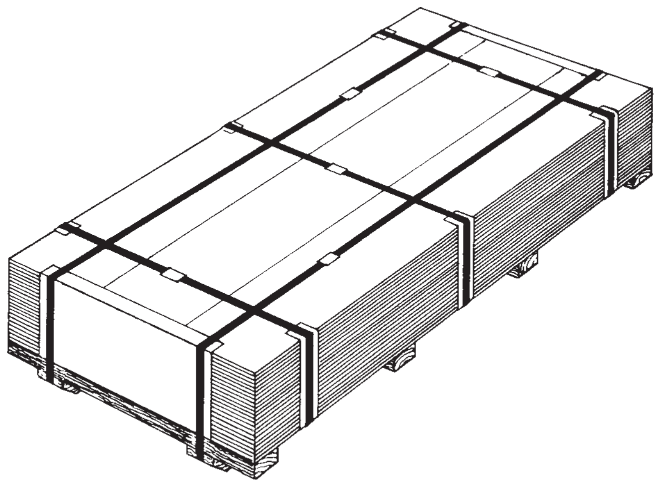

FIG. 90 Bare Package of Stainless Steel Strips on Skeleton Platform

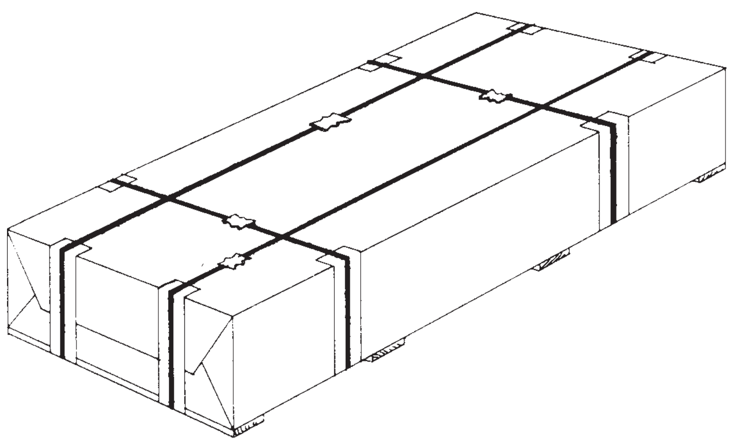

FIG. 91 Suitably Wrapped Stainless Steel Strip on Platform

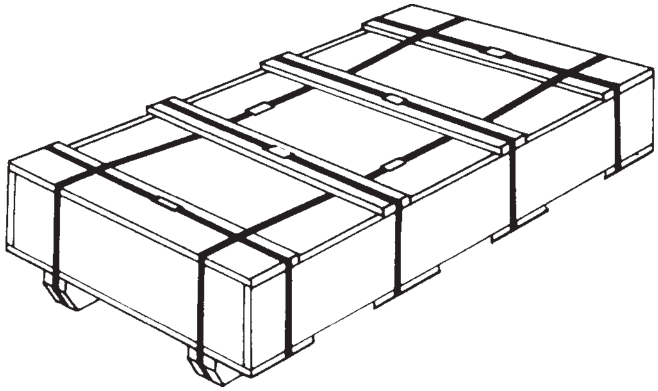

FIG. 92 Suitably Packaged Stainless Steel Strip in a Fully Enclosed Package on a Platform Using Wood Materials

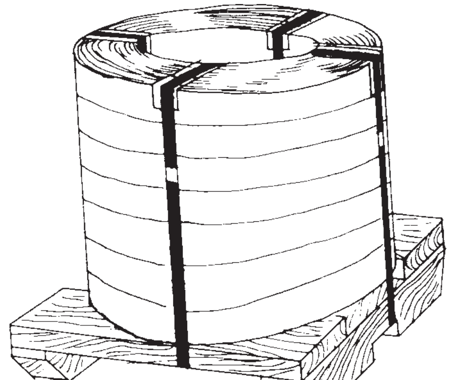

FIG. 93 Suitably Packaged Narrow Stainless Steel Strip Coils on Skeleton Platform

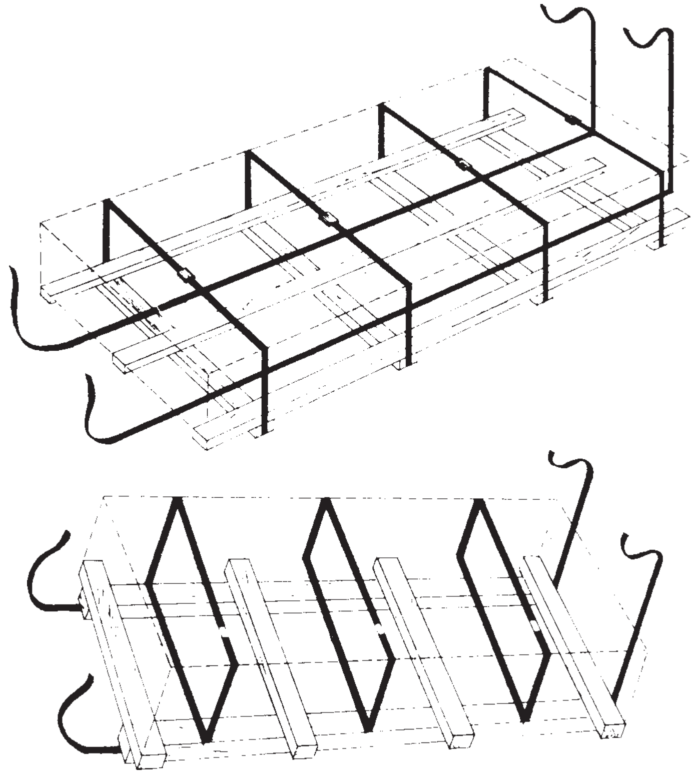

FIG. 94 Two Types of Skeleton Platform Systems

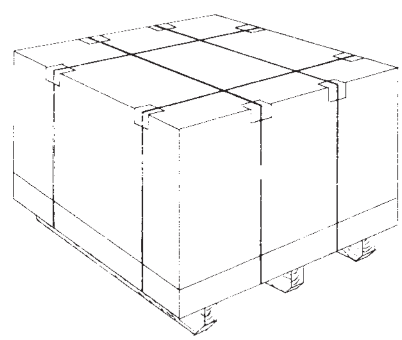

FIG. 95 Suitable Method of Packaging Cut-Length Tin Mill Products in Multiple Package Unit

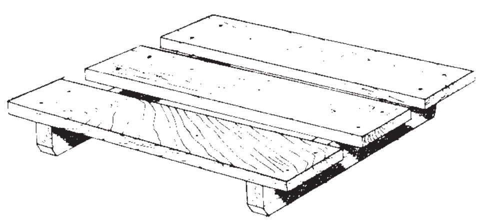

FIG. 96 Standard Skeleton Deck Two-Runner Platform

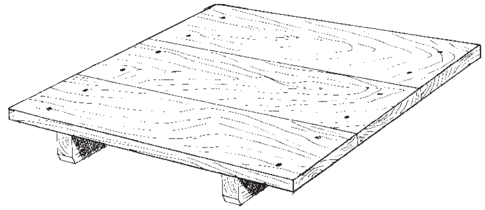

FIG. 97 Standard Solid Deck Two-Runner Platform

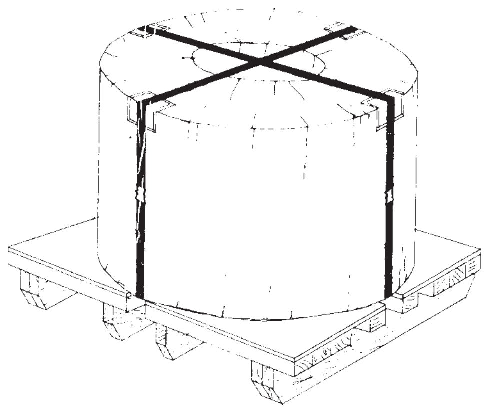

FIG. 98 Paper Wrapped Tin Plate Coil on a Platform

Designation: A 702 – 89 (Reapproved 2000)

Standard Specification for Steel Fence Posts and Assemblies, Hot Wrought[1]

This standard is issued under the fixed designation A 702; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers steel fence posts and assemblies manufactured from hot-wrought sections and intended for use in field and line fencing.

1.2 The posts are available in tee, channel, or U and Y-bar shapes or angle shapes and are furnished painted or galvanized, unless otherwise specified.

1.3 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 36/A 36M Specification for Carbon Structural Steel[3]

A 123 Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products[4]

A 153 Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware[4]

A 499 Specification for Steel Bars and Shapes, Carbon, Rolled from "T" Rails[2]

A 641 Specification for Zinc-Coated (Galvanized) Carbon Steel Wire[4]

A 700 Practices for Packaging, Marking, and Loading Methods for Steel Products for Domestic Shipment[2]

2.2 *Federal Standards:*

Federal Standard No. 123 Marking for Shipments (Civil Agencies)[5]

2.3 *Military Standards:*

MIL-STD-129 Marking for Shipment and Storage[5]

MIL-STD-163 Steel Mill Products, Preparation for Shipment and Storage[5]

3. Terminology

3.1 *Definitions:*

3.1.1 *assemblies*— angel section post components for installation of gates, fence ends or corners, and intermediate bracing.

3.1.2 *line posts*—posts that support the straight-line body of the fence.

4. Ordering Information

4.1 Orders for products under this standard should include the following information:

4.1.1 Quantity (number of pieces) of line posts, end or gate assemblies, corner or intermediate brace assemblies (It is customary to order line posts in multiples of five of the required length and the required number of end or corner assemblies),

4.1.2 Type of section (if a specific section is required) (see 5.2 and Fig. 1),

4.1.3 Length or lengths required (see 6.2),

4.1.4 Finish: galvanized or painted,

4.1.5 ASTM designation and date of issue,

4.1.6 Anchor plates, if required (see 5.4.3), and

4.1.7 Wire fasteners (state weight of zinc coating if other than Class 1) (see 5.6.2 and 5.6.3).

NOTE 1—A typical ordering description is as follows: 500 line posts; 8 ft long; painted; ASTM A 702 dated ___; omit anchor plates.

5. Materials and Manufacture

5.1 *Material*:

5.1.1 Line posts shall be fabricated from Steels A or B and assemblies from Steels A, B, or C as specified in Table 1.

5.1.2 Except as provided in 6.1.3, the finished line post and assemblies shall conform to the tensile properties specified in Table 1 for the applicable steel.

5.1.3 At the manufacturer's option, a Brinell or Rockwell B hardness test may be substituted for the tensile requirements in Table 1. In such cases the material shall conform to the Brinell or Rockwell B hardness specified in Table 2.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys, and is the direct responsibility of Subcommittee A01.15 on Bars. This standard is a revision of Commercial Standard CS 184-51, Steel Fence Posts—Field Line Type, formerly published by the United States Department of Commerce.

Current edition approved Dec. 7, 1989. Published February 1990. Originally published as A 702–74. Last previous edition A 702–87.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.04.

[4] *Annual Book of ASTM Standards*, Vol 01.06.

[5] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

FIG. 1 Typical Cross Sections of Line Post Types

5.2 *Line Post Section*:

5.2.1 The posts shall be furnished as T, channel or U, or Y sections as illustrated in Fig. 1. The cross section of T posts shall be approximately 1⅜ in. (35 mm) wide, 1⅜ in. deep, and ⅛ in. (3.2 mm) thick. Unless otherwise specified by the purchaser, the line post type is at the manufacturer's option.

5.2.2 Dimensions may vary slightly in individual design in maintaining the control weight per foot.

5.3 *Wire Attachments*—Line posts shall have corrugations, knobs, notches, holes, or studs so placed and formed as to engage a substantial number of fence line wires in proper positions.

5.4 *Anchor Plates*:

5.4.1 Each line post shall be manufactured with an anchor plate, unless otherwise specified. The anchor plate shall be made from carbon steel and shall be swaged or riveted to the post in such a manner as to prevent displacement when the posts are driven.

5.4.2 The placement of the anchor plate shall be nominally 14 in. (350 mm), 16 in. (400 mm), or 18 in. (450 mm) from the bottom of the post to the uppermost portion of the anchor plate.

5.4.3 Anchor plates shall be tapered to facilitate driving, shall have a minimum area of 18 in.^{2} (11600 mm^2) and shall weigh 0.67 lb (0.3 kg) ± 5 %.

5.4.4 When specified, line posts may be furnished without anchor plates.

5.4.5 Anchor plates shall be manufactured from Type A or B materials.

5.5 *Post Assemblies*:

5.5.1 Uprights shall consist of angles with a nominal size 2½ by 2½ by ¼ in. (65 by 65 by 6.4 mm) weighing approximately 4.10 lb/ft (6.1 kg/m) prior to fabrication.

5.5.2 Braces shall consist of angles with a nominal size 2 by 2 by ¼ in. (50 by 50 by 6.4 mm) weighing approximately 3.19 lb/ft (4.75 kg/m) prior to fabrication, or an alternative angle of equivalent weight.

5.5.3 Uprights and braces shall be furnished with the necessary holes and galvanized hardware for the required assembly.

5.5.4 All assemblies shall be furnished with one upright. End and gate assemblies shall be furnished with one brace, and corner and intermediate braces with two braces.

5.6 *Wire Fasteners*:

5.6.1 Unless otherwise specified by the purchaser, each line post shall be provided with not less than five suitable fasteners for attaching fence wire to the posts.

5.6.2 The fasteners shall be formed from zinc-coated steel wire not less than 0.120 in. (3.05 mm) diameter zinc coated in accordance with Specification A 641. Class 1 coating shall be furnished unless otherwise specified by purchaser.

5.6.3 When line posts are intended for range type western fencing using three line wires, it is satisfactory to provide only three fasteners for each post.

6. Dimensions, Mass and Permissible Variations

6.1 *Nominal Weights and Tolerances*:

6.1.1 *Nominal Weight*—Prior to fabrication by punching, drilling, attaching anchors, or finish coating, the line post sections shall have a nominal weight of 1.33 lb/ft of the length.

6.1.2 The weight of line posts plus anchor plates (if specified), prior to fabrication, drilling, or finish coating shall not vary from nominal weights specified in Table 3 by more than ± 5 %. Weight shall be determined in lots of five line posts.

6.1.3 The weight of assembly components prior to fabrication, drilling, or finish coating shall not vary from the nominal weights specified in Table 4 by more than ± 5 %. Single assembly components shall be used to determine weight.

6.2 *Standard Lengths and Tolerances*:

6.2.1 Line posts shall be furnished in standard lengths of 5 to 10 ft (1525 to 3050 mm) inclusive, as specified by the purchaser. Standard length increments are shown in Table 3.

6.2.2 The length of line posts, uprights, and braces shall not vary from that specified more than −1.0 in. (−25 mm) or +2 in. (50 mm).

6.2.3 The placement of the anchor plate shall not vary from the nominal by more than ± 3 in. (76 mm).

7. Workmanship, Finish, and Appearance

7.1 Line posts, uprights, and braces shall be furnished painted, or galvanized as specified by the purchaser.

7.2 When specified to be painted, the posts shall be cleaned of all loose scale prior to finishing, and painted with one or more coats of weather resistant, air drying or baking paint or enamel.

7.3 When specified to be galvanized, the posts and post assemblies shall be zinc coated by the hot-dip process in accordance with Specification A 123. The assembly hardware (see 5.5.3) shall be zinc coated in accordance with Specification A 153.

8. General Requirements

8.1 Material furnished under this specification shall conform to the general requirements of the current edition of Specification A 29/A 29M unless otherwise provided herein.

9. Sampling

9.1 One item from each lot shall be selected at random for testing. A lot shall consist of all posts or assemblies or both, of the same length offered for delivery at the same time.

9.2 The post or assembly selected in accordance with 7.1 shall be tested for tensile strength or hardness, weight, and zinc coating, if applicable.

9.3 For purposes of visual inspection, length determinations, and dimensional examination, one post or assembly from each 400, or a total of seven, or whichever is less, shall be selected at random.

9.4 Visual inspection shall include examination for such features as excessive bow, camber, twist, or other injurious

TABLE 1 Materials for Line Posts and Assemblies

Steel	Steel Description	Line Posts		Assemblies	
		Yield Point, min, ksi (MPa)	Tensile Strength, min, ksi (MPa)	Yield Point, min, ksi (MPa)	Tensile Strength, min, ksi (MPa)
A	hot-wrought carbon steel, 0.35% carbon, min	40 (275)	70 (485)	40 (275)	70 (485)
B	hot-wrought carbon steel, or hot-wrought rail steel[A]	50 (345)	80 (550)	50 (345)	80 (550)
C	structural steel[B]	...	...	36 (250)	58 (400)

[A] Hot wrought rail steel in accordance with Specification A 499.
[B] In accordance with Specification A 36/A 36M.

TABLE 2 Brinell Hardness

Steel	Steel Description	Brinell Hardness, min	Rockwell B Hardness, min
A	hot-wrought carbon steel, 0.35 %, carbon, min	143	79
B	hot-wrought carbon steel or rail steel[A]	156	83
C	structural steel[B]	116	68

[A] Hot wrought rail steel in accordance with Specification A 499.
[B] In accordance with Specification A 36/A 36M.

TABLE 3 Nominal Weights of (Raw) Line Posts

Post Length		Weight[A]	
ft	m	lb	kg
5	1.52	7.32	3.32
5½	1.68	7.99	3.61
6	1.83	8.65	3.92
6½	1.98	9.32	4.22
7	2.13	9.98	4.53
7½	2.28	10.64	4.83
8	2.44	11.31	5.13
9	2.74	12.64	5.74
10	3.05	13.97	6.34

[A] Includes weight of anchor plate.

TABLE 4 Nominal Weights of (Raw) Assemblies

	Length		Weight[A]	
	ft	m	lb	kg
Upright and one brace, each (end or gate)	7	2.13	51	23
Upright and two braces, each (corner or intermediate brace)	7	2.13	73	33
Upright and one brace, each	8	2.44	58	26
Upright and two braces, each	8	2.44	84	38
Upright and one brace, each	9	2.74	66	30
Upright and two braces, each	9	2.74	94	43

[A] Includes weight of bolts.

imperfections in surface or coating. Such imperfections may be considered cause for rejection of individual posts or assemblies.

10. Rejection and Retests

10.1 Should the post or assembly fail to meet any of the requirements of 10.2, the lot size shall become 400. One test shall be selected from each lot, and failure of the test shall result in rejection of that particular lot.

10.2 Should two or more posts or assemblies fail to meet any of the requirements of 10.3, the lot size shall become 400. Seven items shall be examined from each lot for compliance to the requirements of 10.3 causing initial failure. If two of more items fail, the entire lot shall be rejected.

10.3 Any individual post or assembly failing to meet the requirements of 10.2 or 10.3 shall be rejected.

11. Inspection

11.1 Unless otherwise specified in the purchase order or contract, the manufacturer is responsible for the performance of all inspection and test requirements specified in this specification. Except as otherwise specified in the purchase order or contract, the manufacturer may use his own or any other suitable facilities for the performance of the inspection and test requirements unless disapproved by the purchaser at the time the order is placed. The purchaser shall have the right to perform any of the inspection and tests set forth in this specification when such inspection and tests are deemed necessary to ensure that the material conforms to prescribed requirements.

12. Rejection and Rehearing

12.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the producer or supplier may make claim for a rehearing.

13. Certification

13.1 When specified in the purchase order or contract, a producer's or supplier's certification shall be furnished to the purchaser that the material was manufactured in accordance with this specification and has been found to meet the requirements.

14. Packaging

14.1 Line posts shall be bound in bundles of 5 posts, and by agreement with the purchaser, may be supplied in master bundles containing up to 250 posts.

14.2 Orders are customarily on piece count rather than on weight of posts or assembles. The nominal weights establish the basis for weight tolerance and transportation data (see Table 3 and Table 4 for nominal weights).

15. Packaging, Marking, and Loading for Shipment

15.1 Unless otherwise specified, packaging, marking, and loading for shipment shall be in accordance with Practices A 700.

15.2 When specified in the contract or order, and for direct procurement by or direct shipment to the U. S. Government, when Level A is specified, preservation, packaging and packing shall be in accordance with Level A requirements of MIL-STD-163.

15.3 When specified in the contract or order, and for direct procurement by or direct shipment to the U. S. Government, marking for shipment, in addition to requirements specified in the contract or order, shall be in accordance with MIL-STD-129 for U. S. Military agencies and in accordance with FED-STD-123 for U. S. Government civil agencies.

16. Keywords

16.1 hot wrought steel bars; steel bars

Standard Specification for Steel Forging Stock[1]

This standard is issued under the fixed designation A 711; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers cast carbon and alloy steel ingots and strand castings, semi-wrought ingots and strand castings and rolled or forged blooms, billets, and slabs for forging.

1.2 Blooms, billets, and slabs are semi-finished steel products, hot rolled or forged to approximate cross-sectional dimensions. Blooms and billets may be square, round, octagonal, or rectangular in section; slabs are rectangular. Although no invariable rule prevails between the terms blooms and billets, and they are frequently used interchangeably, the following size distinctions are in general use.

1.2.1 *Blooms*—Cross-sectional area greater than 36 in.^{2} (232 cm^2).

1.2.2 *Billets*—Maximum cross-sectional area 36 in.^{2} (232 cm^2.

1.2.3 *Slabs*—Minimum thickness, 1½ in. (38.0 mm); width, more than twice the thickness; and generally a cross-sectional area of not less than 16 in.^{2} (103 cm^2).

1.2.4 Ingots either top or bottom poured or secondary remelted are covered.

1.2.5 Strand castings with or without additional reduction are covered.

1.3 Supplementary requirements (S1 to S19) of an optional nature are provided. They shall apply only when specified by the purchaser.

1.4 The values stated in either inch-pound or SI (metric) units are to be regarded separately as standards. Within the text and tables, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore each system must be used independent of the other. Combining values from the two systems may result in nonconformance with the specification.

1.5 Unless the order specifies the ″M″ specification, the material shall be furnished to the inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold Finished, General Requirements for

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings

A 788 Specification for Steel Forgings, General Requirements

E 45 Test Methods for Determining the Inclusion Content of Steel

E 112 Test Methods for Determining the Average Grain Size

E 381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings

3. Ordering Information and General Requirements

3.1 When this specification is to be applied to an inquiry, contract, or order, the purchaser shall furnish the following information in addition to those specified in Specification A 788:

3.1.1 The grade of material desired.

3.1.2 Product form restrictions (for example, ingots, strand castings, billets) if any, and

3.1.3 Applicable supplementary requirements.

3.1.4 Surface condition.

3.2 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retsting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

3.2.1 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved March 1, 2004. Published April 2004. Originally approved in 1974. Last previous edition approved in 2001 as A 711/A 711M – 92 (2001).

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard.**

4. Materials and Manufacture

4.1 *Discard*—Sufficient discard shall be made to secure freedom from piping and undue segregation.

4.2 *Reduction from Ingot*—Except as otherwise agreed in accordance with Supplementary Requirement S3.2, the material shall be made from product having at least two times the cross-sectional area of the material.

4.3 *Stability*—Material shall be furnished in a condition to withstand, for an indefinite time, exposure to all climatic conditions without developing any external or internal cracks. The method of cooling or of treatment before shipment shall be optional with the manufacturer, but he shall be responsible (in the same manner as for defects disclosed after delivery) for cracks that may develop before material is subjected to reheating. When specific stability treatment of material is specified by the purchaser, the manufacturer shall be responsible only for carrying out those specific operations but shall not be responsible for cracks that may develop before material is subjected to reheating.

5. Chemical Composition

5.1 The chemical composition shall conform to the requirements specified in the purchase order or the individual product specification. For convenience the grades commonly specified for carbon and alloy steel, blooms, billets, or slabs are shown in Table 1 and Table 2 of the latest issue of Specification A 29/A 29M. Blooms, billets, or slabs may be ordered to these grade designations, and when so ordered shall conform to the specified limits by heat analysis.

5.2 *Heat Analysis*:

5.2.1 An analysis of each heat of steel shall be made in accordance with Specification A 788.

5.3 *Product Analysis*:

5.3.1 A product analysis may be made by the purchaser in accordance with Specification A 788.

5.3.2 To indicate adequately the composition of a heat or lot, samples selected to represent the heat as fairly as possible shall be taken midway between center and outside of the material from a minimum number of pieces as follows:

Lots	Number of Pieces
15 tons (13.5 t) or less	4
Over 15 tons (13.5 t)	6

5.3.3 If the number of pieces from cast or heat is less than the number of samples specified in 5.3.2, one sample shall be taken from each piece.

5.3.4 When chips are taken by drilling, the approximate diameter of the drill used shall be as follows:

Area of Cross Section to Be Sampled, in.^{2} (cm^2)	Approximate Drill Diameter, in. (mm)
16 (103) and under	½ (12.7)
Over 16 (103)	1 (25.4)

6. Permissible Variations

6.1 The permissible variation from the specified or theoretical weight of blooms, billets, and slabs shall be ±5 % for individual pieces or for lots of less than a carload. For carload lots the permissible variation shall be ±2.5 % of the total weight of the lot.

7. Workmanship, Finish, and Appearance

7.1 The material shall be free of injurious imperfections.

7.2 Conditioning, cutting, or parting of material may be done by scarfing or flame-cutting when methods involving preheating and temperature control necessary to avoid any damage to flame-cut material are employed.

7.3 *Surface Conditioning*—Material may be conditioned to remove injurious surface defects, provided the depth of conditioning does not exceed 1⁄16 in. (1.6 mm) for each inch of dimension concerned, up to a maximum depth of ¾ in. (18.1 mm), and provided that the width of the conditioning is at least four times its greatest depth; except that in the case of slabs where the width is at least twice the thickness, the depth of conditioning on the wide surfaces may exceed this allowance by 50 %, up to a maximum depth of ¾ in. (19.1 mm). The maximum depth of conditioning on two parallel sides at opposite locations shall not exceed one and one half times the maximum allowed for one side. All conditioned areas must be flared to result in a uniform blending.

8. Keywords

8.1 billets; blooms; slabs; steel forging stock

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply when specified by the purchaser in the inquiry, contract, and order. Details of these supplementary requirements shall be agreed upon by the manufacturer and purchaser.

S1. Specified Process

S1.1 The steel shall be vacuum treated.

S2. Discard

S2.1 Specific discard shall be taken as defined in the ordering information.

S3. Reduction in Area

S3.1 The purchaser may specify any definite amount of reduction in area greater than 2.1 as provided in 4.2.

S4. Residual Elements

S4.1 Supplementary Requirement S1 of Specification A 788 shall apply.

S5. Restricted Product Analysis

S5.1 When product analysis to Specification A 788/A 788M is applicable, a more restrictive requirement for one or more chosen elements shall be stated in the ordering information.

S6. Guaranteed Segregation Tests

S6.1 In the ordering information the purchaser or his representative shall note the intention to make product analysis to represent each cast or heat. Two sets of drillings shall be taken from the top face of this piece at points on the same diagonal of the piece. The drillings shall be taken with a ⅝-in. (15.9-mm) drill parallel to the axis of the product as cast. The distance from the center of the piece to the drilling points shall be, respectively 15 and 80 % of the length of the half diagonal of the piece.

S6.2 From the drillings taken at the 80 % point, a complete analysis may be made. The chemical composition thus determined shall conform to the requirements specified.

S6.3 From the drillings taken at the 15 % point, a carbon determination may be made. The difference between the carbon content of the drillings from the 15 % point and that of the drillings from the 80 % point, expressed as a percentage of the latter, shall not exceed the following values:

Thickness, in. (mm)	Carbon Content Difference, %
15 (381) and under	15
Over 15 (381)	20

S6.4 If, in any heat, the drillings taken in accordance with S6.1 do not conform to the requirement prescribed in S6.3, additional drillings may be taken in a similar manner after making a further top discard from the material of at least 10 % of the original weight. The results of this analysis shall conform to the requirements prescribed in S6.3; otherwise, the heat represented shall be rejected.

S7. Guaranteed Heat Treatment

S7.1 The heat treatment requirements involve the size of material to be tested; location of test bar; the size, shape and method of preparing test specimens; temperature and time of treatment; agitation of quenching medium; and similar requirements. The minimum and maximum limits of a specified hardness range shall be consistent with the hardness obtainable in the full range of the specified chemical limits.

S8. Nonmetallic Inclusion Requirement

S8.1 The samples for testing shall be taken on a longitudinal place midway between the center and surface of the material. The samples shall be hardened before being polished to avoid polishing pits; the area to be examined shall be agreed upon between the manufacturer and the purchaser. The rating of the inclusion count shall be based upon the average length of the inclusions, the longest inclusion, and the general background. Any standards agreed upon shall be based upon a magnification of 100×. Reference may be made to Test Methods E 45.

S9. Macroetch Tests

S9.1 The location and number of the macroetch test specimens as well as acceptance criteria shall be as stated in the ordering information. The procedure used shall be in accordance with Method E 381 unless otherwise agreed upon.

S10. Magnetic Particle Examination

S10.1 Magnetic particle examination shall be performed in accordance with Test Method A 275/A 275M. The magnetizing procedure and acceptance limits shall be as stated in the ordering information.

S11. Ultrasonic Examination

S11.1 Unless otherwise agreed upon, the ultrasonic examination shall be based on Practice A 388. The scanning procedure and acceptance criteria shall be as stated in the ordering information.

S12. Grain Size

S12.1 Except as qualified in S12.2, carburized austenitic grain size shall be specified as coarse or fine, to be determined in accordance with Test Methods E 112. The steel shall be designated as coarse grain when the grain structure falls within the limits depicted in photograph numbers 1 to 5, inclusive, of Plate IV of Test Methods E 112 and fine grain when the grain structure falls within photograph numbers 5 to 8, inclusive. The grain structure shall be considered satisfactory if 70 % is within the specified grain size limits. If these ranges are too broad for the purchaser's requirements, more restricted grain size limits may be agreed upon between the purchaser and the manufacturer.

S12.2 Due to certain manufacturing conditions, the grain size distinctions prescribed in S12.1 may not be adhered to in blooms larger than 100 in.^{2} (645 cm^2) in cross-sectional area nor in slabs larger than 20 by 5 in. (508 by 127 mm). For these larger sizes, grain size requirements shall be negotiated between the purchaser and manufacturer.

S12.3 When aluminum is used as a grain refining element, the fine grain size requirement shall be deemed to be fulfilled if, on heat analysis, the aluminum content is not less than 0.015 % acid soluble aluminum, or alternately, 0.020 % total aluminum. The aluminum content shall be reported. The grain size test specified in S12.1 shall contiune to be the referee test.

S13. Fracture Tests

S13.1 A transverse fracture test to indicate soundness and homogeneity shall be made in accordance with the test method and acceptance criteria stated in the ordering information. A central area equivalent to at least 10 % of the total cross sectional area of the end of the piece shall be fractured.

S14. Surface Preparation

S14.1 For purposes of making possible closer inspection, the material shall be pickled in acid, or sand, or shot-blasted, or prepared by any other method agreed upon.

S15. Controlled Cooling and Treatment

S15.1 When more control than is provided in 4.3 is required, any or all of the following requirements, as described in the ordering information shall be done.

S15.1.1 A maximum controlled rate of cooling after hot working,

S15.1.2 Annealing, normalizing, or normalizing and tempering.

S15.1.3 A maximum hardness, or

S15.1.4 Suitability for cold shearing.

S16. Surface Conditioning

S16.1 A more limited removal depth for surface imperfections than that stated in 7.3 shall apply, as stated in the ordering information.

S16.1.1 Material removal shall be by scarfing, grinding, or chipping as stated in the ordering information.

S17. Marking and Identification

S17.1 Marking of the product, in addition to that required by Section 10, shall be as stated in the ordering information.

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes since A 788/A 788M-91 that may impact the use of this standard.

(1) Revised by removing sections which were redundant with A 788/A 788M.

(2) Deleted S5 and S19.

(3) Converted specification to dual format.

Designation: A 723/A 723M – 02

Standard Specification for Alloy Steel Forgings for High-Strength Pressure Component Application[1]

This standard is issued under the fixed designation A 723/A 723M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification[2] covers requirements for high-strength quenched and tempered alloy steel forgings for pressure vessels, isostatic presses, shock tubes, and similar components.

1.2 These materials are not intended for welded construction.

1.3 Three grades of nickel-chromium-molybdenum steels and six classes of increasing tensile strength are included. The strength class, section size, and configuration of the forging will largely dictate the applicable type(s) of steel.

1.4 The values stated in either inch-pound units or SI (metric) units are to be regarded separately as the standard. Within the text and tables, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.5 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings[3]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[4]

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings[3]

A 788 Specification for Steel Forgings, General Requirements[3]

3. Ordering Information and General Requirements

3.1 In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order a detailed drawing, sketch, or written description of the forging and the method of selecting test location (see 6.2). When appropriate, the areas of significant loading in the forging shall be designated.

3.2 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

3.3 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

4. Materials and Manufacture

4.1 *Melting Practice*—The steel melting procedures of Specification A 788 shall apply except that the open-hearth process shall not be used, and that the steel shall be vacuum degassed prior to or during the pouring of the ingot, in order to remove objectionable gases, particularly hydrogen.

4.1.1 Use of secondary remelting or refining operations may be considered for particularly demanding applications.

4.2 *Discard*—Sufficient discard shall be taken from each ingot to secure freedom from piping and excessive segregation.

4.3 *Heat Treatment*:

4.3.1 Forgings shall be rough-machined prior to final heat treatment if it is necessary to reduce the mass to ensure full hardening or to meet the requirements of 6.2. The risk of cracking during heat treatment with high-hardenability steels of the type covered by this specification should be borne in mind when deciding on the degree of surface preparation before heat treatment.

4.3.2 *Heat Treatment for Mechanical Properties*—Heat treatment shall consist of normalizing (which may be part of the preliminary treatment), reaustenitization, liquid quenching, and tempering. The forgings shall be quenched in a suitable liquid medium by spraying or immersion. Quenching shall be followed by tempering at a minimum temperature of 1000°F

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved September 10, 2002. Published January 2003. Originally approved in 1975. Last previous edition approved in 1994 as A 723 – 94 (1999).

[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA–723/SA–723M in Section II of that Code.

[3] *Annual Book of ASTM Standards*, Vol 01.05.

[4] *Annual Book of ASTM Standards*, Vol 01.03.

***A Summary of Changes section appears at the end of this standard.**

[540°C]. The minimum time at tempering temperature shall be ½ h/in. [½ h/25 mm] of maximum section thickness, unless otherwise agreed between supplier and purchaser.

5. Chemical Composition

5.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 shall comply with Table 1.

5.2 *Product Analysis*—The manufacturer shall use the product analysis provision of Specification A 788 to obtain a product analysis from a forging representing each heat or multiple heat. The purchaser may also make this determination in accordance with Specification A 788.

6. Mechanical Properties

6.1 *General Requirements*—The forging shall conform to the requirements of Table 2 and Table 3. The largest obtainable tension test specimen as specified in Test Methods and Definitions A 370 (that is, standard round 0.500-in. [12.5-mm] diameter specimen) shall be used. Charpy V-notch Type A impact specimens, as shown in Test Methods and Definitions A 370, shall be used.

6.2 *Sampling*—The mid-point of the gage length of tension test specimens and the area under the notch of impact specimens shall be located in accordance with one of the following methods as specified by the purchaser, or suggested by the supplier and approved by the purchaser. Wherever practical, all testing shall be from integral prolongations of the forging.

6.2.1 *Method 1*—This method shall always be used when the maximum quenched thickness does not exceed 4 in. [100 mm]. Datum points of the specimens, as described in 6.2, shall be located in the forging or test forging (6.2.4) at mid-thickness and at least ⅔ T (T is the maximum heat-treated thickness) from the quenched end surface or nearest adjacent surfaces.

6.2.2 *Method 2*—t by $2t$, where t is the distance from the area of significant loading (3.1) to the nearest quenched surface. However, the datum points of the specimens as described in 6.2 shall not be nearer to one quenched surface than ¾ in. [20 mm] and to the second quenched surface than 1 ½ in. [40 mm]. When this method of testing is employed, forgings are usually manufactured in accordance with a purchaser-approved drawing showing prequenched dimensions and the location of mechanical test specimens. It is commonly used for disk-type forgings such as tube sheets and covers.

6.2.3 *Method 3*—For maximum quenched thicknesses in excess of 4 in. [100 mm] as heat treated. Where this method of testing is employed, the datum points of the test specimen, as described in 6.2, shall be removed ¼ *T* from the nearest quenched surface and ⅔ *T* from the quenched end surface or nearest adjacent surface.

6.2.4 *Method 4*—Test specimens shall be taken from a representative separate test forging made from the same heat of steel, which shall receive substantially the same reduction and type of hot working, and have a cross section not less than the production forgings which it represents. It shall be heat treated in the same furnace charge and under the same conditions as the production forgings. The test specimen shall be removed using the Method 3 procedure.

6.3 *Thermal Buffers*:

6.3.1 Thermal buffer rings, at least *T* by *T* in cross section or sections of such a ring at least 3 *T* in length, shall be welded to the test end(s) of a forging prior to heat treatment for mechanical properties. The buffer material may be any weldable carbon or low-alloy steel and shall be joined to the forging with a partial penetration-type weld which completely seals the buffered surface. The test coupons shall be removed from the forging in the region buffered by the ring or ring segments. If the latter are used, the test coupons shall be removed from the forging in the area under the center ⅓ of the buffer ring segment length. In either case, the test specimens shall be located at a minimum distance of ½ in. [13 mm] from the buffered surface of the forging and at least ¼ *T* from a quenched surface of the forging. Buffered weld areas must be at least 1 in. [25 mm] from any finished machining surface of the complete forging.

6.3.2 Bearing in mind the characteristics of the base materials included in this specification, precautions should be taken, such as the use of pre- and post-weld heating and austenitic weld metal, to minimize the occurrence of crack-like defects.

6.3.3 Approval of the purchaser should be obtained for the use of this method.

6.4 Samples shall be removed from the forgings after quenching and tempering.

6.5 *Orientation*—For upset disk forgings, the longitudinal axis of all test specimens shall be oriented in the tangential or radial direction. For all other forgings, the longitudinal axis of the specimens shall be oriented in the direction of maximum working of the forging, or as agreed between manufacturer and purchaser.

6.6 *Number of Tests*:

6.6.1 For forgings weighing 1000 lb [455 kg] or less, as heat treated but not exceeding 80 in. [2030 mm] in length, excluding test material, one tension test and one set of impact tests (three specimens) shall be taken to represent each heat in each heat-treatment charge. This testing shall be repeated at the opposite end of the same test forging, if the heat-treated length excluding test material exceeds 80 in. [2030 mm]. When heat treatment is performed in continuous-type furnaces with suitable temperature control and equipped with recording pyrometers so that complete heat-treatment records are available, a heat-treatment charge shall be considered as any continuous run not exceeding 8 h in duration.

6.6.2 Forgings weighing over 1000 lb [455 kg] but not over 5000 lb [2270 kg] as heat treated and not over 80 in. [2030

TABLE 1 Chemical Requirements

	Composition, %		
	Grade 1	Grade 2	Grade 3
Carbon, max	0.35	0.40	0.40
Manganese, max	0.90	0.90	0.90
Phosphorus, max	0.015	0.015	0.015
Sulfur, max	0.015	0.015	0.015
Silicon, max	0.35	0.35	0.35
Nickel	1.5 to 2.25	2.3 to 3.3	3.3 to 4.5
Chromium	0.80 to 2.00	0.80 to 2.00	0.80 to 2.00
Molybdenum	0.20 to 0.40	0.30 to 0.50	0.40 to 0.80
Vanadium, max	0.20	0.20	0.20

TABLE 2 Tensile Requirements

	Class 1	Class 2	Class 2a	Class 3[A]	Class 4[B]	Class 5[C]
Tensile strength, min, ksi [MPa]	115 [795]	135 [930]	145 [1000]	155 [1070]	175 [1205]	190 [1310]
Yield strength, 0.2 % offset, min, psi [MPa]	100 [690]	120 [825]	130 [895]	140 [965]	160 [1105]	180 [1240]
Elongation in 2 in. or 50 mm, min, %	16	14	12.5	13	12	10
Reduction of area, min, %	50	45	43	40	35	30

[A] Typical maximum section size of 10 in. [255 mm] for open-ended vessels, or 7 in. [180 mm] for blind-ended vessels.
[B] Typical maximum section size of 6 in. [150 mm] for open-ended vessels, or 4 in. [100 mm] for blind-ended vessels.
[C] Typical maximum section size of 4 in. [100 mm].

TABLE 3 Charpy V-Notch Impact Requirements at 40°F [4.5°C] max[A]

	Class 1	Class 2	Class 2a[A]	Class 3[B]	Class 4[C]	Class 5[D]
Minimum average value of set of three specimens, ft·lbf [E] (J)	35 [47]	30 [41]	28 [38]	25 [34]	20 [27]	12 [16]
Minimum value of one specimen, ft·lbf (J)	30 [41]	25 [34]	23 [31]	20 [27]	15 [20]	10 [14]

[A]Or such other lower temperature as is specified when supplementary requirement S2 is involved.
[B]Typical maximum section size of 10 in. [255 mm] for open-ended vessels, or 7 in. [180 mm] for blind-ended vessels.
[C]Typical maximum section size of 6 in. [150 mm] for open-ended vessels, or 4 in. [100 mm] for blind-ended vessels.
[D]Typical maximum section size of 4 in. [100 mm].
[E]Not more than one specimen from a set may be below this value.

mm] in length excluding test material, one tension test and one set of three impact tests shall be removed from each forging. When the length of the forging exceeds 80 in. [2030 mm] this testing shall be repeated at the opposite end of the forging.

6.6.3 Forgings exceeding 5000 lb [2270 kg] and not over 80 in. [2030 mm] in length, excluding test material, shall have one tension test and one set of three impact tests removed from each of two locations, 180° apart. For forgings with lengths exceeding 80 in. [2030 mm] this testing shall be repeated at the opposite end of the forging.

7. Nondestructive Examination Requirements

7.1 *Ultrasonic Examination*:

7.1.1 Forgings shall be ultrasonically examined in accordance with the procedures of Practice A 388/A 388M.

7.1.1.1 *Straight-Beam Examination*:

(*a*) Unless otherwise specified, the back-reflection method of tuning shall be used in accordance with Practice A 388/ A 388M.

(*b*) In addition to the reportable conditions of Practice A 388, indications exceeding the resultant back-reflection shall be recorded.

(*c*) A forging shall be unacceptable when one or more reflections are present producing indications accompanied by a complete loss of back-reflection, not attributable to nor associated with the geometric configuration. For this purpose, a back-reflection of less than 5 % of full screen height shall be considered complete loss of back-reflection.

7.1.1.2 *Angle-Beam Examination*:

(*a*) Calibration notches shall be cut into the inside diameter and outside diameter surfaces in accordance with Practice A 388.

(*b*) A forging that contains a discontinuity which results in an indication exceeding the amplitude of the reference line is subject to rejection.

(*c*) The report of the ultrasonic test shall be in compliance with Practice A 388/A 388M.

(*d*) Additional nondestructive examination or trepanning may be employed to resolve questions of interpretation of ultrasonic indications. The manufacturer shall accept responsibility for injurious defects that will not be removed in final machining.

7.2 *Magnetic Particle Examination*:

7.2.1 Each forging shall be examined by magnetic particle methods described in Test Method A 275/A 275M. Acceptance and rejection standards shall be as follows: Only indications with major dimensions greater than 1⁄16 in. [1.6 mm] shall be considered relevant. The following relevant indications are unacceptable:

7.2.1.1 Any linear indications greater than 1⁄16 in. [1.6 mm] long for materials less than 5⁄8 in. [16 mm] thick; greater than 1⁄8 in. [3.2 mm] long for materials from 5⁄8 in. to under 2 in. [50 mm] thick; and 3⁄16 in. [4.8 mm] long for materials 2 in. [50 mm] thick and greater. A linear indication is defined as one whose length is three times its width.

7.2.1.2 Rounded indications with dimensions greater than 1⁄8 in. [3.2 mm] for thicknesses less than 5⁄8 in. [16 mm], and greater than 3⁄16 in. [4.8 mm] for thicknesses 5⁄8 in. [16 mm] and greater.

7.2.1.3 Four or more relevant indications in a line separated by 1⁄16 in. [1.6 mm] or less, edge to edge.

7.2.1.4 Ten or more relevant indications in any 6 in.^{2} [3870 mm^2] of surface with the major dimension of this area not to exceed 6 in. [150 mm] when it is taken in the most unfavorable orientation relative to the indications being evaluated.

8. Rework and Retreatment

8.1 Repair welding shall not be permitted. For retreatment, see 7.2.1.

9. Certification and Reports

9.1 In addition to the certification requirements of Specification A 788, the manufacturer shall include the following in the certification data:

9.1.1 Results of the product analysis,

9.1.2 Method used to locate mechanical test specimens (see Section 6), and

9.1.3 Sketches or drawings as necessary to supplement the nondestructive examination report.

10. Packaging and Package Marking

10.1 Marking shall be in accordance with Specification A 788 but stamping shall be permitted only in areas designated by the purchaser. If no such suitable area is available, a separate nameplate, with the required stamping, shall be permanently affixed to the vessel in a manner that will not be injurious to the vessel.

11. Keywords

11.1 alloy steel forgings; high pressure vessels; high strength; impact tested; isostatic presses; nonweldable; quenched and tempered; vacuum-treated steel

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry or order. Details of these supplementary requirements shall be agreed upon by the manufacturer and the purchaser.

S1. Charpy V-Notch Impact Transition Curve

S1.1 Sufficient impact tests shall be made from the forging test material to establish a temperature-absorbed energy curve. The test temperature range shall be wide enough to establish the upper and lower shelf foot·pound-force energies, with sufficient testing at intermediate temperatures to permit plotting a reasonably smooth curve.

S1.2 Instead of plotting an impact transition curve, impact requirements may be specified as 50 % fibrous fracture at a specified maximum temperature.

S2. Additional Charpy Data

S2.1 The percent shear fracture and mils of lateral expansion, defined in Test Methods and Definitions A 370, shall be reported for each Charpy specimen tested.

S3. Charpy Impact Tests

S3.1 Charpy impact tests shall be made in accordance with the provisions of Section 6 of this specification, except that the tests shall be at a specified temperature lower than 40°F [4.5°C]. These tests shall be instead of those specified in Section 6, and shall meet the requirements of Table 3.

S4. Impact Testing

S4.1 For Class 2a forgings, impact tests shall be made in accordance with the provisions of Section 6 of this specification except that the acceptance criteria shall be a minimum of 45 ft·lbf [61 J] and 25 mils [0.635 mm] lateral expansion at a test temperature specified by the purchaser.

S5. Mechanical Test Location Discard

S5.1 Instead of the discard of ¼ *T* x ⅔ *T* required by 6.2.3, a minimum discard of ¼ *T* x *T* shall be employed for Method 3.

SUMMARY OF CHANGES

(1) Section 4.1.1 added

Designation: A 729 – 93 (Reapproved 1999)

Standard Specification for Alloy Steel Axles, Heat-Treated, for Mass Transit and Electric Railway Service[1]

This standard is issued under the fixed designation A 729; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers quenched and tempered alloy steel axles for mass transit and commuter cars in electric railway service.

1.2 This specification is for solid design roller bearing axles with machined bodies.

1.3 Various axle designs are used for this service including motor and nonmotor with either inboard or outboard journals.

1.4 Supplementary requirements are provided for use when additional testing or inspection is desired. These shall apply only when specified individually by the purchaser in the order.

1.5 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[2]

E 112 Test Methods for Determining the Average Grain Size[3]

E 127 Practice for Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks[4]

E 381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings[3]

NOTE 1—References to analysis standards are for guidance only; other methods of equivalent accuracy may be used.

3. Ordering Information

3.1 Orders for material under this specification shall include the following information:

3.1.1 Quantity.

3.1.2 Purchaser's drawing showing complete details pertaining to dimensions, tolerances if more restrictive than those contained in this specification, degree of finish and location of stamping and any other information that will aid the manufacturer to furnish a satisfactory product.

3.1.3 Supplementary requirements, if any.

4. Manufacture

4.1 *Process*—The steel shall be made by any of the following processes: open-hearth, electric-furnace, or basic-oxygen.

4.2 *Discard*—A sufficient discard shall be made to assure freedom from piping and undue segregation.

4.3 *Forging Practice*—The axle may be made direct from the ingot or from blooms, the total reduction from ingot or strand cast blooms to forging being not less than 3 to 1, unless otherwise specified.

4.4 *Cooling and Heating*:

4.4.1 After axle blooms are produced they shall be slow cooled in closed containers, hoods, or furnaces.

4.4.2 Blooms shall be reheated for forging in a manner that will prevent internal bursts and overheating.

4.4.3 After forging, axles shall be slow cooled in closed containers, covered conveyors, or hoods. If axles are heat-treated directly from the forging, they shall be slow cooled following the final heat treatment.

4.4.4 Axles that are heat-treated directly from forging (*1*) shall be cooled below the transformation temperature or to approximately 1000°F (538°C) before any reheating operation, and (*2*) must not be permitted to cool below 500°F (260°C) without slow cooling as defined in 4.4.3.

NOTE 2—As the temperature of the axles approaches the minimum of 500°F (260°C) a supplemental heat source may be necessary to assure an effective slow cooling cycle.

4.4.5 When properly vacuum-degassed steel is used, the slow cooling requirements of 4.4.1, 4.4.3, and 4.4.4 may be omitted but axle blooms must then be pile cooled.

4.5 *Heat Treatment*:

4.5.1 *Quenching*—After heating to a suitable temperature the axles shall be quenched in a suitable medium under reasonably uniform conditions. A furnace charge thus treated is termed a quenching charge.

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] *Annual Book of ASTM Standards*, Vol 01.03.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] *Annual Book of ASTM Standards*, Vol 03.03.

4.5.2 *Tempering*—Axles shall be reheated gradually to, and held at, a suitable temperature below the critical range and shall then be allowed to cool under suitable conditions. A furnace charge thus treated is termed a tempering charge.

4.5.3 Heat treatment may be performed in either batch-type furnaces or continuous furnaces.

4.6 *Straightening*—Straightening shall be done before machining and preferably at a temperature not lower than 950°F (510°C). Straightening performed at temperatures lower than 950°F shall be followed by stress relieving or applicable heat treatment.

5. Chemical Requirements

5.1 *Chemical Composition*—The steel shall conform to the chemical requirements specified in Table 1 or to the composition agreed upon by the manufacturer and the purchaser.

5.2 *Heat Analysis*—An analysis of each heat of steel shall be made by the manufacturer to determine the percentage of carbon, manganese, phosphorus, sulfur, and silicon. The chemical composition thus determined shall be reported to the purchaser or his representative and shall conform to the requirements of 5.1.

5.3 *Product Analysis*—An analysis may be made by the purchaser from one axle representing each heat. The chemical composition thus determined shall conform to the requirements of 5.1 subject to tolerances included in Table 2. The sample for these analyses shall be taken from one end of the test axle or full-sized prolongation at a point midway between the center and surface. If drillings are taken, they shall be obtained using a ⅝ -in. (16-mm) diameter drill or turnings may be taken from a tension test specimen.

6. Metallurgical Requirements

6.1 A specimen, representing each heat in each heat-treatment lot, shall be taken for microscopical test from the tension test specimen. This section for microscopical test shall be cut from the large undistorted portion of the tension test specimen in such a way as will give a face transverse to the axis of the axle.

6.2 The face shall be polished practically free of scratches and shall be etched to define the microstructure. The specimen shall be examined under a magnification of 100 diameters.

6.3 The entire specimen shall show a uniform, fine-grained structure of no. 5 or finer as measured in accordance with Test Methods E 112.

7. Tension Test Requirements

7.1 Tension tests shall be made in accordance with Test Methods A 370.

7.1.1 Axles shall conform to the requirements in Table 3.

TABLE 1 Chemical Requirements

Element	Composition, %
Carbon, max	0.60
Manganese	1.30–1.70
Phosphorus, max	0.045
Sulfur, max	0.050
Silicon, min	0.15

TABLE 2 Permissible Variations for Product Analysis (for Cross Section 100 in.^{2}(645 cm^2) and Under)

NOTE—Product cross-sectional area is defined as either:
(*a*) maximum cross-sectional area of rough machined forging (excluding boring),
(*b*) maximum cross-sectional area of the unmachined forging, or
(*c*) maximum cross-sectional area of the billet, bloom, or slab.
Area taken at right angles to the axis of the original ingot or billet.

Element	Permissible Variations, Over the Maximum Limit or Under the Minimum Limit, %
Manganese	0.06
Phosphorus	0.008
Sulfur	0.008
Silicon	0.02

7.1.2 The diameter of the test prolongation of axle forgings shall be determined by the forged diameter of the journal.

7.1.3 The yield strength prescribed in Table 3 shall be determined by a strain gage or extensometer reading to 0.0002 in. (0.005 mm). Yield strength may be defined as the stress at 0.6 % total strain under load or as the stress at 0.2 % offset. The method described in Test Methods A 370 shall be followed. After the yield point has been passed the extensometer may then be removed and the test continued to determine the tensile strength.

7.1.4 Tests shall be made only after final heat treatment.

7.1.5 *Tension Test Specimens*:

7.1.5.1 Tension test specimens shall be taken from the test prolongation or an axle in accordance with the provision in 7.2.

7.1.5.2 Unless otherwise specified, the axis of the specimen shall be located at any point midway between the center and surface of the axle or full-sized prolongation and shall be parallel to the axis of the axle.

7.1.5.3 The tension test specimen shall be machined to the form and dimensions shown in Fig. 6 of Test Methods A 370 covering the standard round tension test specimen with a 2-in. (50-mm) gage length.

7.2 *Prolongation for Test*:

7.2.1 For test purposes, prolongations shall be attached to at least 5 % of the axles in each heat in each heat-treating lot.

7.2.2 If axles with prolongations have been expended then axles may be used for test procurement.

7.3 *Number of Tests*:

7.3.1 Unless otherwise specified by the purchaser, mechanical tests shall be made as covered in 7.3.2 and 7.3.3.

7.3.2 Where batch-type furnaces are used, one test per heat per size classification is required, but each test shall represent no more than 70 axles. The axles represented by this test shall be called a heat-treatment lot.

7.3.3 Where continuous heat-treating furnaces are used, one test per heat per size classification is required, but each test shall represent no more than 70 axles. The axles represented by this test shall be called a heat-treatment lot.

7.3.4 If any test specimen fails because of a mechanical condition of the testing apparatus it may be discarded and another specimen taken.

7.4 *Retest*:

TABLE 3 Tensile Requirements

Test Prolongation Diameter									
Over		Not Over		Tensile Strength, min		Yield Strength, min		Elongation in 2 in or 50 mm, min, %	Reduction of Area, min, %
in.	mm	in.	mm	ksi	MPa	ksi	MPa		
4	102	7	178	100	690	65	450	20	45

7.4.1 If the results of the mechanical tests of any lot do not conform to the requirements specified because a flaw developed in the test specimen during testing, a retest shall be allowed if the defect is not caused by ruptures, cracks, or flakes in the steel.

7.4.2 If the results of the mechanical tests of any lot do not conform to the requirements specified, the axles may be retreated, but not more than three additional times, and retests shall be made in accordance with Section 7.

8. Nondestructive Testing Requirements

8.1 *Ultrasonic Inspection*—The purpose of this inspection is to evaluate the quality of new axles (*1*) by determining end face to end face penetrability, and (*2*) by detecting discontinuities that may be harmful to axle service.

8.2 *Equipment*—Equipment requirements are as follows:

8.2.1 The instrument used must be a pulse echo type.

8.2.2 The instrument shall be operated at a 2¼ -MHz frequency for both penetrability and discontinuity detection.

8.2.3 The instrument may use various transducers, namely, quartz 1 in. (25.4 mm) square or 1⅛ in. (28.6 mm) round, or barium titanate ¾ in. (19.1 mm) to 1 in. round. The transducer type is at the option of the axle manufacturer. Other transducers of similar response capability as those described may be used.

8.3 *Time of Inspection*—Inspection shall be made after heat treatment and after the axle ends are machined and centered, or at any subsequent stage of processing.

8.4 *Instrument Sensitivity and Scanning*:

8.4.1 *Instrument Sensitivity*:

8.4.1.1 The instrument sensitivity shall be adjusted to produce an indication of 20 % full screen height (FSH) from a reference test block manufactured from a quench and tempered axle forging having a ⅛ -in. (3.18-mm) diameter, 1 in. (25.4 mm) deep, flat-bottomed hole drilled perpendicularly to and at a distance of 15 in. (381 mm) from the test end face of the axle section. The reference blocks shall have a surface finish of 80 to 125 µin. (2.03 to 3.18 µm).

8.4.1.2 At the sensitivity established in 8.4.1.1 the instrument shall detect in reference axles a flat-bottom hole of the size and distance specified in the table below.

Minimum Size (Flat-Bottom Holes) Detectable at Various Distances from End Faces

Test Distance to 15 in. (381 mm)	Test Distance 15 to 30 in. (381 to 762 mm)	Test Distance over 30 in. (762 mm)
⅛ in. (3.18 mm)	¼ in. (6.35 mm)	⅜ in. (9.52 mm)

8.4.2 *Scanning*:

8.4.2.1 Scanning shall be performed from both end faces, which shall have a surface finish of 125 µin. (3.18 µm) maximum. The scanning shall include the maximum end face area obtainable by manual or automated inspection techniques.

8.4.2.2 During scanning the amplitude of the indication from the end face opposite the search unit shall be monitored and the amplitudes of all discontinuity indications shall be evaluated with respect to the distance from the test surface (see 8.4.3 and 8.7.2).

8.4.3 *Distance-Amplitude Correction*— The amplitude of an ultrasonic indication must be considered in relation to its distance from the testing surface to evaluate its significance. This can be accomplished by an electronic device or by distance-amplitude curves (DAC), which are described in 8.7.2.

8.5 *Rejection*:

8.5.1 *Longitudinal Penetration*—Axles that do not produce a 40 % FSH back reflection from the end of face opposite the search unit shall be rejected or made acceptable by heat treatment.

8.5.2 *Discontinuity Test*—The axle shall be rejected if the amplitude of any discontinuity indication exceeds the indication levels obtained from the flat-bottom holes listed in the table under 8.4.1.2 considering the distance-amplitude correction as described in 8.4.3.

8.6 *Marking*—Axles that meet the ultrasonic inspection requirements of this specification shall be stamped with the letter "T" on the end face adjacent to the heat number or serial number.

8.7 *Additional Information*:

8.7.1 *Alternative Reference Standards*— Alternative references may be used to establish the test sensitivity if they are cross referenced with the reference test block described in 8.4.1.1. For example, alternative references for quenched and tempered axles that give equivalent sensitivity: (*1*) a 1-in. (25.4-mm) indication from a No. 1 series "A" Alcoa block, and (*2*) a 1½ -in. (38.1-mm) indication from an ASTM Practice E 127 (latest edition) block No. 1-0300.

8.7.2 *Distance-Amplitude Correction*—The amplitude of an ultrasonic indication from a given discontinuity size varies with its distance from the test surface. To compensate for this effect, a distance-amplitude relationship is employed. The relationship can be established by an electronic device or by curves. Because the distance-amplitude relationship is influenced primarily by the ultrasonic transducer and instrument, it is necessary to relate this factor to the specific equipment used. Appropriate distance-amplitude curves shall be developed. A typical example is shown in Fig. 1 as related to the axle in Fig. 2.

8.7.3 *Spurious Ultrasonic Indications from Contour Variations*—Because an axle varies in cross section it is

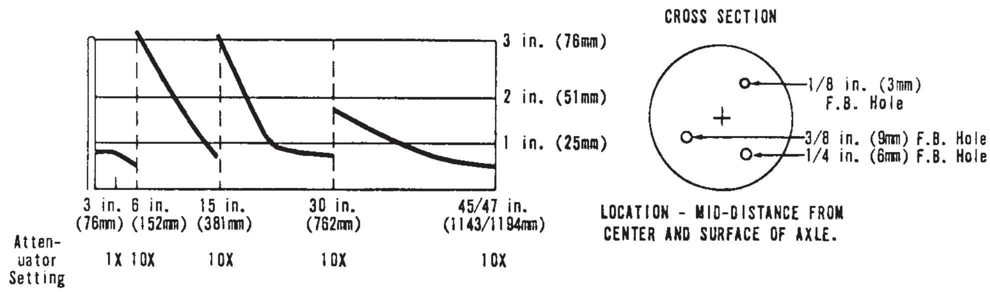
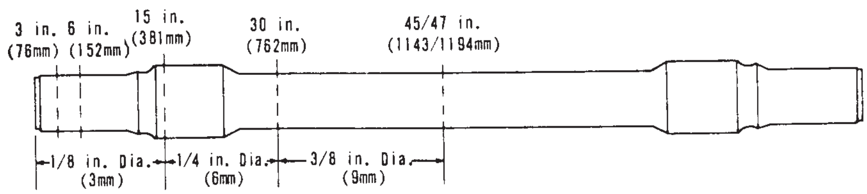


FIG. 1 Typical Distance-Amplitude Curve for Quenched and Tempered Axle as Determined with a Sperry Reflectoscope, Type UM Using a 1⅛ –in. (28.6-mm) Diameter 2.25-MHz Quartz Transducer



Flat Bottom Hole Sizes for Quenched and Tempered Axle

FIG. 2 Showing Location of Reference Holes in Axle

possible to produce spurious indications, particularly at changes of cross section. These must be recognized, and are not reason for rejection. It is not practical to define these indications as responses from axle contours.

8.7.4 *Near-Field Resolution*—It should be recognized that detection of discontinuities near the test surface is limited by the ultrasonic test frequency. In the case of quenched and tempered axles, this is approximately 1 in. (25.4 mm) from the test surface.

9. Dimensional Tolerances

9.1 *Length and Diameter*:

9.1.1 For axles ordered to finished length, the overall length shall not be less than the specified minimum length nor more than 1⁄16 in. (1.6 mm) over.

9.1.2 For axles ordered for finished-end facing by the purchaser, the overall length shall range from ⅛ in. (3.2 mm) to ¼ in. (6.4 mm) over the specified minimum length.

9.1.3 For any other axles ordered to final length and not covered by the above classifications, the overall length shall not be less than the specified minimum length nor more than ⅛ in. (3.2 mm) over.

9.1.4 The specified minimum length shall be the nominal overall final length less any allowable tolerances.

9.1.5 Rough-machined areas, either the entire axle or designated parts thereof, shall be ⅛ in. (3.2 mm) to ¼ in. (6.4 mm) over the finished diameter; in the case of motor axles having a conglomerate of diameters for the seats for wheel, gear, gear case bearing, and grounding ring the entire area shall be rough machined to a single diameter ⅛ to ¼ in. over the finished diameter of the segment having the largest diameter. Longitudinally ⅛ to ¼ in. of metal shall be allowed at each change of cross section for finish machining.

9.1.6 The smooth-machined body shall be to the specified size with no more than ⅛ in. (3.2 mm) over on the diameters and shall have no more than ⅛ in. allowance longitudinally at each change of cross section.

10. Workmanship and Finish

10.1 Axles shall conform to the size, shape, and finish shown on the purchaser's drawing and unless otherwise specified shall have center holes with clearance drilled for lathe center points and not counterbored. All machining shall be done in a workmanlike manner.

10.2 Where a smooth-machined finish on the body (9.1.6) is specified it shall be to a maximum of 250 µin. (6.35 µm). Rough machining shall be free of excessively rough ridges and coarse chatter marks.

10.3 Finish machined axle surfaces shall be free of injurious imperfections as described in Annex A1.

10.4 The interpretation of injurious imperfections in axles shall comply with Annex A1 to this specification.

11. Inspection

11.1 Inspection of the axles shall be made as agreed upon by the purchaser and seller as part of the purchase contract.

11.2 The inspector representing the purchaser shall have entry, at all times while the work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the axles ordered. The manufacturer shall afford the inspector all reasonable facilities and necessary assistance to satisfy him that the material is being furnished in accordance with their specification. Tests and inspection for acceptance shall be made at the place of manufacture.

11.3 The purchaser may make tests to cover the acceptance or rejection of the axles in his own laboratory or elsewhere.

11.4 The purchaser's representative shall examine each axle for workmanship, imperfections, and conformity to the dimensions given on the order or drawing. If imperfections are found in this inspection that the manufacturer can remedy, he may correct such imperfections.

12. Rejection

12.1 Any axle that fails to meet the requirements of this specification shall be rejected.

12.2 Axles that show injurious imperfections subsequent to their original inspection and acceptance at the manufacturer's works, or elsewhere, shall be rejected and the manufacturer shall be notified.

13. Rehearing

13.1 Samples of axles tested in accordance with this specification that represent rejected material shall be held 14 days from the date of the test report. In case of dissatisfaction with the results of the tests the manufacturer may request a rehearing within that time.

14. Certification

14.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the test results shall be furnished at the time of shipment.

15. Product Marking

15.1 Axles shall be legibly cold-stamped with letters and figures not less than ¼ in. (6.4 mm) high. This stamping shall be on the end face or under cut shoulder at the end of the journal as shown on the purchaser's drawing. It should include month and year made, manufacturer's name or trademark, heat number, and serial number.

15.2 In addition to the above required markings, bar code tags may be applied to the axles. If these tags are applied, it is recommended that Bar Code 39 be used. The size and location of the tags, as well as the information to be included, shall be agreed upon by the purchaser and the manufacturer.

16. Keywords

16.1 axles; rail applications; steel forgings

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirement shall apply only when specified by the purchaser. Details shall be agreed upon by the manufacturer and the purchaser.

S1. Macroscopical Tests

S1.1 The prolongation from the largest axle in each heat shall be sawed normal to the axis of the axle and shall then be split longitudinally. The transverse and the longitudinal face shall be etched for macroscopical examination. Reference shall be made to Method E 381.

ANNEX

(Mandatory Information)

A1. INTERPRETATION OF IMPERFECTIONS CONSIDERED INJURIOUS IN AXLES

A1.1 General

A1.1.1 The conditions that have been most difficult for inspectors to evaluate are light lines visible to the normal unaided eye, variously described as actual seams, hairlines, stringers, shadow seams, ghost lines, etc., which appear after the axles have been finish machined and burnished or ground. It is, therefore, advisable to describe these conditions in more detail.

A1.1.2 The interpretation of injurious imperfections as enumerated below is not to be considered as precluding other unforeseen or objectionable conditions not specifically listed. The right of the purchaser is reserved to reject temporarily such axles and make final settlement on the basis of further negotiations between representatives of the manufacturer and the purchaser who are especially qualified to decide such questions.

A1.1.3 Any transverse or circumferential seams, cracks, or laps of indeterminate depth on the axle surfaces other than the discolorations listed in A1.1.4 regardless of their location, are considered to be injurious and are cause for rejection without further machining.

A1.1.4 Ghost lines, shadow marks, or other similar discolorations, visible to the normal unaided eye that are not actual separations in the metal are not considered injurious regardless of location.

A1.1.5 Any longitudinal discontinuity, variously termed hairline, stringer, or fine seam, in machined fillets is considered to be injurious and is cause for rejection without further conditioning.

A1.2 Journals and Dust Guards

A1.2.1 Fine longitudinal discontinuities on the finished (burnished or ground) surfaces variously termed hairlines, stringers, or fine seams are not considered injurious if they meet the following conditions:

A1.2.1.1 Must not extend into fillets.

A1.2.1.2 Must not be over ¾ in. (19.1 mm) long individually in the journal nor ½ in. (12.7 mm) long individually in the dust-guard seat.

A1.2.1.3 Total length of such imperfections over ¼ in. (6.4 mm) long must not exceed 2 in. (50.8 mm) in any one end of the axle.

A1.3 Wheel Seats, Gear Seats, Gear Case Bearing Seat, and Grounding Ring Seats

A1.3.1 Longitudinal discontinuities on the finished-machined surface of wheel and gear seats, variously termed hairlines, stringers, fine seams, tight seams, surface imperfections, etc., are not considered injurious if they meet the following conditions:

A1.3.1.1 Must not extend within 1½ in. (38.1 mm) of either end of the seats covered in this section.

A1.3.1.2 Must not be over ½ in. (12.7 mm) long individually.

A1.3.1.3 Total length of such imperfections, ¼ in. (6.4 mm) to ½ in. (12.7 mm) long, must not exceed 3 in. (76.2 mm) in any one end of the axle.

A1.4 Areas Between Attachment Seats (Body) Specified to Be Smooth Machined

A1.4.1 Longitudinal discontinuities on the smooth machined body, variously termed hairlines, stringers, or fine seams, are not considered injurious if they meet the following conditions:

A1.4.1.1 Must not extend into fillets at the ends of the body.

A1.4.1.2 Must not be over ½ in. (12.7 mm) long individually.

A1.4.1.3 Total length of such imperfections, ¼ in. (6.4 mm) to ½ in. (12.7 mm) long, must not exceed 1½ in. (38.1 mm) in any 12 in. (305 mm) of body length.

A1.4.1.4 Axles containing longitudinal discontinuities in the body in excess of those described in A1.4.1.2 and A1.4.1.3 may be reconditioned by grinding or machining provided the diameter is not reduced below the specified minimum.

Designation: A 730 – 93 (Reapproved 1999)

Standard Specification for Forgings, Carbon and Alloy Steel, for Railway Use[1]

This standard is issued under the fixed designation A 730; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers eight grades of untreated and heat-treated carbon steel forgings and six grades of heat-treated alloy steel forgings for railway use.

NOTE 1—It is recommended, when semi-finished steel is desired to process these forgings, that the latest issue of ASTM Specification A 711, for Carbon and Alloy Steel Blooms, Billets, and Slabs for Forging,[2] be used. This will enable the forger to select semi-finished material of such chemistry as he desires.

NOTE 2—Railway axles are covered by Specification A 21.

1.2 The grades of carbon steel forgings and the purposes for which they are frequently used are as follows, the choice depending on design and stress or service to be imposed:

1.2.1 *Grade A* is untreated and is mostly used for drop forgings and parts of minor importance, and those which are to be case hardened.

1.2.2 *Grade B* is untreated and is used for a general group of miscellaneous ordinary forgings where heat treatment is not deemed necessary.

1.2.3 *Grade C* is annealed, normalized, or normalized and tempered.

1.2.4 *Grade D* is annealed, normalized, or normalized and tempered.

1.2.5 *Grade E* is normalized and tempered.

1.2.6 *Grade F* is double normalized and tempered.

1.2.7 *Grade G* is quenched and tempered.

1.2.8 *Grade H* is normalized, quenched, and tempered.

1.2.9 *Grades E, F, G,* and *H* forgings are used in high-duty service on locomotives, cars, and other equipment.

1.3 The grades of alloy steel forgings are as follows:

1.3.1 *Grades I, J, and K* are normalized and tempered.

1.3.2 *Grades L, M, and N* are normalized, quenched, and tempered, and are used in heavy-duty service on locomotives, cars, and special equipment.

NOTE 3—The forgings described above were formerly designated as follows:

Current Grade	Former Designation and Grade
A	A 236, A
B	A 236, B
C	A 236, C
D	A 236, D
E	A 236, E
F	A 236, F
G	A 236, G
H	A 236, H
I	A 238, A
J	A 238, B
K	A 238, C
L	A 238, D
M	A 238, E
N	A 238, F

1.4 Supplementary Requirements (Sections S1 to S5) of an optional nature are provided. These shall apply only when specified by the purchaser.

1.5 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 21 Specification for Carbon Steel Axles, Non-Heat-Treated and Heat-Treated, for Railway Use[2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

A 711 Specification for Steel Forging Stock[4]

E 112 Test Methods for Determining the Average Grain Size[5]

E 381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings[5]

3. Ordering Information

3.1 The purchaser shall specify in the inquiry, contract, and order the grade of steel desired, and any restrictive modifications of this specification.

3.2 Supplementary requirements are provided and shall apply only when specified in the purchase order.

4. Manufacture

4.1 *Melting Process*—The steel shall be made by one or more of the following processes: open-hearth, basic-oxygen, or electric-furnace.

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] *Annual Book of ASTM Standards*, Vol 01.04.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards*, Vol 01.05.

[5] *Annual Book of ASTM Standards*, Vol 03.01.

4.2 *Discard*—Sufficient discard shall be made to assure freedom from piping and undue segregation.

4.3 *Forging Practice*—The forgings may be made direct from the ingot or from blooms. The total reduction from ingot or strand cast bloom to forging shall not be less than 3 to 1, unless otherwise specified.

4.4 *Cooling and Heating*:

4.4.1 After carbon steel blooms are produced, they shall be allowed to cool uniformly and shall not be subject to contact with water or drafts.

4.4.2 After alloy steel blooms are produced, they shall be cooled in closed containers, hoods, or furnaces.

4.4.3 Blooms shall be reheated for forging in a manner that will prevent internal bursts and overheating.

4.4.4 Forgings (Grades C through N) shall be slow cooled in closed containers, covered conveyors, or hoods. If forgings (Grades C through N) are heat treated directly from forging, they shall be slow cooled following the final heat treatment.

4.4.5 Forgings (Grades C through N) that are heat treated directly from forging (*1*) shall be cooled below the transformation temperature or to approximately 1000°F (538°C) before any reheating operation, and (*2*) must not be permitted to cool below 500°F (260°C) without slow cooling as defined in 4.4.4.

NOTE 4—As the temperature of the forgings approaches the minimum of 500°F (260°C) a supplemental heat source may be necessary to assure an effective slow cooling cycle.

4.4.6 When properly vacuum degassed steel is used, the slow cooling requirements of 4.4.2, 4.4.4 and item (*2*) of 4.4.5 may be omitted, but forging blooms must then be pile cooled.

4.5 *Boring*:

4.5.1 Boring, if specified under Supplementary Requirement S5, shall be performed before normalizing or quenching in the case of normalized and tempered or quenched and tempered forgings, and before either normalizing or quenching, in the case of normalized, quenched, and tempered forgings.

4.5.2 For quenched and tempered forgings or normalized, quenched and tempered forgings it is recommended, but not mandatory, that all forgings over 7 in. (178 mm) in diameter be bored.

4.5.3 For carbon steel no solid forgings over 10 in. (254 mm) in diameter and no forgings over 8 in. (203 mm) in wall thickness shall be liquid quenched under this specification.

4.5.4 In bored forgings, the diameter of the hole shall be a matter of agreement between the manufacturer and the purchaser.

4.6 *Heat Treatment*:

4.6.1 Forgings for heat treatment shall be reheated gradually and uniformly to the proper temperature to refine the grain and shall be held at this temperature for a sufficient time to effect the desired change.

4.6.2 *Annealing*—After heating to a suitable temperature the forgings shall be allowed to cool slowly and uniformly. A furnace charge thus treated is termed an annealing charge.

4.6.3 *Normalizing*—After heating to a suitable temperature, the forgings shall be withdrawn from the furnace and allowed to cool uniformly in air. A furnace charge thus treated is termed a normalizing charge. Cooling may be accelerated by increased air circulation, which must be controlled to provide reasonably uniform cooling.

4.6.4 *Double Normalizing*—The procedure shall consist of two separate heat treatments. The second treatment shall be performed at a lower temperature than the first. A furnace charge thus treated is termed a double-normalizing charge. Cooling may be accelerated by increased air circulation, which must be controlled to provide reasonably uniform cooling.

4.6.5 *Quenching*—After heating to a suitable temperature, the forgings shall be quenched in a suitable medium under reasonably uniform conditions. A furnace charge thus treated is termed a "quenching charge."

4.6.6 *Tempering*—Forgings shall be reheated gradually to, and held at, a suitable temperature below the critical range and shall then be allowed to cool under suitable conditions. A furnace charge thus treated is termed a "tempering charge."

4.6.7 Heat treatment may be performed in either batch-type furnaces or continuous furnaces.

4.7 *Straightening*:

4.7.1 Straightening of forgings shall be done before machining and in such a manner as to leave the surface free of injurious scars.

4.7.2 Straightening preferably shall be performed at a temperature no lower than 950°F (510°C). Straightening performed at temperatures lower than 950°F shall be followed by stress relieving or applicable heat treatment.

5. Chemical Requirements

5.1 *Composition*:

5.1.1 Carbon steel (Grades A through H) shall conform to the requirements for chemical composition prescribed in Table 1.

5.1.2 Alloy steel (Grades I through N) shall conform to the following requirements for chemical composition:

Phosphorus 0.045 max
Sulfur 0.050 max

TABLE 1 Chemical Requirements for Carbon Steels

Elements	Composition, %				Grades G and H
	Grade A	Grade B	Grades C, D, and E	Grade F	
Carbon	0.15 max	0.15–0.25	0.40–0.55	0.45–0.59	. . .
Manganese	0.30–0.60	0.30–0.60	0.60–0.90	0.60–0.90	0.60–0.90
Phosphorus, max	0.045	0.045	0.045	0.045	0.045
Sulfur, max	0.050	0.050	0.050	0.050	0.050
Silicon, min	. . .	. . .	0.15	0.15	0.15

By agreement between purchaser and manufacturer, analysis may be required and limits established for elements not specified above.

5.2 *Cast or Heat Analysis*:

5.2.1 An analysis of each cast or heat of carbon steel shall be made by the manufacturer to determine the percentages of carbon and the elements prescribed in Table 1. The chemical composition thus determined shall be reported to the purchaser or his representative and shall conform to the requirements prescribed in Table 1.

5.2.2 An analysis of each cast or heat of alloy steel shall be made by the manufacturer to determine the percentage of carbon, manganese, phosphorus, sulfur, and silicon; also the alloying elements agreed upon in accordance with 5.1.2. The chemical composition thus determined shall be reported to the purchaser or his representative and shall conform to the requirements specified and agreed upon in 5.1.2.

5.3 *Product Analysis*:

5.3.1 An analysis may be made by the purchaser from a carbon steel forging representing each heat. The chemical composition thus determined shall conform to the requirements in Table 1, subject to the tolerances shown in Table 2.

5.3.2 An analysis may be made by the purchaser from an alloy steel forging representing each heat. The chemical composition thus determined shall conform to the requirements of 5.1.2 subject to tolerances shown in Table 3.

5.3.3 Samples for analysis may be taken from the forging or from a full-size prolongation, at any point midway between the center and surface when solid, or midway between the inner and outer surfaces of the wall when bored. If drillings are taken, they shall be obtained by using a ⅝ -in. (16-mm) diameter drill, or turnings may be taken from the test specimen.

6. Physical Requirements

6.1 *Tensile Properties*:

6.1.1 Carbon steel forgings (Grades C through H) and alloy steel forgings (Grades I through N) shall conform to the requirements prescribed in Table 4 when tested in accordance with the latest issue of Test Methods A 370.

6.1.2 The size classification of forgings shall be determined by the specified diameter or thickness of solid forgings disregarding large ends or collars or by the specified wall thickness of bored forgings that are heat treated after rough boring.

TABLE 2 Permissible Variations for Product Analysis of Carbon Steels

Elements	Permissible Variations, over the Maximum Limit or Under the Minimum Limit, %	
	100 in.^{2} (645 cm^2) and Under^A	Over 100 to 400 in.^{2} (645 to 2581 cm^2), incl^A
Carbon (Grades A and B)	0.02	0.04
Manganese	0.03	0.05
Phosphorus	0.008	0.010
Sulfur	0.008	0.010
Silicon	0.02	0.02

^{A} Determine by cross section from which drillings are taken.

6.1.3 The diameter of the test prolongation of forgings shall be the specified diameter or thickness of the forgings disregarding large ends or collars.

6.1.4 Tests of forgings shall be made only after final heat treatment.

6.2 *Number of Specimens*:

6.2.1 Test prolongations shall be attached to at least 5 % of the forgings in each size classification in each heat in each heat treatment lot.

6.2.2 Forgings may be used for test procurement if forgings with prolongations are not available or have been expended.

6.2.3 Mechanical tests shall be made from each size classification shown in Table 4 in each heat in each annealing or normalizing charge, or from each size classification in each heat in each normalizing or quenching charge represented in each tempering charge.

6.2.4 Where batch-type heat treating furnaces are used, one test shall be made from each size classification shown in Table 4 of each heat represented in each annealing or normalizing charge, or from each size classification in eachheat in each normalizing or quenching charge represented in each tempering charge.

6.2.5 Where continuous heat-treating furnaces are used, one test shall be made from each grade from each size classification shown in Table 4 represented by each heat. The pieces represented by each test shall be designated a heat treatment lot, and each lot shall contain no more than 70 pieces from each heat.

6.2.6 If any test specimen fails because of mechanical condition of the testing apparatus, it may be discarded and another specimen taken.

6.3 *Test Location and Orientation*:

6.3.1 Test specimens shall be taken from the test prolongation or a forging in accordance with the provisions of 6.2.

6.3.2 The axis of the specimen shall be located at any point midway between the center and surface of the solid forging or full-sized prolongation, or at any point midway between the inner and outer surfaces of the wall of bored forgings, and shall be parallel to the axis of the forging in the direction in which the metal is most drawn out.

6.3.3 Test specimens shall conform to dimensions shown in Fig. 6 of Test Methods A 370.

6.4 *Test Method*:

6.4.1 The yield point specified in Table 4 for Grades C, D, E, F, I, and J may be determined by the drop of the beam or halt of the gage of the testing machine, or by the use of dividers. Where a definite yield point is not exhibited, the yield strength defined in 6.4.2 shall be used.

6.4.2 The yield strength specified in Table 4 for Grades G, H, K, L, M, and N forgings shall be determined by a strain gage or extensometer reading to 0.0002 in. (0.005 mm). Yield strength may be defined as the stress at 0.6 % total strain under load or as the stress at 0.2 % offset. The procedure described in Test Methods A 370 shall be followed. After the yield point has been passed, the extensometer may then be removed and the test continued to determine the tensile strength.

TABLE 3 Permissible Variations for Product Analysis of Alloy Steels

Elements	Limit, or Maximum of Specified Element, %	Variation Over Maximum Limit or Under Minimum Limit, %			
		To 100 in.^{2} (645 cm^2)	Over 100 to 200 in.^{2} (645 to 1290 cm^2), incl	Over 200 to 400 in.^{2} (1290 to 2580 cm^2), incl	Over 400 to 800 in.^{2} (2580 to 5160 cm^2), incl
Carbon	To 0.30, incl	0.01	0.02	0.03	0.01
	Over 0.30 to 0.75, incl	0.02	0.03	0.04	0.05
	Over 0.75	0.03	0.04	0.05	0.06
Manganese	To 0.90, incl	0.03	0.04	0.05	0.06
	Over 0.90 to 2.10, incl	0.04	0.05	0.06	0.07
Phosphorus	Over maximum only	0.005	0.010	0.010	0.010
Sulfur	To 0.060, incl	0.005	0.010	0.010	0.010
Silicon	To 0.35, incl	0.02	0.02	0.03	0.04
	Over 0.35 to 2.20, incl	0.05	0.06	0.06	0.07
Nickel	To 1.00, incl	0.03	0.03	0.03	0.03
	Over 1.00 to 2.00, incl	0.05	0.05	0.05	0.05
	Over 2.00 to 5.30, incl	0.07	0.07	0.07	0.07
	Over 5.30 to 10.00, incl	0.10	0.10	0.10	0.10
Chromium	To 0.90, incl	0.03	0.04	0.04	0.05
	Over 0.90 to 2.10, incl	0.05	0.06	0.06	0.07
	Over 2.10 to 3.99	0.10	0.10	0.12	0.14
Molybdenum	To 0.20, incl	0.01	0.01	0.02	0.03
	Over 0.20 to 0.40, incl	0.02	0.03	0.03	0.04
	Over 0.40 to 1.15, incl	0.03	0.04	0.05	0.06
Tungsten	To 1.00, incl	0.04	0.05	0.05	0.06
	Over 1.00 to 4.00, incl	0.08	0.09	0.10	0.12
Vanadium	To 0.10, incl	0.01	0.01	0.01	0.01
	Over 0.10 to 0.25, incl	0.02	0.02	0.02	0.02
	Over 0.25 to 0.50, incl	0.03	0.03	0.03	0.03
	Minimum value specified, check under minimum limit	0.01	0.01	0.01	0.01

7. Metallurgical Structure

7.1 For Grades D, E, F, G, H, I, J, and K forgings, one microscopy test shall be made from each size classification in each heat represented in each heat treatment lot. The entire specimen shall show a uniform, heat-treated grain size of No. 5 or finer measured in accordance with Test Methods E 112.

7.2 For grades specified in 7.1, a specimen for the microscopical test shall be cut from the large undistorted portion of the tension test specimen in such a way as will give a face transverse to the axis of the forging.

8. Workmanship, Finish, and Appearance

8.1 The forgings shall conform to the sizes and shapes specified by the purchaser. When centered, standard 60-deg centers with clearance drilled for lathe center points shall be used.

8.2 The forgings shall be free of injurious imperfections and shall have a workmanlike finish.

9. Number of Tests and Retests

9.1 If the results of the mechanical tests of any test lot do not conform to the requirements specified because a flaw developed in the test specimen during testing, a retest shall be allowed if the defect is not caused by ruptures, cracks, or flakes in the steel.

10. Reheat Treatment

10.1 If the results of the mechanical tests of any test lot do not conform to the requirements specified, the manufacturer may retreat such lot, but not more than three additional times, and retests shall be made in accordance with Sections 6 and 7, and shall meet the requirements for the grade of forgings involved.

11. Inspection

11.1 Inspection of the material shall be made as agreed upon by the purchaser and manufacturer as part of the purchase contract.

12. Rejection and Rehearing

12.1 *Rejection*:

12.1.1 Any rejection based on tests made in accordance with 5.3 shall be reported to the manufacturer within 5 working days from the receipt of samples by the purchaser.

12.1.2 Material that shows injurious imperfections subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

12.2 *Rehearing*—Samples tested in accordance with this specification that represent rejected material, shall be held for a period of 14 days from the date of notification. In case of

TABLE 4 Tensile Requirements

Grade	Size								Tensile Strength, min		Yield Point or Yield Strength, min		Elongation in 2 in. or 50 mm, min, %	Reduction of Area, min, %
	Solid Diameter or Thickness				Bored Wall Thickness[A]									
	Over		Not Over		Over		Not Over							
	in.	mm	in.	mm	in.	mm	in.	mm	psi	MPa	psi	MPa		
C (Annealed, normalized, or normalized and tempered)[B]	. . .	. . .	8	203	. . .	. . .	. . .	. . .	75 000	515	37 500[C]	260	20	33
	8	203	14	356	. . .	. . .	. . .	. . .	75 000	515	37 500[C]	260	19	31
D (Annealed, normalized, or normalized and tempered)[B]	. . .	. . .	8	203	. . .	. . .	. . .	. . .	80 000	550	40 000[C]	275	22	35
	8	203	14	356	. . .	. . .	. . .	. . .	80 000	550	40 000[C]	275	21	33
E (Normalized and tempered)	. . .	. . .	8	203	. . .	. . .	. . .	. . .	85 000	585	44 000[C]	305	25	40
	8	203	14	356	. . .	. .	. . .	. . .	83 000	570	43 000[C]	295	23	37
F (Double normalized and tempered)	. . .	. . .	8	203	. . .	. . .	4	102	88 000	605	50 000[C]	345	22	37
	8	203	12	305	4	102	6	152	86 000	595	48 000[C]	330	21	35
	12	305	14	356	. . .	. . .	. . .	. . .	84 000	580	46 000[C]	315	20	33
G (Quenched and tempered)	. . .	. . .	4	102	. . .	. . .	2	51	90 000	620	55 000[D]	380	20	39
	4	102	7	178	2	51	3½	89	85 000	585	50 000[D]	345	20	39
	7	178	10	254	3½	89	5	127	85 000	585	50 000[D]	345	19	37
	. . .	. . .	. . .	. . .	5	127	8	203	82 500	565	48 000[D]	330	19	36
H (Normalized, quenched and tempered)	. . .	. . .	7	178	. . .	. . .	. . .	. . .	115 000	795	75 000[D]	515	16	35
	7	178	10	254	. . .	. . .	4	102	105 000	725	65 000[D]	450	18	35
	. . .	. . .	. . .	. . .	4	102	8	203	100 000	690	60 000[D]	415	18	35
I (Normalized and tempered)	. . .	. . .	8	203	. . .	. . .	4	102	80 000	550	55 000[C]	380	28	60
	8	203	20	508	4	102	8	203	80 000	550	55 000[C]	380	28	55
J (Normalized and tempered)	. . .	. . .	5	127	. . .	. . .	2½	64	90 000	620	60 000[C]	415	24	48
	5	127	9	229	2½	64	4½	114	90 000	620	60 000[C]	415	22	44
	9	229	13	330	4½	114	6½	165	90 000	620	58 000[C]	400	21	42
	13	330	20	508	6½	165	8	203	88 000	605	56 000[C]	385	20	40
K (Normalized and tempered)	. . .	. . .	5	127	. . .	. . .	2½	64	95 000	655	72 000[D]	495	23	55
	5	127	9	229	2½	64	4½	114	95 000	655	70 000[D]	485	22	53
	9	229	13	330	4½	114	6½	165	93 000	640	67 000[D]	460	22	50
	13	330	20	508	6½	165	8	203	91 000	625	65 000[D]	450	21	48
L (Normalized, quenched, and tempered)	. . .	. .	7	178	. . .	. . .	3½	89	95 000	655	70 000[D]	485	23	54
	7	178	10	254	3½	89	5	127	90 000	620	65 000[D]	450	20	50
	. . .	. . .	. . .	. . .	5	127	8	203	85 000	585	60 000[D]	415	20	50
M (Normalized, quenched, and tempered)	. . .	. . .	7	178	. . .	. . .	3½	89	105 000	725	80 000[D]	550	20	50
	7	178	10	254	3½	89	5	127	100 000	690	75 000[D]	515	19	50
	. . .	. . .	. . .	. . .	5	127	8	203	95 000	655	70 000[D]	485	19	50
N (Normalized, quenched, and tempered)	. . .	. . .	4	102	. . .	. . .	2	51	125 000	860	105 000[D]	725	16	50
	4	102	7	178	2	51	3½	89	115 000	795	95 000[D]	655	16	45
	7	178	10	254	3½	89	5	127	110 000	760	85 000[D]	585	16	45

[A] Where no figures are shown in the bored wall thickness column, it is understood that the size classification is determined by the outside diameter, whether the forging is bored or not.
[B] Alternative treatments specified are optional with the manufacturer.
[C] Yield point, see 6.4.1.
[D] Yield strength, see 6.4.2.

dissatisfaction with the results of the tests, the manufacturer may request a rehearing within that time.

13. Certification

13.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification, together with a report of the test results, shall be furnished at the time of shipment.

14. Product Marking

14.1 Identification marks shall be legibly stamped on each forging and each test specimen. The purchaser may indicate the location of such identification marks.

14.2 After the material has been inspected, the inspector shall stamp each accepted forging with his private mark.

14.3 In addition to the above required markings, bar code tags may be applied to the forgings. If these tags are applied, it is recommended that Bar Code 39 be used. The size and location of the tags, as well as the information to be included, shall be agreed upon by the purchaser and the manufacturer.

15. Keywords

15.1 alloy steel forgings; carbon steel forgings; rail applications

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order. Details shall be agreed upon by the manufacturer and the purchaser.

S1. Chemical Composition

S1.1 The purchaser may specify on Grades A through H that the residual alloy elements, not intentionally added, shall not exceed 0.25 % nickel, 0.20 % chromium, and 0.06 % molybdenum.

S1.2 The purchaser may specify on Grades I through N that the residual alloy elements, not intentionally added, shall not exceed 0.35 % copper, 0.25 % nickel, 0.20 % chromium, and 0.06 % molybdenum.

S2. Turning

S2.1 The purchaser may specify a preliminary rough machining prior to the heat treating operation.

S3. Macroscopic Tests

S3.1 The prolongation from the largest forging in each heat shall be sawed normal to the axis of the forging and shall then be split longitudinally. The transverse and longitudinal faces shall be etched for macroscopic examination. When macroetch testing of forgings is required, reference shall be made to the latest issue of Method E 381.

S4. Boring

S4.1 Boring, as described in 4.5, may be specified.

S5. Additional Tests

S5.1 Any testing Sections 6 and 7 shall be a matter of agreement between the manufacturer and the purchaser.

S5.2 The purchaser may specify mechanical tests of Grades A and B forgings. If mechanical property tests do not conform to the requirements agreed upon, the manufacturer may anneal or normalize the lot involved, but not more than three times.

Designation: A 739 – 90a (Reapproved 2000)

Standard Specification for Steel Bars, Alloy, Hot-Wrought, for Elevated Temperature or Pressure-Containing Parts, or Both[1]

This standard is issued under the fixed designation A 739; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification[2] covers hot-wrought, ferritic alloy steel bars for elevated temperature or pressure-containing parts suitable for fusion welding or both.

1.2 The bars are furnished in the following grades:

Grade B 11: 1.25 % chromium, 0.55 % molybdenum
Grade B 22: 2.25 % chromium, 1.00 % molybdenum

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[3]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[4]

3. Ordering Information

3.1 Orders for material under this specification should include the following information:

3.1.1 Quantity (weight or number of pieces),

3.1.2 Name of material (ferritic alloy steel bars),

3.1.3 Condition (hot wrought, normalized and tempered, machine straightened and descaled),

3.1.4 Dimensions (cross-sectional shape, size, and length),

3.1.5 ASTM designation and date of issue,

3.1.6 Grade (Table 1),

3.1.7 Additions to the specification, and

3.1.8 End use.

TABLE 1 Chemical Requirements

Element	Composition, %	
	Grade B 11	Grade B 22
Carbon, max	0.05–0.20	0.05–0.15
Manganese	0.40–0.65	0.30–0.60
Phosphorus, max	0.035	0.035
Sulfur, max	0.040	0.040
Silicon	0.50–0.80	0.50 max
Chromium	1.00–1.50	2.00–2.50
Molybdenum	0.45–0.65	0.90–1.10

NOTE 1—A typical description is as follows: 10 000 lb, Ferritic Alloy Steel Bars, Hot Wrought Normalized and Tempered, and Descaled, 1.000-in. diameter by 10 ft, ASTM A 739 dated____, Grade B 11, Special Straightened, Special Machined Fittings.

4. Materials and Manufacture

4.1 *Melting Practice*—The steel shall be made by one or more of the following primary processes: open-hearth, basic-oxygen, or electric-furnace. The primary melting may incorporate separate degassing or refining and may be followed by secondary melting using electroslag remelting or vacuum arc remelting. Where secondary melting is employed, the heat shall be defined as all of the ingots remelted from a single primary heat.

4.2 *Condition*—Unless otherwise specified, bars shall be hot wrought, heat treated, and descaled.

4.3 *Heat Treatment*:

4.3.1 The bars shall be normalized and tempered.

4.3.2 Austenitizing temperature shall be within the range from 1700 to 1800°F (927 to 982°C).

4.3.3 Cooling from the austenitizing temperature may be accomplished by cooling in still air or moving air, at the producer's option. When permitted by the purchaser, cooling from the austenitizing temperature may be accelerated by spray or liquid quenching.

4.3.4 The minimum tempering temperature shall be 1200°F (649°C) for Grade B 11 and 1250°F (677°C) for Grade B 22.

5. Chemical Composition

5.1 The heat analysis shall conform to the limits for chemical composition specified in Table 1 for the grade ordered.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

Current edition approved Aug. 31, 1990. Published October 1990. Originally published as A 739–76. Last previous edition A 739–90.

[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-739 in Section II of that code.

[3] *Annual Book of ASTM Standards*, Vol 01.05.

[4] *Annual Book of ASTM Standards*, Vol 01.03.

6. Mechanical Properties

6.1 *Tensile Requirements*—The bars as represented by the test specimens shall conform to the tensile requirements specified in Table 2.

6.2 *Specimens*—Tension test specimens shall be taken longitudinally and machined from the locations specified in Test Methods and Definitions A 370.

6.3 *Number of Tests*:

6.3.1 Two tension tests shall be made to represent bars of the same size from each heat in each heat treatment charge. For continuous heat-treated material, not fewer than two tension tests shall represent a lot selected on the basis of one tension test from each 10 000 lb (4500 kg).

6.3.2 When heat treated without interruption in continuous furnaces, the material in a lot shall be from the same heat, same prior condition, same size, and subjected to the same heat treatments.

6.4 *Test Methods*—Tension tests shall be made in accordance with Test Methods and Definitions A 370. The yield strength shall be determined by the 0.2 % offset method.

7. Workmanship, Finish, and Appearance

7.1 *Workmanship*—The bars shall be free of pipe, cracks, and flakes. Within the limits of good manufacturing and inspection practices the bars shall be free of injurious seams, laps, segregation, or other imperfections which, due to their nature, degree or extent, will interfere with the use of the material in machining or fabrication.

7.2 *Descaling*—Unless otherwise specified, the bars shall be descaled.

TABLE 2 Tensile Requirements

	Grade B 11	Grade B 22
Tensile strength, ksi (MPa)	70.0–95.0 (483–655)	75.0–95.0 (517–655)
Yield strength, min, ksi (MPa)	45.0 (310)	45.0 (310)
Elongation in 2 in. or 50 mm, min, %	18	18
Reduction of area, min, %	45	45

8. General Requirements

8.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 29/A 29M.

9. Certification and Test Reports

9.1 A manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the analysis and tension test results shall be furnished at the time of shipment. The report shall include the name of the manufacturer, ASTM designation number and year date and revision letter, if any, grade, heat number, and size.

10. Product Marking

10.1 The bars shall be marked in accordance with Specification A 29/A 29M except as modified or supplemented by 10.2 through 10.4 of this specification.

10.2 When specified by the purchaser, the heat number shall be permanently stamped on one end of each bar 2.50 in. and larger in nominal diameter (or equivalent cross-sectional area).

10.3 The bars shall neither be hot nor cold stamped on the sides unless approved by the purchaser on the purchase order.

10.4 Each lift, regardless of size, shall be tagged with the information required by Specification A 29/A 29M.

11. Keywords

11.1 alloy steel bars; high-temperature applications; hot-wrought steel bars; pressure-containing parts; steel bars; temperature service application—high

Designation: A 745/A 745M – 94 (Reapproved 2003)

Standard Practice for Ultrasonic Examination of Austenitic Steel Forgings[1]

This standard is issued under the fixed designation A 745/A 745M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice[2] covers the standards and procedures for the contact, pulse-echo ultrasonic examination of austenitic steel forgings by the straight or angle beam techniques, or both.

1.2 This practice shall be used whenever the inquiry, proposal, contract, order, or specification states that austenitic steel forgings are to be subject to ultrasonic examination in accordance with Practice A 745/A 745M. Ultrasonic examination of nonmagnetic retaining ring forgings should be made to Practice A 531, not to this practice.

1.3 The values stated in either inch-pound or SI units are to be regarded as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the practice.

1.4 This practice and the applicable material specifications are expressed in both inch-pound units and SI units. However, unless the order specifies the applicable "M" specification designation [SI units], the material shall be furnished to inch-pound units.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [3]

A 531/A531M Practice for Ultrasonic Inspection of Turbine-Generator Steel Retaining Rings

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Examination Instruments and Systems Without the Use of Electronic Measurement Instruments

E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Examination

2.2 *American Society for Nondestructive Testing Document:*

SNT-TC-1A Recommended Practice for Nondestructive Personnel Qualification and Certification[4]

3. Ordering Information

3.1 When this practice is to be applied to an inquiry or purchase order, the purchaser shall furnish the following information:

3.1.1 Quality level of examination (see Section 12).

3.1.2 Additional requirements to this practice.

3.1.3 Applicability of supplementary requirements (see Supplementary Requirements section).

3.2 When specified, the manufacturer shall submit an examination procedure for purchaser approval that shall include, but not be limited to, a sketch of the configuration as presented for ultrasonic examination showing the surfaces to be scanned, scanning directions, notch locations and sizes (if applicable), extent of coverage (if applicable), and an instruction listing calibration and inspection details and stage of manufacture.

4. Apparatus

4.1 An electronic, pulsed, reflection type of instrument shall be used for this examination. The system shall have a minimum capability for operating at frequencies from 0.5 to 5.0 MHz. Either video or r-f presentation is acceptable.

4.2 The ultrasonic instrument shall provide linear presentation (within ± 5 % of the signal height) for at least 75 % of the screen height (sweep line to top of screen). This 5 % linearity

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[1] This practice is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys, and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-745/SA-745M in Section II of that Code.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, OH 43228–0518.

is descriptive of the screen presentation of amplitude. Instrument linearity shall be verified in accordance with the intent of Practice E 317.

4.3 Instruments with incremental gain control (accurate over its useful range to ± 10 % of the nominal attenuation ratio) shall be used when possible to allow measurement of signals beyond the linear display range of the instrument.

4.4 *Search Units*:

4.4.1 Search units having transducers of either quartz or other piezoelectric materials may be employed.

4.4.2 The maximum nominal active area of 1½ in.^{2} [970 mm^2] with ½-in. [13 mm] minimum to 1⅛-in. [30 mm] maximum dimensions or ¾-in. [20 mm] diameter minimum dimension shall be used for straight-beam scanning.

4.4.3 Angle-beam scanning transducers shall have a nominal active area of ½ to 1 in.^{2} [325 to 650 mm^2]. The search unit used for angle-beam examination shall produce a beam angle of 30 to 70° in the material.

4.4.4 Other search units, including frequencies other than those listed in Section 8 , may be used for evaluating and pinpointing indications of discontinuities.

4.5 *Couplant*—A suitable couplant having good wetting characteristics shall be used between the transducer and the examination surface. The same couplant shall be used for calibration and examination.

4.6 *Reference Blocks*:

4.6.1 All ultrasonic standard reference blocks shall be in accordance with the general guidelines of Practice E 428. However, absolute conformance to Practice E 428 is not mandatory due to the nature of the material covered by this practice.

4.6.2 The reference block grain size, as measured by the relative acoustic penetrability of the reference blocks, should be reasonably similar to the forging under examination. However, it must be recognized that large austenitic forgings vary considerably in acoustic penetrability throughout their volume due to variations in grain size and structure. Reference blocks should be chosen that reasonably approximate the average penetrability of the forging under examination. Supplementary blocks of coarser or finer grain may be used for evaluation of indications as covered in Section 11.

4.6.3 As an alternative method, where practicable, the appropriate size of reference hole (or holes) or notches may be placed in representative areas of the forging for calibration and examination purposes when removed by subsequent machining. When holes or notches are not removed by subsequent machining, the purchaser must approve the location of holes or notches.

5. Personnel Requirements

5.1 Personnel performing the ultrasonic examinations to this practice shall be qualified and certified in accordance with a written procedure conforming to Recommended Practice No. SNT-TC-1A or another national standard that is acceptable to both the purchaser and the supplier.

6. Forging Conditions

6.1 Forgings shall be ultrasonically examined after heat treating.

6.2 The surfaces of the forging to be examined shall be free of extraneous material such as loose scale, paint, dirt, etc.

6.3 The surface roughness of scanning surfaces shall not exceed 250 µin. [6 µm] unless otherwise stated in the order or contract.

6.4 The forgings shall be machined to a simple configuration, that is, rectangular or parallel or concentric surfaces where complete volumetric coverage can be obtained.

6.5 In certain cases, such as with contour forged parts, it may be impractical to assure 100 % volumetric coverage. Such forgings shall be examined to the maximum extent possible. A procedure indicating the extent of examination coverage shall be submitted for the purchaser's approval (see 3.2).

7. Procedure

7.1 Perform the ultrasonic examination after heat treatment when the forging is machined to the ultrasonic configuration but prior to drilling holes, cutting keyways, tapers, grooves, or machining sections to final contour.

7.2 To ensure complete coverage of the forging volume when scanning, index the search unit with at least 15 % overlap with each pass.

7.3 The scanning rate shall not exceed 6 in. [150 mm]/s.

7.4 Scan all regions of the forging in at least two perpendicular directions to the maximum extent possible.

7.5 Scan disk and disk-type forgings using a straight beam from at least one flat face and radially from the circumference when practicable. For the purposes of this practice, a disk is a cylindrical shape where the diameter dimension exceeds the height dimension. Disk-type forgings made as upset-forged "pancakes" shall be classified as disks for inspection purposes although at the time of inspection, the part may have a center hole, counterturned steps, or other detail configuration.

7.6 Scan cylindrical sections, ring and hollow forgings from the entire external surface (sides or circumference), using the straight-beam technique, and scan the forging in the axial direction to the extent possible. When the length divided by the diameter ratio (slenderness ratio) exceeds 6 to 1 (or axial length exceeds 24 in. [600 mm]), scan axially from both end surfaces to the extent possible. If axial penetration is not possible due to attenuation, angle-beam examination directed axially may be substituted in place of axial straight beam. Examine ring and hollow forgings having an outside-diameter to inside-diameter ratio of less than 2 to 1 and a wall thickness less than 8 in. [200 mm] by angle-beam techniques from the outside diameter or inside diameter, or both, using full node or half-node technique (see 10.1.2 and 10.1.3) as necessary to achieve either 100 % volumetric coverage or the extent of coverage defined by an approved procedure (see 3.2).

8. Examination Frequency

8.1 Perform all ultrasonic examination at the highest frequency practicable (as specified in 8.1.1, 8.1.2, or 8.1.3) that will adequately penetrate the forging thickness and resolve the applicable reference standard. Include in the ultrasonic examination report the examination frequency used. Determine the test frequency at the time of actual examination by the following guidelines:

8.1.1 The nominal test frequency shall be 2.25 MHz. Use of this frequency will generally be restricted due to attenuation.

8.1.2 One megahertz is acceptable and will be the frequency generally applicable.

8.1.3 When necessary, due to attenuation, 0.5-MHz examination frequency may be used. The purchaser may request notification before this lower frequency is employed.

8.1.4 In the event that adequate penetration of certain regions is not possible even at 0.5 MHz, alternative nondestructive examination methods (such as radiography) may be employed to ensure the soundness of the forging by agreement between the purchaser and the manufacturer.

9. Straight-Beam Examination

9.1 *Method of Calibration*:

9.1.1 Perform calibration for straight-beam examination on the flat-bottom hole size determined by the applicable quality level (see Section 12).

9.1.2 Determine the calibration method by the test metal distance involved.

9.1.2.1 Thicknesses up to 6 in. [150 mm] may be examined using either the single-block or the distance-amplitude curve calibration method.

(a) *(a) Single-Block Method*—Establish the test sensitivity on the reference standard representing the forging thickness. Drill flat-bottom holes normal to the examining surface, to midsection in material up to 1.5 in. [40 mm] in thickness and at least 0.75 in. [20 mm] in depth but no deeper than midsection in thicknesses from 1.5 to 6 in. [40 to 150 mm]. Make evaluations of indications at the estimated discontinuity depth at which they are observed using supplementary reference standards, if necessary.

(b) *(b) Distance-Amplitude-Curve Correction Method*—Establish the test sensitivity on the reference standard whose metal travel distance represents the greater metal travel distance of the part under examination, within ±1 in. [25 mm].

9.1.2.2 Examine thicknesses from 6 to 24 in. [150 to 600 mm] using the distance-amplitude calibration method. Calibration to ½ thickness test metal distance may be used provided examinations from two opposing surfaces are made.

9.1.2.3 For metal travel distances over 24 in. [600 mm], perform one of the following examinations:

(a) *(a)* Perform a back-reflection examination from at least one surface to QL-5 (see 12.1.1) or to a purchaser-approved procedure (see 3.2).

(b) *(b)* On hollow-round forgings with wall thicknesses less than 8 in. [200 mm], perform an axial angle-beam scan in place of the straight-beam scan from the end surfaces. Calibration for this scan may be established on the existing axial notches required for the circumferential scan or on transverse oriented notches installed specifically for axial angle beam.

9.2 *Calibration Procedure*—Over an indication-free area of the forging and with the proper test frequency, adjust the amplitude of the back reflection to the maximum limit of vertical linearity of the instrument. The adjusted instrument sensitivity display shall be the primary calibration reference for both the single-block and multiple-block calibration methods. If, at this gain setting, the amplitude response from the flat-bottom hole in the longest calibration block is not equal to or greater than 0.5 in. [13 mm] sweep-to-peak, adjust the instrument gain further to obtain a 0.5-in. [13 mm] sweep-to-peak minimum response. To complete the distance-amplitude correction curve, determine the remaining points defining the shape of the curve at this adjusted gain setting and mark the curve on the shield of the cathode ray tube or plot on a graph. At least three blocks shall be used with test metal distances of 3 in. [75 mm] ½ *T*, and *T*. However, the distance between any of the test blocks shall be 1½ in. [40 mm] minimum. If indications closer than 3 in. [75 mm] from the initial pulse must be evaluated, an additional block with 1½ in. [40 mm] test metal distance shall be used. This is the fixed reference against which all indications shall be evaluated at the maximum obtainable response at whatever depth the indications are observed. This will constitute an acceptable examination if there are no indications exceeding the acceptance limits. In large forgings, it is expected that a portion of the distance-amplitude curve will be above the vertical linearity limits of the instrument. If an indication appears in this area, readjust the instrument through the use of a calibrated gain control or through recalibration to the initial calibration level to bring the appropriate portion of the presentation on screen for evaluation of that specific area.

NOTE 1—When flat surfaced reference block calibration is used for examination of forgings with surface curvature, compensation for curvature shall be made and the method for curvature correction shall be a matter of agreement between the producer and the purchaser. For diameters 80 in. [2000 mm] and over, no correction factor is required.

10. Angle-Beam Examination

10.1 Ring and hollow round forgings, as defined in 7.6, shall be angle-beam examined from their outer periphery in both circumferential directions employing the following method of calibration:

10.1.1 Notches of 1.25 in. [30 mm] maximum surface length, with the length perpendicular to sound propagation; depth based on quality level (Section12), either rectangular with a width not greater than twice its depth or 60° minimum to 75° maximum included angle, located in the forging so as to produce no interference with each other, shall be used as calibration standards.

10.1.2 Determine the response from the inside and outside diameter calibration notches with the search unit positioned to produce the maximum response from each notch. Adjust the sensitivity of the ultrasonic equipment so that the indication from the notch at the greatest test metal distance is at least 0.5 in. [13 mm] sweep-to-peak. Draw a straight line connecting the peaks of the responses obtained from the inside and outside diameter notches. This shall be the primary reference line. This procedure is considered full node calibration.

10.1.3 In the event that a response of at least 0.5 in. [13 mm] sweep-to-peak cannot be obtained from both the inside and outside diameter notches, calibrate from both the outer periphery (the outside diameter surface) and the inside diameter surface. Adjust the sensitivity of the ultrasonic equipment so that the indication from the notch in the opposite surface is at least 0.5 in. [13 mm] sweep-to-peak in magnitude. This procedure is considered half-node calibration. Axial angle beam may be substituted for straight beam from the end surfaces, when specified.

NOTE 2—Long cylinders or cylinders with small inside diameters are difficult to examine from the inside diameter surface. Normally, neither inside diameters smaller than 18 in. [450 mm] nor long cylinders exceeding 36 in. [900 mm] in length are scanned from the inside diameter surface.

11. Evaluation of Material

11.1 Coarse-grained austenitic materials frequently display sweep noise, particularly when an examination is performed at high sensitivities. For this reason, it is important to critically scrutinize reportable and rejectable indications to determine whether they result from defects or grain structure. It is desirable to have several sets of calibration blocks with varying degrees of grain coarseness so that the attenuation of the defective area can be reasonably matched with a test block for a more accurate minimum defect size estimation. Due to the normal wide variation in attenuation throughout a given large austenitic forging, it is permissible to evaluate rejectable indications on the basis of alternative calibration blocks that compare more reasonably in attenuation to the defect area. It is also permissible to insert reference holes into representative areas of the forging itself, with the approval of the purchaser, to be used for calibration and evaluation of indications. Loss of back reflection results not only from internal discontinuities but also from coarse or nonuniform grain structures, variations in coupling, nonparallel reflecting surfaces, and other factors that must be considered before concluding that loss of back reflection resulted from discontinuities.

12. Quality Levels for Acceptance

12.1 One of the following quality levels may be specified by the purchaser:

12.1.1 *Straight Beam*:

12.1.1.1 Material producing an indication response whose maximized amplitude equals or exceeds 100 % of the primary reference or distance-amplitude correction curve at the estimated discontinuity depth shall be considered unacceptable.

(a) *(a) QL-1*—A distance-amplitude curve shall be based upon the amplitude response from No. 8 flat-bottom hole (8⁄64 in. [3 mm]).

(b) *(b) QL-2*—A distance-amplitude curve shall be based upon the amplitude response from No. 16 flat-bottom hole 16⁄64 in. [6 mm]).

(c) *(c) QL-3*—A distance-amplitude curve shall be based upon the amplitude response from No. 24 flat-bottom hole 24⁄64 in. [10 mm]).

(d) *(d) QL-4*—A distance-amplitude curve shall be based upon the amplitude response from No. 32 flat-bottom hole 32⁄64 in. [13 mm]).

(e) *(e) QL-5*—A back reflection examination shall be performed guaranteeing freedom from complete loss of back reflection accompanied by an indication of a discontinuity. For this purpose, a back reflection of less than 5 % of full screen height shall be considered complete loss of back reflection.

12.1.1.2 The applicable quality level will necessarily vary with test metal distance, purchasers' requirements, and the type and size of forging involved. Large disks, rings, or solid forgings and complex forgings present extraordinary problems and quality level application shall be a matter of agreement between the manufacturer and the purchaser. For general guidance purposes, the following list of test metal distances versus quality level attainable is provided for general information.

(a) *(a) QL-1*—Generally practical for thicknesses up to 3 in. [75 mm].

(b) *(b) QL-2*—Generally practical for thicknesses up to 8 in. [200 mm].

(c) *(c) QL-3*—Generally practical for thicknesses up to 12 in. [300 mm].

(d) *(d) QL-4*—Generally practical for thicknesses up to 24 in. [600 mm].

(e) *(e) QL-5*—Frequently practical for thicknesses over 24 in. [600 mm].

12.1.2 *Angle Beam*—Material producing indications with amplitudes equal to or exceeding the primary reference-acceptance line (full node calibration; see 10.1.2) at the estimated discontinuity depth observed shall be considered unacceptable. When examining with only one calibration notch (half node calibration; see 10.1.3), material containing indications of discontinuities equal to or exceeding the notch indication amplitude shall be considered unacceptable.

12.1.2.1 *QA-1* Angle beam reference acceptance shall be based on a notch depth of 3 % of the thickness of the forging at the time of examination.

12.1.2.2 *QA-2* Angle beam reference acceptance line shall be based on a notch depth of the lesser of 5 % of the thickness of the forging at the time of inspection, or ¾ in. [19.05 mm].

13. Reportable Indications

13.1 A record that shows the location and orientation of all indications or groups of indications with amplitudes as defined below shall be submitted to the purchaser for information.

13.1.1 Indications accompanied by a loss of back reflection of 75 % of screen height. Similar loss in back reflection without indications shall be scanned at lower frequencies; if unsuccessful, the area shall be reported as "not inspected."

13.1.2 Indications distinct from the normal noise level and traveling to the left or right on the cathode ray tube with movement of the transducer 1.0 in. [25 mm] or more over the surface of the forging.

13.1.3 Indications equal to or exceeding 50 % of the applicable reference acceptance curve (both straight and angle beam).

14. Keywords

14.1 acceptance criteria; austenitic forgings; contact method; ultrasonic examination

SUPPLEMENTARY REQUIREMENTS

Supplementary requirements shall apply only when specified by the purchaser in the inquiry or order. Details of these supplementary requirements shall be agreed upon between the manufacturer and the purchaser.

S1. Angle Beam Calibration Based on Final Thickness

S1.1 The depth of the calibration notch (see 12.1.2) shall be based upon the final ordered thickness of the forging rather than the thickness at the time of inspection.

Designation: A 756 – 94 (Reapproved 2001)

Standard Specification for Stainless Anti-Friction Bearing Steel[1]

This standard is issued under the fixed designation A 756; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers the requirements for chromium-carbon bearing quality stainless steel to be used in the manufacture of anti-friction bearings.

1.2 Supplementary Requirements of an optional nature are provided and when desired shall be so stated in the order.

1.3 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 484/A 484M Specification for General Requirements for Stainless Steel Bars, Billets, and Forgings[2]

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products[2]

E 45 Test Methods for Determining the Inclusion Content of Steel[3]

E 381 Test Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings [3]

E 1019 Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel and in Iron, Nickel, and Cobalt Alloys[4]

E 1077 Test Method for Estimating the Depth of Decarburization of Steel Specimens[3]

2.2 *Other Standard:*

SAE J418a Grain Size Determination of Steel[5]

3. Ordering Information

3.1 Orders for material under specification should include the following information:

3.1.1 Quantity,

3.1.2 Grade identification,

3.1.3 Specification designation and year of issue,

3.1.4 Dimensions, shape, and

3.1.5 Supplementary Requirements, if desired.

4. Process

4.1 The steel shall be made by a process that is capable of providing a high-quality product meeting the requirements of this specification.

5. Chemical Composition

5.1 Typical examples of chemical compositions are shown in Table 1. Other compositions may be specified.

5.2 An analysis of each heat of steel shall be made by the steel manufacturer in accordance with Test Methods A 751. The chemical composition thus determined shall conform to the requirements specified in Table 1 for the ordered grade or to requirements agreed upon between the manufacturer and the purchaser.

5.3 Product analysis may be made by the purchaser in accordance with Test Methods A 751. Permissible variations in product analysis shall be made in accordance with Specification A 484/A 484M.

6. Dimensions, Mass, and Permissible Variations

6.1 The size and shape of the material shall be agreed upon between manufacturer and purchaser.

6.2 Dimensional tolerances for hot-rolled or hot-rolled and annealed bars, in straight lengths or coils, and cold-finished bars 0.500 in. (12.7 mm) and larger in diameter furnished under this specification shall conform to the requirements specified in the latest edition of Specification A 484/A 484M.

6.3 Dimensional tolerances for cold-finished coils for ball and roller material shall be as shown in Table 2.

6.4 Coil tolerances also apply to cold-finished straight lengths under 0.500 in. (12.7 mm) in diameter.

7. Quality Tests

7.1 The supplier shall be held responsible for the quality of the material furnished and shall make the necessary tests to ensure this quality. The supplier shall be required to report on the results of the macroetch and microinclusion rating tests detailed below. Quality tests shown in 7.2 through 7.4 are based upon procedures established in Test Methods E 45.

7.2 *Sampling*—Samples taken in accordance with the following paragraphs shall be obtained from 4 by 4-in. (102 by 102-mm) rolled billets or forged sections. Tests may be made

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.28 on Bearing Steels.

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[2] *Annual Book of ASTM Standards*, Vol 01.03.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] *Annual Book of ASTM Standards*, Vol 03.05.

[5] Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

TABLE 1 Chemical Composition

Element	440C	440C MOD
Carbon	0.95 to 1.10	1.00 to 1.10
Manganese, max	1.00	0.30 to 1.00
Phosphorus, max	0.025	0.025
Sulfur, max	0.025	0.025
Silicon, max	1.00	0.20 to 1.00
Chromium	16.00 to 18.00	13.00 to 15.00
Nickel, max	0.75	0.75
Copper, max	0.50	0.50
Molybdenum	0.40 to 0.65	3.75 to 4.25

TABLE 2 Dimensional Tolerances for Cold-Finished Coils

Size, in. (mm)	Total Tolerance, in. (mm)
Through 0.096 (2.44)	0.002 (0.05)
Over 0.096 to 0.270 (2.44 to 6.86), incl	0.003 (0.08)
Over 0.270 to 0.750 (6.86 to 19.1), incl	0.004 (0.10)

on smaller or larger sections by agreement with the purchaser. A minimum 3 to 1 reduction of rolled billets or forged sections is required for strand cast products.

7.2.1 For top poured products, a minimum of six samples representing the top and bottom of first, middle, and last usable ingots shall be examined.

7.2.2 For bottom poured products, a minimum of six samples shall be examined and they shall represent the top and bottom of three ingots. One ingot shall be taken at random from the first usable plate poured, one ingot, at random, from the usable plate poured nearest to the middle of the heat, and one ingot, at random, from the last usable plate poured. When two usable plates constitute a heat, two of the sample ingots shall be selected from the second usable plate poured. Where a single usable plate constitutes a heat, any three random ingots may be selected. Other methods of sampling shall be as agreed upon between the manufacturer and the purchaser.

7.2.3 For strand cast products, a minimum of six samples representing the first, middle, and last portion of the heat cast shall be examined. At least one sample shall be taken from each strand.

7.3 *Macroetch*—Specimens representative of cross sections of billets shall be macroetched and rated in accordance with Test Method E 381 acid and water (1:1) at 160 to 180°F (71 to 82°C). Such specimens shall not exceed S 2, R 2, and C 2 of Test Method E 381.

7.4 *Inclusion Rating*—The specimens shall be ⅜ by ¾ in. (9.5 by 19.1 mm) and shall be taken from an area halfway between the center and outside of the billet. The polished face shall be longitudinal to the direction of rolling. The scale used for rating the specimens shall be the Jernkontoret chart described in Method A of Test Methods E 45, Plate III. Plate I is to be used for inclusion exceeding a rating of 2½ . Fields with sizes or numbers of all types of inclusions intermediate between configurations shown on the chart shall be classified as the lesser of the rating number. The worst field of each inclusion type from each specimen shall be recorded as the rating for the specimen. Two thirds of all specimens and at least one from each ingot tested, as well as the average of all specimens, shall not exceed the rating specified in Table 3.

TABLE 3 Inclusion Rating

	Rating Units	
Type	Thin Series	Heavy Series
A	2.0	1.5
B	2.5	1.5
C	2.0	1.5
D	2.0	1.0

8. Response to Heat Treatment

8.1 Specimens with sections ⅜ in. (9.5 mm) in thickness, cut from a bar, billet, or forging, shall be placed in a furnace that is at 1875 ± 10°F (1023.8 ± 5.5°C), allowed to heat to 1875 ± 10°F, held at heat 25 min, and cooled in still air. Hardness of such specimens shall be not lower than 58 HRC.

8.2 Samples heat treated as in 8.1 shall show a fracture grain size of No. 6 or finer. (See SAE J418a.)

9. Decarburization and Surface Imperfections

9.1 Decarburization and surface imperfections shall not exceed the limits specified in Table 4 and Table 5. Decarburization shall be measured using the microscopical methods described in Test Method E 1077.

10. Microstructure and Hardness

10.1 The material shall be free of excessive carbide segregation.

10.2 When annealing is specified in the order, the steel shall have a completely spheroidized microstructure and a hardness as specified in Table 6.

10.3 Small sizes where Rockwell B scale hardness readings are impractical shall show a maximum tensile strength of 115 000 psi (792 mPa).

11. Inspection

11.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Mill inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All

TABLE 4 Decarburization and Surface Imperfections for Coils and Bars for Balls and Rollers

	Decarburization or Surface Imperfections per Side, max, in. (mm)	
Size, in. (mm)	Hot-Rolled or Hot-Rolled Annealed	Cold-Finished Annealed
Through 0.250 (6.35)	0.005 (0.13)	0.003 (0.08)
Over 0.250 (6.35) to 0.500 (12.7), incl	0.006 (0.15)	0.004 (0.10)
Over 0.500 (12.7) to 0.750 (19.1), incl	0.008 (0.20)	0.006 (0.15)
Over 0.750 (19.1) to 1.000 (25.4), incl	0.010 (0.25)	0.008 (0.20)

TABLE 5 Decarburization and Surface Imperfections for Bars and Tubes

Size, in. (mm)	Decarburization or Surface Imperfections per Side, max, in. (mm)				
		Hot-Rolled Annealed		Cold-Finished Annealed	
	Hot-Rolled Bars	Bars	Tubes	Bars	Tubes
Through 1.000 (25.4)	0.012 (0.31)	0.015 (0.38)	0.012 (0.31)	0.012 (0.31)	0.010 (0.21)
Over 1.000 (25.4) to 2.000 (50.8), incl	0.017 (0.43)	0.022 (0.56)	0.020 (0.51)	0.015 (0.38)	0.014 (0.36)
Over 2.000 (50.8) to 3.000 (76.2), incl	0.025 (0.64)	0.030 (0.76)	0.030 (0.76)	0.025 (0.64)	0.019 (0.48)
Over 3.000 (76.2) to 4.000 (101.6), incl	0.035 (0.89)	0.045 (1.14)	0.035 (0.89)		0.024 (0.61)
Over 4.000 (101.6) to 5.000 (127.0), incl	0.055 (1.40)	0.065 (1.65)	0.040 (1.02)		0.028 (0.71)

TABLE 6 Maximum Hardness for Annealed Material

Product	Condition	Maximum Hardness	
		Brinell	Rockwell
Coils	hot-rolled-annealed	. . .	25 HRC
Bars and tubes	hot-rolled-annealed	255 HB	. . .
Coils, bars, and tubes	cold-drawn-annealed	255 HB	100 HRB
Coils, bars, and tubes	annealed-cold-drawn	as agreed upon between the purchaser and the manufacturer	

tests and inspections shall be made at the place of manufacture, unless otherwise agreed to.

12. Certification and Reports

12.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification, together with a report of the test results, shall be furnished at the time of the shipment.

SUPPLEMENTARY REQUIREMENTS

One or more of the Supplementary Requirements described below apply when included in the purchaser's order or contract. When so included, a Supplementary Requirement shall have the same force as if it were in the body of the specification. Supplementary Requirements' details not fully described shall be agreed upon between the purchaser and the supplier, but shall not negate any of the requirements in the body of the specification.

S1. Residual Elements

S1.1 The purchaser may specify that the analysis of titanium, aluminum, and/or oxygen (Test Methods E 1019) be provided by agreement with the steel manufacturer. The number and location of samples shall be by agreement between the purchaser and manufacturer.

S2. Calcium Additions

S2.1 Intentional additions of calcium or calcium alloys for deoxidation or inclusion shape control are not permitted unless specifically approved by the purchaser. The use oflime or fluorspar, or both, in the steelmaking slag is acceptable.

S3. Magnetic Particle Method

S3.1 The purchaser may specify that the magnetic particle method described be used in addition to the microinclusion rating system described in 7.4. The magnetic particle method measures bearing steel cleanliness by evaluating the total length of macroinclusions for a stated area or per unit area. Results are commonly expressed in millimetres per square metre.

S3.2 *Sampling*—See 7.2.

S3.3 Test specimens shall be straight cylinder quarter section samples prepared and examined in accordance with the magnetic particle method of Test Methods E 45.

S3.4 For purposes of calculation, an inclusion length shall be taken as the mean length of the length bracket into which it falls; that is, an inclusion in the $\frac{1}{16}$ to $\frac{1}{8}$ -in. bracket shall be taken as being $\frac{3}{32}$ in. in length. The sum of all lengths for each specimen shall be determined and expressed as total length per area inspected. The average total length per area inspected of all six specimens shall not exceed 200 mm /m^2 (or equivalent).

S4. Sample Reduction Ratio

S4.1 For the sampling described in 7.2, the purchaser may specify that he reduction ratio from as-cast section to test section be provided.

Designation: A 765/A 765M – 01

Standard Specification for Carbon Steel and Low-Alloy Steel Pressure-Vessel-Component Forgings with Mandatory Toughness Requirements[1]

This standard is issued under the fixed designation A 765/A 765M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification[2] covers heat-treated carbon steel and alloy steel forgings with mandatory toughness requirements. These forgings are intended for pressure vessels, feedwater heaters, and similar uses.

1.2 These forgings include tube sheets, covers, channel barrels, integral forged channels, rings, nozzles, flanges, and similar parts.

1.3 All grades are considered weldable under proper conditions.

1.4 The maximum thickness of forgings produced to this specification is limited only by the capacity of the selected grade to respond to any heat treatment specified and to meet the specified mechanical tests, including impact tests at the specified temperature.

1.5 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

1.6 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

1.7 The values stated in either inch-pound units or SI [metric] units are to be regarded separately as the standard; within the text and tables, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.8 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings[3]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[4]

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings[3]

A 788 Specification for Steel Forgings, General Requirements[3]

E 112 Test Methods for Determining the Average Grain Size[5]

E 165 Test Method for Liquid Penetrant Examination[6]

2.2 *ASME Standards:*

Boiler and Pressure Vessel Code[7]

3. Ordering Information

3.1 In addition to the ordering information requirements of Specification A 788, a detailed sketch or written description of the forging and the method of selecting the test location (see 6.2) should be supplied to the producer, when appropriate areas of significant in-service loading of the forging need to be designated.

3.2 The required impact test temperature should be supplied if different than the temperature listed in Table 3, otherwise the impact test shall be conducted at the temperature listed in Table 3 for the chosen Grade.

3.3 If a hubbed tube sheet is to be supplied for ASME Boiler and Pressure Code Application Supplementary Requirement S12 of Specification A 788 should be specified.

4. Heat Treatment for Mechanical Properties

4.1 Heat treatment shall consist of normalizing and tempering, double normalizing and tempering, or quenching and tempering at the manufacturer's option.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA–765/SA–765M in Section II of that code.

[3] *Annual Book of ASTM Standards*, Vol 01.05.

[4] *Annual Book of ASTM Standards*, Vol 01.03.

[5] *Annual Book of ASTM Standards*, Vol 03.01.

[6] *Annual Book of ASTM Standards*, Vol 03.03.

[7] Available from American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017.

TABLE 1 Chemical Requirements

	Composition, %				
	Grade I	Grade II	Grade III	Grade IV	Grade V
Carbon, max	0.30	0.30	0.20	0.20	0.30
Manganese	0.60 to 1.05	0.60 to 1.35	0.90 max	1.00–1.60	0.60–1.35
Phosphorus, max	0.020	0.020	0.020	0.020	0.020
Sulfur, max	0.020	0.020	0.020	0.020	0.020
Silicon	0.15 to 0.35	0.15 to 0.35	0.15 to 0.35	0.15–0.50	0.15–0.35
Nickel[A]	0.50 max	0.50 max	3.3 to 3.8	0.50 max	1.0–2.0
Vanadium, max	0.05	0.05	0.05	0.06	0.03
Aluminum, max	0.05	0.05	0.05	0.05	0.05
Chromium,[A] max	0.40	0.40	0.20	0.40	0.30
Molybdenum,[A] max	0.10	0.10	0.06	0.10	0.12
Copper, max	0.35	0.35	0.35	0.35	0.35

[A] Intentional additions of Cr, Mo, and Ni up to the specified maximum are permitted to be made to Grades I, II, and IV by the manufacturer.

5. Chemical Requirements

5.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 shall comply with Table 1.

5.2 *Product Analysis*—The purchaser may use the product analysis provision of Specification A 788 to obtain a product analysis from a forging representing each heat or multiple heat.

6. Mechanical Requirements

6.1 *General Requirements*—The forgings shall conform to the tension test requirements of Table 2. The forgings shall also conform to the impact test requirements of Table 3. The largest obtainable round tension test specimen as specified in Test Methods and Definitions A 370 shall be used. Impact specimens shall be Charpy V-notch, Type A, as in Test Methods and Definitions A 370. The usage of subsize impact specimens must have prior purchaser approval.

6.1.1 When agreed upon between the purchaser and the producer and specified on the order, impact tests may be made at temperatures different from those shown in Table 3 provided the test temperature is at least as low as the intended service temperatures and the provided impact energy requirements of Table 3 are met. Such forgings shall be suitably marked in accordance with 8.1 to identify the test temperature.

6.2 *Test Location*—Test coupons shall be taken so that the longitudinal axis and mid-length of tension and impact test specimens shall be positioned in accordance with one of the following methods:

6.2.1 *Method 1*—Forgings with 2 in. [50 mm] maximum thickness. The specimens shall have their longitudinal axis at the midthickness or the center of the cross section and with the midlength of the specimen at least 2 in. [50 mm] from any second surface.

6.2.2 *Method 2*—Grade I and Grade II forgings with thicknesses greater than 2 in. up to 4 in. [50 to 100 mm] inclusive, or Grade III and IV forgings with thicknesses greater than 2 in. up to 6 in. [50 to 150 mm] inclusive. The specimens shall have their longitudinal axis at least ¼ *T* of maximum heat-treated thickness from any surface and with the midlength of the specimen at least one *T* from any second surface. This is normally referred to as ¼ *T* by *T* when *T* is the maximum heat-treated thickness. A thermal buffer may be used to adhere to the condition in 6.3. Unless otherwise agreed upon, the following limitation for heat-treated thickness shall apply:

Grade	in. [mm], min	in. [mm], max
I	2 [50]	4 [100]
II	2 [50]	4 [100]
III	2 [50]	6 [150]
IV	2 [50]	6 [150]
V (Classes 1 and 2)	2 [50]	6 [150]

6.2.3 *Method 3*—For forgings thicker than described in Method 2 (6.2.2):

6.2.3.1 Prior to heat treatment the forging shall be machined to a purchaser supplied or approved drawing that indicates the locations of significant in-service loading in the finished part. The mechanical test specimens shall be located as an integral part of the forging such that the mid-point of the gauge length of the tension test specimen and the area under the notch of the impact specimens are located no closer than the dimension *t* from one heat treated surface and 2*t* from any other heat treated surface where *t* is the dimension from the area of significant loading to the heat treated surface, or ¾ in. [20 mm] whichever is the greater.

6.2.4 *Method 4*—This method shall be limited to forgings with a rough machined weight of not more than 1000 lb [455 kg]. Separate test forging when agreed upon between the purchaser and the supplier. Test coupons representing forgings from one heat and one heat treatment lot may be taken from a separately forged piece under the following conditions:

6.2.4.1 The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forging it represents.

6.2.4.2 The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forging.

6.2.4.3 The separate test forging shall be of the same nominal thickness as the production forging.

6.2.4.4 Test coupons for small forgings as described in Method 2 shall be taken so that specimens shall have their longitudinal axes at the region midway between midthickness and the surface and with the midlength of the specimens no nearer any heat-treated edge than a distance equal to the forging thickness except when the thickness-to-length ratio of the production forging does not permit, in which case a production forging shall be used as the test forging and the midlength of the specimens shall be at the midlength of the test forging.

6.2.4.5 Test coupons for larger forgings shall be taken in accordance with Method 3 (6.2.3).

6.3 *Metal Buffers*—The required distances from treated surfaces may be obtained with metal buffers instead of integral extensions. Buffer material may be carbon or low-alloy steel, and shall be joined to the forging with a partial penetration weld that seals the buffered surface. Specimens shall be located at ½ in. [13 mm] minimum from the buffered surface of the forging. Buffers shall be removed and the welded areas subjected to magnetic particle test to assure freedom from

TABLE 2 Tensile Requirements

	Grade I	Grade II	Grade III	Grade IV	Grade V	
					Class 1	Class 2
Tensile strength, ksi [MPa]	60 to 85 [415 to 585]	70 to 95 [485 to 655]	70 to 95 [485 to 655]	80–105 [550–725]	60–85 [415– 585]	70–95 [485–655]
Yield strength,[A] in, ksi [MPa]	30 [205]	36 [250]	37.5 [260]	50 [345]	30 [205]	37.5 [260]
Elongation in 2 in. [50 mm], min, %	25	22	22	22	25	22
Reduction of area, min, %	38	30	35	30	38	35

[A] 0.2 % offset or 0.5 % total extension underload method.

TABLE 3 Charpy V-Notch Impact Requirements

	Grade I	Grade II	Grade III	Grade IV	Grade V (Classes 1 and 2)
Minimum average value of set of three specimens, ft-lbf (J)	13 [18]	15 [20]	15 [20]	26 [35][A]	15 [20]
Minimum value of one specimen, ft-lbf (J)	10 [14]	12 [16]	12 [16]	20 [27][A]	12 [16]
Test temperature of,[B] °F [°C]	−20 [−30]	−50 [−45]	−150 [−100]	−20 [−30]	-75 [-60]

[A] Mandatory conformance to the values listed is a matter of agreement between the purchaser and the manufacturer. The energy values above are shown for information as to guarantees that are generally available.

[B] Actual test temperature should be established at time of order. If no temperature is specified, tests will be made at test temperatures shown in this table.

cracks unless the welded areas are completely removed by subsequent machining.

6.4 Samples shall be removed from forgings after heat treatments. This sample material shall be subjected to a simulated post-weld heat treatment if Supplementary Requirement S6 is specified.

6.5 *Test Orientation*:

6.5.1 For upset disk forgings such as tube sheets the longitudinal axis of test specimens may be oriented in the radial or tangential direction, or parallel to the axis of the forging, as shown in Supplementary Requirement S12 of Specification A 788.

6.5.2 For all other forgings the longitudinal axis of test specimens may be oriented parallel to the direction of maximum hot working of the forging.

6.6 *Number of Tests*:

6.6.1 *Forgings Under 500 lb [230 kg] As Treated*—For duplicate forgings weighing less than 500 lb as treated, one tension test and one impact test (three specimens) shall be made to represent each heat in each heat-treatment charge. When heat treatment is performed in continuous-type furnaces with suitable temperature control and equipped with recording pyrometers so that complete heat-treatment records are available, a heat-treatment charge shall be considered as any continuous run not exceeding an 8-h duration.

6.6.2 *Forging Weighing 500 to 10 000 lb [230 to 4500 kg] As-Heat Treated*—One tension and one impact test (three specimens) shall be made for each forging.

6.6.3 Each forging weighing over 10 000 lb [4500 kg] shall require two tension tests and two impact tests (three specimens). When the length (excluding prolongs) is equal to or less than 1½ times the diameter, the tests may be taken from one end of the forging with a tension test and one set of impact tests at each of two locations oriented 180° apart. When the length (excluding prolongs) is greater than 1½ times the diameter, one tension test and one set of impact tests must be taken from each location from opposite ends of the forging and the locations on each end should be oriented 180° apart from each other.

7. Repair Welding

7.1 Repair welding, as permitted by the purchaser, shall be performed in accordance with the ASME Boiler and Pressure Vessel Code.

8. Product Marking

8.1 The test temperature, if different from that given in Table 3, shall be marked on the forging as a suffix to the Grade and Class designation. A prefix of 0 to the test temperature indicates that the temperature was under 0°F, or 0°C if the M designation specification is being used. For example, A765-11-075 would indicate that the impact testing for Grade 11 was done at -75°F instead of -50°F. A marking of A765M-11-10 would indicate that the impact testing was done at 10°F for a Grade 11 forging. For forgings tested under the M designation an example would be A765M-11-060 for a Grade 11 forging tested at -60°C or A765M-11-10 for a Grade 11 forging tested at 10°C.

9. Keywords

9.1 alloy steel forgings; carbon steel forgings; heat-treated; impact tested; pressure vessel; weldable

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the order. Details of these supplementary requirements shall have been previously negotiated and mutually agreed to between the forging manufacturer and the purchaser.

S1. Product Analysis

S1.1 The manufacturer shall use the product analysis provision of Specification A 788 to obtain a product analysis from a forging representing each heat or multiple heat.

S2. Grain Size

S2.1 The forgings, subsequent to the final heat treatment, shall have prior austenitic grain size of 5 or finer as determined by the McQuaid-Ehn Test (Test Methods E 112).

S3. Impact Transition Curve

S3.1 Sufficient impact tests shall be made from the forging test material to establish a temperature versus absorbed-energy curve. The test temperature range shall be wide enough to establish the upper and the lower shelf foot-pound-force (or joules) energies, with sufficient testing at intermediate temperatures to permit plotting a reasonably smooth curve.

S4. Magnetic Particle Examination

S4.1 All accessible surfaces of the finished forging shall be examined by a magnetic particle method. This method shall be in accordance with Test Method A 275/A 275M.

S4.2 Acceptance criteria shall be specified.

S5. Liquid Penetrant Examination

S5.1 All surfaces shall be examined by a liquid penetrant method. The method shall be in accordance with Practice E 165.

S5.2 Acceptance criteria shall be specified.

S6. Simulated Post-Weld Heat Treatment of Mechanical Test Samples

S6.1 All test coupons shall be subjected to single or multiple heat treatments at subcritical temperatures prior to testing. Such treatments are intended to simulate post-weld or other treatments to which the forgings will be subjected during subsequent fabrication. The purchaser shall furnish the manufacturer with details of the desired heat treatment for the test coupons, including temperatures, times, and cooling rates.

S7. Vacuum Treatment

S7.1 The molten steel shall be vacuum treated prior to or during the pouring of the melt. Unless otherwise agreed upon with the purchaser, it is the responsibility of the manufacturer to select suitable process procedures subject to the following requirements:

S7.1.1 When the vacuum stream degassing is used, the vacuum system must be of sufficient capacity to effect a blank-off pressure low enough (usually less than 1000 µm Hg) to break up the normal tight, rope-like stream of molten metal into a wide-angled conical stream of relatively small droplets. The capacity of the system must also be sufficiently high to reduce the initial surge pressure at the start of the pour to a low level within 2 min.

S7.1.2 When the vacuum-lift process is utilized, the molten metal shall be drawn into the evacuated vessel a sufficient number of times to assure thorough mixing and degassing of the entire volume of metal. The evacuation system shall be capable of reducing the pressure surges which occur each time a new portion of steel is admitted to the vessel to increasingly lower levels until a blank-off pressure of less than 1000 µm Hg is achieved, thus signifying the end of the degassing treatment.

S8. Ultrasonic Examination

S8.1 Forgings shall be ultrasonically examined in accordance with the procedures of Practice A 388/A 388M.

S8.2 Acceptance criteria shall be specified.

S9. Special Tension Specimens for Hubbed Flanges and Tube Sheets

S9.1 For forged-hub tube sheets and flanges to be used in ASME Code stamped vessels, a tension specimen shall be taken as close to the hub as possible. The longitudinal axis of the specimen shall be parallel to the length of the hub (see Fig. UW 13.3, ASME Code Section VIII/1).

Designation: A 768 – 95 (Reapproved 2001)

Standard Specification for Vacuum-Treated 12 % Chromium Alloy Steel Forgings for Turbine Rotors and Shafts [1]

This standard is issued under the fixed designation A 768; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers vacuum-treated 12 % chromium steel forgings for turbine rotors and shafts.

1.2 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings[2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

A 418 Test Method of Ultrasonic Examination of Turbine and Generator Steel Rotor Forgings[2]

A 472 Test Method for Heat Stability of Steam Turbine Shafts and Rotor Forgings[2]

A 788 Specification for Steel Forgings, General Requirements[2]

3. Ordering Information

3.1 In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order a detailed drawing, sketch, or written description of the forging, including the mechanical test specimen location.

4. General Requirements

4.1 Material supplied to this specification shall conform to the requirements of Specification A 788 which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

4.2 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

5. Manufacture

5.1 The melting processes of Specification A 788 shall be applicable except that the open-hearth or basic oxygen methods of primary melting shall not be used, and the molten steel shall be vacuum degassed prior to or during pouring of the ingot.

5.1.1 If the ESR process is used, then the electrodes shall have been produced from vacuum degassed primary heat(s).

5.2 In addition to the requirements of Specification A 788, it is important to maintain the axial center of the forging in common with the axial center of the original ingot.

5.3 *Heat Treatment*:

5.3.1 The heat treatment for mechanical properties shall consist of quenching and tempering.

5.3.1.1 The preliminary heat treatment shall consist of normalizing well above the transformation temperature range. This operation may be performed before preliminary machining (see 5.4.1).

5.3.1.2 The quenching treatment shall be from above the transformation range but below the normalizing temperature described in 5.3.1.1. This treatment shall be performed after preliminary machining (see 5.4.1). Austenitizing temperatures shall be in accordance with Table 1.

5.3.1.3 The final tempering temperature shall be in accordance with Table 1.

5.3.1.4 After heat treatment and subsequent rough machining and boring (see 5.4.2 and 5.4.3), the forging shall be stress-relieved at a temperature not more than 100°F (55°C) below the final tempering temperature, but not less than 1100°F (593°C).

5.3.1.5 With the prior approval of the purchaser, the stress-relief temperature may approach, equal, or slightly exceed the final tempering temperature as a means of adjusting final strength or toughness. If the stress relief temperature is within 25°F (14°C) of the final tempering temperature, or higher, additional tension tests must be obtained (see 7.1.3).

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved Jan. 15, 1995. Published March 1995. Originally published as A 768 – 79. Last previous edition A 768 – 93.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

TABLE 1 Heat Treating Requirements

Grade	Austenitizing Temperature, °F	1st Tempering Temperature, min	2nd Tempering Temperature
1	1725–1825	1125	1100
2	1900–1940	1040	1010–1040
3	1700–1800	1120	1100
4	1700–1800	975	950

5.3.1.6 The method of cooling during quenching and from the final tempering and stress relieving temperatures shall be reported.

5.4 *Machining*:

5.4.1 *Preliminary Rough Machining*—All exterior surfaces of the forging shall be machined prior to heat treatment for mechanical properties.

5.4.2 *Second Rough Machining*—After heat treatment for mechanical properties, all surfaces of the forging shall be rough machined prior to stress relief and the stability test.

5.4.3 *Boring*:

5.4.3.1 Forgings shall be bored to permissible bore size and tolerance when required by the purchaser's drawing.

5.4.3.2 Forgings may be bored to limits agreed to by the purchaser or indicated on the purchaser's drawing, to remove objectionable center conditions revealed by ultrasonic inspection.

5.4.3.3 Unless otherwise specified by the purchaser, the manufacturer may bore the forging at any time prior to stress relief (see Supplementary Requirement S1).

5.4.4 *Machining to Purchaser's Requirements for Shipment*—The forging as shipped shall conform to the finish and dimension requirements specified on the purchaser's drawing or order.

6. Chemical Composition

6.1 The steel shall conform to the requirements for chemical composition prescribed in Table 2.

6.2 *Product Analysis*—The manufacturer shall make a product analysis from each forging. The chemical composition thus determined shall not vary from the requirements specified in Table 1 by more than the amounts prescribed in Specification A 788.

7. Mechanical Properties

7.1 *Tension Test*:

7.1.1 The steel shall conform to the tensile requirements of Table 3.

7.1.2 The number and location of tension test specimens shall be as specified on the forging drawings furnished by the purchaser.

7.1.3 Final acceptance tests shall be made after heat treatment of the forging for mechanical properties prior to stress relief, unless the stress relief temperature is within 25°F (14°C) of the tempering temperature, or higher, in which case check tests shall be made after the stress relief treatment and reported to the purchaser. The purchaser may require check tests after completion of all heating cycles, including stress relief and the heat stability tests.

7.1.4 The yield strength prescribed in Table 3 shall be determined by the offset method of Test Methods and Definitions A 370.

7.2 *Impact Test*:

7.2.1 The steel shall conform to the requirements for notch toughness (both transition temperature and room temperature impact values) prescribed in Table 3.

7.2.2 The notch toughness specimens shall be machined from radial bars taken from the main body of the forging, as shown in the forging drawing. The specimens shall be charpy V-notch, Type A, as shown in Test Methods and Definitions A 370. The notch direction of the charpy bars shall be tangential.

8. Nondestructive Tests

8.1 *General Requirements*:

8.1.1 The forgings shall be free of cracks, seams, laps, shrinkage, and other injurious imperfections.

8.1.2 The purchaser may request ultrasonic, magnetic particle, dye penetrant, etch, or other accepted nondestructive inspection necessary to evaluate imperfections and to ensure compliance with this requirement.

8.2 *Ultrasonic Inspection*:

8.2.1 An ultrasonic inspection shall be made on the machined forging at the manufacturer's plant. This inspection shall be made in accordance with Test Method A 418 to demonstrate freedom from detrimental internal defects.

8.2.2 The ultrasonic inspection shall be made from all available surfaces prior to removal of test specimens that would interfere with complete testing of the forging.

8.2.3 Forgings with recordable ultrasonic indications shall be referred to the purchaser for evaluation based on the nature,

TABLE 2 Chemical Requirements

Composition, %	Grade 1	Grade 2	Grade 3	Grade 4
Carbon	0.15 max	0.08–0.15	0.10–0.16	0.05–0.07
Manganese	1.0 max	0.50–0.90	0.25–1.00	0.70–1.00
Phosphorus	0.018 max	0.02 max	0.015 max	0.015 max
Sulfur	0.015 max	0.015 max	0.012 max	0.012 max
Silicon	0.35 max	0.30 max	0.15–0.45	0.30–0.50
Nickel	0.40–0.75	2.0–3.0	0.75 max	3.5–4.25
Chromium	11.5–13.0	11.0–13.0	11.0–13.0	11.25–12.25
Molybdenum	0.50 max	1.5–2.0	0.20 max	0.30–0.50
Vanadium	...	0.25–0.40	...	0.03 max
Columbium	...	...	0.15 min	...
Aluminum	...	...	...	0.03 max
Nitrogen	...	0.06 max	...	...

TABLE 3 Tensile and Notch Toughness Requirements

	Grade 1		Grade 2	Grade 3		Grade 4	
	Class 1	Class 2		Class 1	Class 2	Class 1	Class 2
Tensile strength, ksi	90–110	85 min	150 min	90–110	105–125	110–140	120–150
Yield strength (0.2 % offset) ksi	70 min	63 min	110 min	70 min	80 min	85 min	95 min
Elongation, min, %	16	18	15	15	16	16	15
Reduction of area, min, %	45	45	45	45	45	45	42
$FATT_{50}$, max, °F	175	140	25	140	175	60	80
Room temperature impact, min, ft-lb	15	20	50	15	15	35	25

frequency, and location of indications, both stationary and traveling. If the ultrasonic indications are considered objectionable, it shall be determined by conventional or mutually acceptable inspection procedures whether the forging will be rejected.

8.3 *Internal Inspection*:

8.3.1 Boring, when specified for internal periscopic inspection, shall be in accordance with the drawings furnished by the purchaser. The drawings shall specify the nominal dimensions of the bore hole.

8.3.2 If objectionable conditions are encountered during the internal inspection of the bore hole, the manufacturer shall notify the purchaser of the location and nature of the condition. Further action shall be taken only after mutual agreement between the manufacturer and purchaser.

9. Stability Test

9.1 Each forging shall be subjected to a heat stability test at the manufacturer's plant in accordance with the latest issue of Test Method A 472 to determine the stability or freedom from tendency to distort during high temperature operating conditions.

9.2 The stability test shall be conducted after the forging has been stress relieved in accordance with 5.3.1.4.

NOTE 1—If agreed to by the purchaser, the stress relief may be performed as part of the stability test.

9.3 *Stability Test Requirements*:

9.3.1 The purchaser's drawings shall indicate the minimum portion of the forging to be included within the heating chamber during the stability test.

9.3.2 The purchaser's drawings or order shall indicate the minimum stability test temperature.

10. Retreatment

10.1 If the results of the mechanical tests of any forging do not conform to the requirements specified, the manufacturer may retreat the forging one or more times, but not more than three additional times, without the approval of the purchaser.

10.2 If bore core properties are specified under Supplementary Requirement S1 and retemper is necessary after boring, the remaining portions of the bore core shall be replaced in the bore during retemper.

10.3 If complete retreatment, including normalizing or quenching, is necessary after boring, the feasibility of retreating portions of the bore core in the bore of the forging shall be discussed between manufacturer and purchaser and a procedure agreed upon before treatment.

11. Certification and Reports

11.1 In addition to the certification requirements of Specification A 788, the following shall be reported:

11.1.1 Product analysis results.

12. Package Marking, Packaging, and Loading

12.1 Each forging shall be legibly stamped by the manufacturer with the manufacturer's name or symbol, the manufacturer's identification number, ASTM designation, the appropriate class number, and identification numbers specified by the purchaser on his drawings or order.

12.2 The location of such identification marks may be specified by the purchaser on his drawings or order.

12.3 Test specimens shall be identified with numbers corresponding to the forging identification numbers and numbers corresponding to test location and type if specified on the purchaser's drawings or order.

12.4 The axial bores of bored forgings shall be protected and suitably plugged to prevent damage or corrosion during shipment or storage.

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirement shall apply only when specified by the purchaser in the inquiry, contract, and order. Details of this supplementary requirement shall be agreed upon between the manufacturer and the purchaser.

S1. Bore Core Properties

S1.1 The purchaser may require the removal of the longitudinal bore core from the forging after heat treatment for mechanical properties and subsequent approval of the usual surface mechanical property tests.

S1.1.1 The diameter of the longitudinal bore core shall be subject to agreement between the manufacturer and the purchaser.

S1.1.2 The purchaser may require mechanical tests on tension of impact specimens from locations in the longitudinal bore core as specified on the forging drawings furnished by the purchaser.

S1.1.3 The acceptable level of mechanical properties obtained from specimens from the longitudinal bore core shall be as agreed upon between the manufacturer and the purchaser.

S2. Magnetic Particle Examination

S2.1 A magnetic particle examination of the complete exterior and bore surfaces of the machined forging shall be made at the forging manufacturer's plant. The examination shall be performed in accordance with the latest issue of Test Method A 275/A 275M.

S2.2 Forgings with either cracks or linear indications of any length are subject to rejection unless they can be removed to the purchaser's satisfaction.

Designation: A 788 – 04

An American National Standard

Standard Specification for Steel Forgings, General Requirements[1]

This standard is issued under the fixed designation A 788; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification[2] covers a group of common requirements that, unless otherwise specified in the individual product specification, shall apply to steel forgings under any of the following specifications issued by ASTM:

ASTM Designation	Title
A 266	Forgings, Carbon Steel for Pressure Vessel Components
A 288	Carbon and Alloy Steel Forgings for Magnetic Retaining Rings for Turbine Generators
A 289	Alloy Steel Forgings for Nonmagnetic Retaining Rings for Generators
A 290	Carbon and Alloy Steel Forgings for Rings for Reduction Gears
A 291	Carbon and Alloy Steel Forgings for Pinions and Gears for Reduction Gears
A 336	Steel Forgings, Alloy, for Pressure and High-Temperature Parts
A 372	Carbon and Alloy Steel Forgings for Thin-Walled Pressure Vessels
A 427	Wrought Alloy Steel Rolls for Cold and Hot Reduction
A 469	Vacuum-Treated Steel Forgings for Generator Rotors
A 470	Vacuum-Treated Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts
A 471	Vacuum-Treated Alloy Steel Forgings for Turbine Rotor Disks and Wheels
A 508/A 508M	Quenched and Tempered Vacuum-Treated Carbon and Alloy Steel Forgings Pressure Vessels
A 521	Steel Closed-Impression Die Forgings for General Industrial Use
A 541/A 541M	Steel Forgings, Carbon and Alloy, Quenched and Tempered, for Pressure Vessel Components
A 579	Superstrength Alloy Steel Forgings
A 592	High-Strength Quenched and Tempered Low-Alloy Steel Forged Fittings and Parts for Pressure Vessels
A 649/A 649M	Forged Steel Rolls Used for Corrugating Paper Machinery
A 668/A 668M	Steel Forgings Carbon and Alloy for General Industrial Use
A 723/A 723M	Alloy Steel Forgings for High-Strength Pressure Component Application
A 765/A 765M	Carbon Steel and Low-Alloy Steel Pressure Vessel Component Forgings with Mandatory Toughness Requirements
A 768	Vacuum-Treated 12 % Chromium Alloy Steel Forgings for Turbine Rotors and Shafts
A 837	Steel Forgings, Alloy, For Carburizing Applications
A 859/A 859M	Steel Forgings, Low-Carbon Age-Hardening Nickel-Copper-Chromium-Molybdenum Alloy Steel, for Pressure Vessel Components
A 891	Precipitation Hardening Iron Base Superalloy Forgings for Turbine Rotor Disks and Wheels
A 909	Specification for Steel Forgings, Microalloy, for General Industrial Use
A 940	Specification for Vacuum Treated Steel Forgings, Alloy, Differentially Heat Treated, for Turbine Rotors
A 965/A 965M	Specification for Steel Forgings, Austenitic, for Pressure and High Temperature Parts

1.2 In case of conflict in requirements, the requirements of the individual product specifications shall prevail over those of this specification.

1.3 The purchaser may specify additional requirements (see 4.2.3) that do not negate any of the provisions of either this specification or of the individual product specifications. The acceptance of any such additional requirements shall be dependent on negotiations with the supplier and must be included in the order.

1.4 If, by agreement, forgings are to be supplied in a partially completed condition, that is, all of the provisions of the product specification have not been filled, then the material marking (see Section 17) and certification (see Section 16) shall reflect the extent to which the product specification requirements have been met.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys, and is the direct responsibility of Subcommittee A1.06 on Steel Forgings and Billets.

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[2] For ASME Boiler and Pressure Vessel Code applications, see related Specification SA–788 in Section II of that code.

***A Summary of Changes section appears at the end of this standard.**

2. Referenced Documents

2.1 *ASTM Standards:* [3]

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products

A 833 Practice for Indentation Hardness of Metallic Materials by Comparison Hardness Testers

A 939 Test Method for Ultrasonic Examination from Bored Surfaces of Cylindrical Forgings

A 941 Terminology Relating to Steel, Stainless Steel, Related Alloys, and Ferroalloys

A 966/A 966M Test Method for Magnetic Particle Examination of Steel Forgings Using Alternating Current

A 991/A 991M Test Method for Conducting Temperature Uniformity Surveys of Furnaces Used to Heat Treat Steel Products

A 1021 Specification for Martensitic Stainless Steel Forgings and Forging Stock for High-Temperature Service

E 23 Test Methods for Notched Bar Impact Testing of Metallic Materials

E 112 Test Methods for Determining Average Grain Size

E 165 Test Method for Liquid Penetrant Examination

E 399 Test Method for Plane Strain Fracture Toughness of Metallic Materials

E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection

E 1290 Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness

E 1820 Test Method for Measurement of Fracture Toughness

E 1916 Guide for Identification and/or Segregation of Mixed Lots of Metals

3. Terminology

3.1 Terminology A 941 is applicable to this Specification. Additional terms and wording more applicable to forgings are as noted in this section.

3.2 *Definitions*:

3.2.1 *steel forging*—the product of a substantially compressive plastic working operation that consolidates the material and produces the desired shape. The plastic working may be performed by a hammer, press, forging machine, or ring rolling machine, and must deform the material to produce an essentially wrought structure. Hot rolling operations may be used to produce blooms or billets for reforging. Forgings may be subdivided into the following three classes on the basis of their forging temperatures:

3.2.1.1 *cold–worked forgings*—forgings produced by plastic working well below the temperature range at which recrystallization of the material occurs. Cold-worked forgings must be made from material previously hot worked by forging or rolling.

3.2.1.2 *hot-cold–worked forgings*—forgings worked at elevated temperatures slightly below the recrystallization range to increase mechanical strength. Hot-cold-worked forgings must be made from material previously hot worked by forging or rolling. A hot-cold-worked forging may be produced in one continuous operation wherein the material is first hot worked and then cold-worked by control of the finishing temperature.

Discussion—Because of differences in manufacture, hot rolled, or hot rolled and cold finished bars (semi-finished or finished), billets or blooms are not considered to be forgings.

3.2.1.3 *hot-worked forgings*—forgings produced by working at temperatures above the recrystallization temperature for the material.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *bottom pouring*—steel from a single heat, or from a multiple heat tapped into a common ladle (see 8.1.1 and 8.1.2), introduced into ingot mold(s) such that they are filled from the bottom up. One or more molds can be set up on an individual plate, and more than one plate may be poured in sequence from a heat. The plate is generally constructed such that the molten steel can be ducted through refractory channels to the bottom of each mold on the plate. The steel is poured into a central sprue which is high enough to permit filling the ingot molds to the required level.

3.3.2 *ingot*—the product obtained when molten steel, upon being cast into a mold, is subsequently capable of being wrought in conformance with 3.1. Open-ended molds, that are usually cooled and used, for example, in the continuous casting of steel, are considered to be included in this definition.

3.3.3 *killed steel*—steel deoxidized, either by the addition of strong deoxidizing agents or by vacuum treatment, to reduce the oxygen content to such a level that essentially no reaction occurs between carbon and oxygen during solidification

3.3.3.1 *Discussion*—Vacuum carbon deoxidation (VCD) is a steelmaking process in which primary deoxidation occurs during vacuum treatment as a result of the carbon-oxygen reaction. In order for primary deoxidation to occur during vacuum treatment, deoxidizing agents such as aluminum or silicon are not to be added to the melt in any significant amount prior to the vacuum treatment operation.

3.3.3.2 *Discussion*—Precipitation deoxidation is a steelmaking process in which primary deoxidation is achieved by the addition of strong deoxidizing agents such as aluminum early in the process, and holding the steel in the molten state for sufficient time for the products of deoxidation to separate from the melt to the slag.

3.3.4 *sequential or continuous strand casting*—steel from several heats poured consecutively into a cooled open-ended mold to form a continuous cast product with a change from heat to heat along its length.

3.3.5 *strand casting*—steel from one heat poured into a cooled open-ended mold to form a continuous strand or strands.

3.3.6 *intercritical heat treatment*—use of a multi-stage heat treatment procedure in which the material is first austenitized at

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

a temperature above the upper critical temperature (Ac3) followed by cooling below the lower critical temperature (Ac1). The material is then reheated to a temperature in the intercrtical range between the Ac1 and the Ac3 and again cooled below the Ac1, followed by subcritical tempering in the range specified in the material specification.

3.3.6.1 *Discussion*—This procedure is generally applicable to low hardenability carbon and low alloy steels that would usually have a microstructure of ferrite and pearlite in the heat treated section size of the component being heat treated.

4. Ordering Information

4.1 Orders shall include the following information:

4.1.1 Quantity,

4.1.2 Dimensions, including tolerances and surface finishes,

4.1.3 Specification number with type, class, and grade as applicable (including year date), and should include:

4.1.4 Number of copies of the material test report.

4.2 Additional information including the following may be added by agreement with the supplier:

4.2.1 Type of heat treatment when alternative methods are allowed by the product specification,

4.2.2 Supplementary requirements, if any, and

4.2.3 Additional requirements (see 1.4, 16.1.5, and 16.1.6).

4.2.4 Repair welding NOT permitted.

5. Melting Process

5.1 Unless otherwise specified in the product specification, the steel shall be produced by any of the following primary processes: electric-furnace, basic oxygen, vacuum-induction (VIM) or open-hearth. The primary melting may incorporate separate degassing or refining and may be followed by secondary melting, using electro slag remelting (ESR) or vacuum arc remelting (VAR).

5.1.1 The steel shall be fully killed.

5.2 The molten steel may be vacuum-treated prior to or during pouring of the ingot.

5.2.1 When vacuum treatment of the molten steel is required by the product specification the following conditions shall apply:

5.2.1.1 When the vacuum stream degassing process is used, the vacuum system must be of sufficient capacity to effect a blank-off pressure low enough (usually less than 1000 µm), to break up the normal tight, rope-like stream of molten metal into a wide-angled conical stream of relatively small droplets. The capacity of the system must also be sufficiently high to reduce the initial surge pressure at the start of the pour to a low level within 2 min.

5.2.1.2 When the vacuum-lift process is utilized, the molten metal shall be repeatedly drawn into the evacuated vessel to give a recirculation factor (see Annex A1) of at least 2.5 to ensure thorough degassing and mixing of the entire heat. The evacuation system shall be capable of reducing the pressure surges, which occur each time a new portion of steel is admitted to the vessel to increasingly lower levels, until a blank-off pressure, (usually less than 1000 µm) is achieved signifying the end of the degassing treatment.

5.2.1.3 When the ladle degassing process is used, the evacuation system shall be capable of reducing the system vacuum pressure to a low level (usually less than 1000 µm). The molten metal shall be adequately stirred for a sufficient length of time to maximize exposure to the evacuated atmosphere.

5.2.1.4 Other methods of vacuum treatment may be used if the supplier can demonstrate adequate degassing and acceptable properties in the finished forging to the satisfaction of the purchaser.

6. Forging

6.1 Forgings shall be made in accordance with 3.2.1.

7. Cooling Prior to Heat Treatment

7.1 After forging and before reheating for heat treatment, the forgings shall be allowed to cool in such a manner as to prevent injury and, in the case of ferritic forgings, to permit substantially complete transformation of austenite.

8. Chemical Composition

8.1 *Heat Analysis*:

8.1.1 An analysis of each heat of steel shall be made by the steel producer to determine the percentages of those elements specified in the product specification. This analysis shall be made from a test sample preferably taken during the pouring of the heat and shall conform to the requirements of the product specification.

8.1.2 When multiple heats are tapped into a common ladle, the ladle chemistry shall apply. The chemical composition thus determined shall conform to the requirements of the product specification.

8.1.3 For multiple-heat ingots, either individual heat analyses or a weighted average (see Annex A2) may be taken. The results of the method used shall conform to the requirements of the product specification.

8.1.4 With the exception of the product from multiple heats sequentially cast in strand casting machines (see 8.1.6), if the test sample taken for a heat analysis is lost or declared inadequate for chemical determinations, the steel producer may take alternative samples from appropriate locations near the surface of the ingot or forging as necessary to establish the analysis of the heat in question.

8.1.5 *Heat Analysis for Remelted Ingots*:

8.1.5.1 When consumable remelting processes are used, a chemical analysis taken from one remelted ingot (or the product of one remelted ingot) per heat shall be taken as the heat analysis.

8.1.5.2 When electrodes from different master heats are remelted sequentially, an analysis shall be made in each zone of the remelted ingot corresponding to at least one electrode from each master heat. The resultant chemical analysis of each zone shall conform to the requirements of the product specification. The heat analysis of the remelted ingot shall be represented by a weighted average (see Annex A2) of the individual chemical analyses for each zone.

8.1.5.3 Limits on aluminum content in remelt ingots shall be set as required in the product specification.

8.1.6 For multiple heats sequentially cast in strand casting machines, the heat analysis shall be determined for each individual heat in accordance with 8.1.1, or 8.1.2 if applicable.

8.1.6.1 If, for multiple heats sequentially strand cast, the test sample is lost or declared inadequate for chemical analysis determination, alternative samples, remote from the transition zones, may be taken by the steel producer from the cast material or product of that heat, as defined in 8.2 or 8.3 as appropriate.

8.2 *Heat Number Assignment for Sequentially Strand Cast Material*—When heats of the same chemical composition are sequentially strand cast, the heat number assigned to the cast product may remain unchanged until all of the steel in the product is from the following heat, except when Supplementary Requirement S3 is invoked.

8.3 *Identification of Material of Different Chemical Composition Ranges, Sequentially Strand Cast*—Because of intermixing in the tun dish, separation and identification of the resultant transition material is required when steels of different chemical composition ranges are sequentially strand cast. The steel producer shall remove the transition material by any established procedure that positively separates the grades.

8.4 *Product Analysis*:

8.4.1 An analysis may be made by the purchaser from a forging representing each heat or multiple heat (see 8.1). Samples for analysis may be taken from the forging or from a full-size prolongation at any point from the midradius to the outer surface of disk or other solid forgings or midway between the inner and outer surfaces of hollow or bored forgings. The analysis may also be taken from a mechanical test specimen or the mechanical test location as defined in the product specification.

8.4.2 The chemical composition thus determined shall conform to the requirements of the forging specification subject to the permissible variations specified in Table 1, for those elements listed in the product specification. Limitations on the application of the allowances in Table 1 may be made in the product specification for specified elements.

8.5 *Residual and Unspecified Elements*— Provisions for the limitation of certain residual and unspecified elements have been made in Supplementary Requirements S1 and S2, respectively.

8.6 Grade substitution is not permitted.

8.7 *Method of Analysis*—Methods included in Test Methods, Practices, and Terminology A 751 shall be used for referee purposes.

9. Heat Treatment

9.1 Heat treatment shall be performed as specified in the product specification. Supplementary Requirement S4 concerns a specialized heat treat process (see 3.3.6) whose application will be controlled in the product specification. Unless otherwise specified during a heat treating hold cycle the recorded furnace temperature shall be within ±25°F (±15°C) of the controlling set point temperature. Material shall be heat treated in the working zone of a furnace that has been surveyed in accordance with Test Method A 991/A 991M provided that the working zone was established using a variation of ±25°F (±15°C) or less from the furnace set point.

10. Mechanical Testing

10.1 *Test Methods*—All tests shall be conducted in accordance with Test Methods and Definitions A 370.

10.1.1 In addition to the hardness testing provisions of Test Methods and Definitions A 370, comparison hardness testing in accordance with Practice A 833 may be used in determining the hardness of forgings.

10.2 *Retests*—If the results of the tension tests do not conform to the requirements specified, retests are permitted as outlined in Test Methods and Definitions A 370 or as follows:

10.2.1 If the percentage of elongation or reduction of area of any tension test specimen is less than specified because a flaw becomes evident in the test specimen during testing, a retest shall be allowed provided that the defect was not attributable to ruptures, cracks, or flakes in the steel.

10.2.2 If the average impact energy value meets the specification requirements, but the energy value for one specimen is below the specified minimum value for individual specimens prescribed in the material specification, a retest is permitted. This shall consist of two impact specimens from a location adjacent to and on either side of the specimen that failed. Each of the retested specimens must exhibit an energy value equal to or greater than the minimum average value required by the product specification.

11. Reheat Treatment

11.1 If the results of the initial mechanical tests do not conform to the specified requirements, the forgings may be heat treated (if initially tested in the as-forged condition) or reheat treated (if heat treated prior to initial testing).

12. Repair Welding

12.1 Repair welding of forgings is not permitted unless specifically allowed by the product specification (see also 4.2.4).

13. Dimensions and Finish

13.1 The forgings shall conform to the dimensions, tolerances, and finishes required by the ordering information (4.1.2). Supplementary Requirements S5 or S6, concerning straightening of forgings, may be used.

14. Inspection

14.1 All tests and inspections other than 8.4 shall be made at the place of manufacture, unless otherwise agreed upon.

14.2 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with the material specification.

14.3 Mill inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations.

15. Rejection

15.1 Any rejection based on the presence of an injurious defect found subsequent to acceptance at the manufacturer's works or based on the results of a product analysis made in accordance with 8.4 shall be reported to the manufacturer.

TABLE 1 Permissible Variations in Product Analysis for Killed Steel

NOTE 1—This table covers permissible variations in product analysis for most of the elements commonly found in killed steels under the jurisdiction of A01.06. This table is applicable only for those elements for which product analysis variations are permitted by the material specification.

NOTE 2— Product cross-sectional area (taken at right angles to the axis of the original ingot or billet) is defined as either: (*a*) maximum cross-sectional area of rough machined forging (excluding boring), (*b*) maximum cross-sectional area of the unmachined forging, (*c*) maximum cross-sectional area of the billet bloom or slab.

		Permissible Variation Over the Specified Maximum Limit or Under the Specified Minimum Limit, %					
Element	Unit or Maximum Specified Range—I	Up to and incl 100 in.^{2} (650 cm^2)^A	Over 100^A to 200 in.^{2} incl (650 to 1300 cm^2)	Over 200 in.^{2} to 400 in.^{2} incl (1300 to 2600 cm^2)	Over 400 in.^{2} to 800 in.^{2} incl (2600 to 5200 cm^2)	Over 800 in.^{2} to 1600 in.^{2} incl (5200 to 10300 cm^2)	Over 1600 in.^{2} (over 10300 cm^2)
Carbon	Up to and incl 0.05	0.005	0.005	0.005	0.01	0.01	0.01
	0.06 to 0.10, incl	0.01	0.01	0.01	0.01	0.01	0.01
	0.11 to 0.25, incl	0.02	0.03	0.03	0.04	0.05	0.05
	0.26 to 0.55, incl	0.03	0.04	0.04	0.05	0.06	0.06
	0.56 and over	0.04	0.05	0.05	0.06	0.07	0.07
Manganese	Up to and incl 0.90	0.03	0.04	0.05	0.06	0.07	0.08
	0.91 and over	0.06	0.06	0.07	0.08	0.08	0.09
Phosphorus	Up to and incl 0.05	0.008	0.008	0.010	0.010	0.015	0.015
Sulfur	Up to and incl 0.030	0.005	0.005	0.005	0.005	0.006	0.006
	0.031 to 0.060 incl	0.008	0.010	0.010	0.010	0.015	0.015
Silicon	Up to and incl 0.35	0.02	0.03	0.04	0.04	0.05	0.06
	0.36 and over	0.05	0.06	0.06	0.07	0.07	0.08
Nickel	Up to and incl 1.00	0.03	0.03	0.03	0.03	0.03	0.03
	1.01 to 2.00, incl	0.05	0.05	0.05	0.05	0.05	0.05
	2.01 to 5.30, incl	0.07	0.07	0.07	0.07	0.07	0.07
	5.31 to 10.00, incl	0.10	0.10	0.10	0.10	0.10	0.10
	10.01 and over	0.15	0.15	0.15	0.15	0.15	0.15
Chromium	Up to and incl 0.90	0.03	0.04	0.04	0.05	0.05	0.06
	0.91 to 2.10, incl	0.05	0.06	0.06	0.07	0.07	0.08
	2.11 to 10.00, incl	0.10	0.10	0.12	0.14	0.15	0.16
	10.01 to 15.00, incl	0.15	0.15	0.15	0.17	0.17	0.19
	15.01 to 20.00, incl	0.20	0.20	0.20	0.22	0.24	0.24
	20.01 and over	0.25	0.25	0.25	0.27	0.27	0.29
Molybdenum	Up to and incl 0.20	0.01	0.02	0.02	0.02	0.03	0.03
	0.21 to 0.40, incl	0.02	0.03	0.03	0.03	0.04	0.04
	0.41 to 1.15, incl	0.03	0.04	0.05	0.06	0.07	0.08
	1.16 to 5.50, incl	0.05	0.06	0.08	0.10	0.12	0.12
Vanadium	Up to and incl 0.10	0.01	0.01	0.01	0.01	0.01	0.01
	0.11 to 0.25, incl	0.02	0.02	0.02	0.02	0.02	0.02
	0.26 to 0.50, incl	0.03	0.03	0.03	0.03	0.03	0.03
	0.51 to 1.25, incl	0.04	0.04	0.04	0.04	0.04	0.04
Columbium (Niobium)	Up to and incl 0.14	0.02	0.02	0.02	0.02	0.03	0.03
	0.15 to 0.50, incl	0.06	0.06	0.06	0.06	0.07	0.08
Titanium	Up to and incl 0.85	0.05	0.05	0.05	0.05	0.05	0.05
Cobalt	Up to and incl 0.25	0.01	0.01	0.01	0.01	0.01	0.01
	0.25 to 5.00, incl	0.07	0.07	0.07	0.08	0.08	0.09
	5.01 to 10.00, incl	0.14	0.14	0.14	0.16	0.16	0.18
Tungsten	Up to and incl 1.00	0.05	0.05	0.05	0.06	0.06	0.07
	1.01 to 4.00, incl	0.09	0.09	0.10	0.12	0.12	0.14
Copper	Up to and incl 1.0	0.03	0.03	0.03	0.03	0.03	0.03
	1.01 to 2.00, incl	0.05	0.05	0.05	0.05	0.05	0.05
	2.01 to 5.00, incl	0.07	0.07	0.07	0.07	0.07	0.07
Aluminum	Up to and incl 0.03	0.01	0.01	0.01	0.01	0.01	0.01
	Over 0.03 to 0.05, incl	0.01	0.01	0.02	0.02	0.03	0.03
	0.06 to 0.15, incl	0.02	0.02	0.02	0.03	0.03	0.03
	0.16 to 0.50, incl	0.05	0.05	0.06	0.07	0.07	0.08
	0.50 to 2.00, incl	0.10	0.10	0.10	0.12	0.12	0.14
Zirconium	Up to and incl 0.15	0.01	0.01	0.01	0.01	0.01	0.01
Nitrogen	Up to 0.02 incl	0.005	0.005	0.005	0.005	0.005	0.005
	Over 0.02 to 0.19, incl	0.01	0.01	0.01	0.01	0.01	0.01
	Over 0.19 to 0.25, incl	0.02	0.02	0.02	0.02	0.02	0.02
	Over 0.25 to 0.35, incl	0.03	0.03	0.03	0.03	0.03	0.03
	Over 0.35 to 0.45, incl	0.04	0.04	0.04	0.04	0.04	0.04

^{A} When the product size range up to 100 in.^{2} is deleted, then the 100 to 200-in.^{2} column shall be changed to read up to and including 200 in.^{2}

15.2 Disposition of forgings rejected by the purchaser under 15.1 shall be as agreed upon between manufacturer and the purchaser.

16. Certification

16.1 The manufacturer shall furnish to the purchaser the number of copies of the material test report specified in the ordering information (4.1.4). The following items shall be reported:

16.1.1 Purchase order number,

16.1.2 Forging identification number,

16.1.3 Product specification number including the designation and year date, as well as the appropriate class, type, and grade,

16.1.4 Heat number and analysis,

16.1.5 Results of the required acceptance tests for mechanical properties,

16.1.6 Results of any required nondestructive examinations,

16.1.7 Final heat treatment cycle including austenitizing and tempering temperatures and holding times and cooling methods if required by the product specification or 4.2.3,

16.1.8 Extent to which the forging is incomplete with respect to the product specification (see 1.4 and 16.1.7), and

16.1.9 Results of any supplementary and additional test requirements that were specified.

16.1.10 The material test report may be sent to the purchaser in electronic form from an electronic data interchange (EDI) transmission, and this shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document shall meet the requirements of the invoked ASTM standard(s) and conform to any existing EDI agreement between the purchaser and the supplier. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

17. Packaging and Package Marking

17.1 Each forging shall be legibly identified as required by the product specification and instructions from the purchaser. When not otherwise defined, each forging shall be identified by the manufacturer as follows:

17.1.1 Manufacturer's name or symbol.

17.1.2 Manufacturer's identification or heat number.

17.1.3 Product specification number.

17.1.4 The class, grade, and type identification as appropriate.

17.1.5 Purchaser's identification (4.2.3).

17.1.6 Location of stamping (4.2.3).

17.1.7 Incomplete forging (1.4). The marking shall include the suffix Y immediately following the ASTM number, and preceding any other suffix. This suffix shall not be removed until the material specification requirements have been completed and the material test report supplemented.

17.2 Marking shall be done by impression stamping or other acceptable means specified in the product specification or order. Bar coding is an acceptable supplemental identification method. The purchaser may specify in the order a specific bar coding system to be used. The bar coding system, if applied at the discretion of the supplier, should be consistent with one of published industry standards for bar coding.

17.3 The specification year date, and revision letter are not required to be marked on the forgings.

18. Keywords

18.1 general delivery requirements; steel forgings—alloy; steel forgings—carbon

SUPPLEMENTARY REQUIREMENTS

(GENERAL)

The following supplementary general requirements are common to the forging specifications listed in this specification. *Those which are considered to be suitable for use in individual specifications are listed by number and title in that specification.* These and other limitations or tests may be performed by agreement between the supplier and purchaser. The additional requirements shall be specified in the order, and shall be completed by the supplier before the shipment of the forgings.

S1. Residual Elements

S1.1 Small quantities of certain unspecified elements may be present in carbon and low alloy steel forgings. These elements are considered as incidental and may be present to the following maximum amounts:

Copper	0.35 %
Nickel	0.30 %
Chromium	0.25 %
Molybdenum	0.10 %
Vanadium[A]	0.03 %

[A] Unless Supplementary Requirement S2 is required.

S2. Unspecified Elements

S2.1 Vanadium used for grain refinement or deoxidation shall not exceed 0.08 %.

S3. Sequential or Continuous Strand Casting

S3.1 When multiple heats of the same chemical composition range are sequentially strand cast, the heats shall be separated by an established procedure such that intermix material will not be supplied.

S4. Intercritical Heat Treatment

S4.1 The austenitizing stage in the heat treatment of ferritic forgings is intended to be done at suitable temperatures above the upper critical temperature (Ac_3) for the heat of steel involved, that is, full austenitization. However, when multiple austenitizing stages are used the temperature for the last may be set between the upper (Ac_3) and lower (Ac_1) critical temperature for partial austenitizing. Such cycles shall be followed by tempering within the temperature limits required by the material specification.

S5. Straightening of Forgings

S5.1 Unless otherwise specified by Supplementary Requirement S6, straightening of forgings after heat treatment for properties shall be performed at a temperature which is not more than 100°F (55°C) below the final tempering temperature. Following straightening, forgings shall be stress relieved at a temperature of 50 to 100°F (30 to 55°C) below the final tempering temperature and shall be reported on the material test report. Any straightening performed before heat treatment for properties does not require an intermediate stress-relief heat treatment.

S6. Post-Heat Treatment Straightening of Forgings

S6.1 Straightening after heat treatment for specified properties is not permitted without prior approval by the purchaser.

S7. Fracture Toughness Test

S7.1 The Purchaser shall specify one or more of the following test methods for fracture toughness determination. Required information including test temperature, conditioning, environment, and acceptance criteria shall be provided as necessary.

S7.2 Determination of the plane strain fracture toughness in accordance with Test Method E 399.

S7.3 Fracture toughness determination in accordance with Test Method E 1820.

S7.4 Crack-tip opening displacement determination in accordance with Test Method E 1290.

S8. Vacuum Degassing

S8.1 The vacuum degassing requirements of 5.2 shall apply.

S9. Vacuum Carbon Deoxidation

S9.1 The molten steel shall be vacuum carbon deoxidized (VCD) during processing, in which case the silicon content shall be 0.10 % maximum.

S10. Restricted Phosphorus and Sulfur, Levels A or B

S10.1 For level A, the phosphorus and sulfur levels shall be limited as follows:

		Heat	Product
Level A	P	0.015 % maximum	0.018 % maximum
	S	0.018 % maximum	0.021 % maximum

S10.2 For level B the phosphorus and sulfur levels shall be limited to the following:

		Heat	Product
Level B	P	0.012 % maximum	0.015% maximum
	S	0.015% maximum	0.018 % maximum

S11. Restricted Copper, Levels A or B

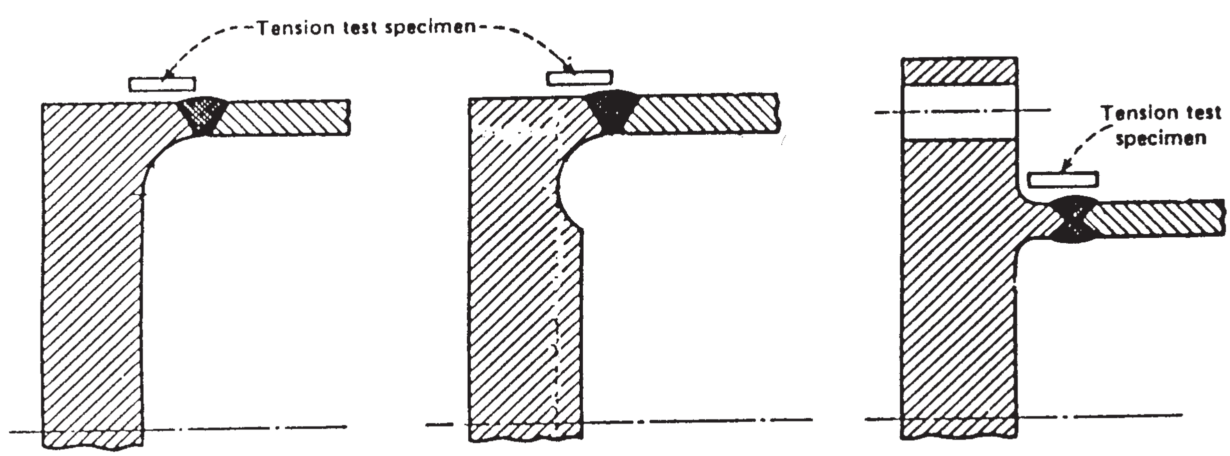
S11.1 For level A, the heat and product analyses limits for copper shall be 0.15 % maximum.

S11.2 For level B, the heat and product analyses limits for copper shall be 0.10 % maximum.

S12. Tension Specimens for Hubbed Flanges and Tube Sheets

S12.1 For hubbed tube sheets and flanges to be used in ASME Boiler and Pressure Vessel Code construction, an axial tension specimen shall be taken as close as possible to the hub and either inboard or outboard of it, using a sub size specimen if necessary. The longitudinal axis of the specimen shall be parallel to the length of the hub, as shown in Fig. S1.

S12.2 By agreement with the purchaser, this test orientation may replace a specified tension test specimen, provided that other location criteria are met.



NOTE—Tension test specimens also may be located inboard of the hub.

FIG. S1 Tension Test Specimens

S13. Charpy Impact Tests

S13.1 Charpy impact tests shall be made. The number, orientation and location of the tests shall be specified along with the test temperature and the applicable acceptance criteria for absorbed energy, fracture appearance, lateral expansion, or both.

S13.2 The specimens shall be machined and tested in accordance with Test Methods and Definitions A 370.

S14. Charpy V Notch Impact Transition Curve

S14.1 Sufficient impact tests shall be made from the forging material to establish a transition temperature curve based upon one or several of the following criteria:

S14.1.1 Absorbed energy (ft·lbf (J)) (See Test Methods E 23),

S14.1.2 Fracture appearance (see Supplement 5 of Test Methods and Definitions A 370), or

S14.1.3 Lateral expansion.

S14.1.4 The test temperature range shall be wide enough to establish the upper and lower shelf energies, with sufficient testing at intermediate temperatures to permit a smooth curve to be plotted. A minimum test temperature may be set by agreement instead of establishing the lower shelf temperature. The upper shelf energy level is defined as having at least 95 % fibrous fracture and the lower shelf level is defined as showing 5 % or less fibrous fracture.

S14.2 The purchaser shall furnish the manufacturer with details of sample location, number of specimens, heat treatments, and information to be derived from the test.

S15. Grain Size

S15.1 When a grain size range is required, it shall be specified in the ordering information as heat treated or austenitic, and shall be determined by an agreed-upon method from Test Methods E 112.

S15.2 Samples for grain size estimation from heat treated products shall be taken from the tension test specimen location.

S16. Rough Machining and Boring

S16.1 The position of the rough machining and boring in the manufacturing sequence shall be specified by the purchaser, particularly with regard to heat treatment for mechanical properties.

S17. Simulated Post-Weld Heat Treatment of Mechanical Test Samples

S17.1 All test coupons shall be subjected to single or multiple heat treatments at subcritical temperatures prior to testing. Such treatments are intended to simulate post-weld or other treatments to which the forgings will be subjected during subsequent fabrication. The purchaser shall furnish the manufacturer with details of the desired heat treatment for the test coupons, including temperatures, times and cooling rates.

S18. Magnetic Particle Examination

S18.1 All accessible surfaces of the finished forging shall be subject to magnetic particle examination in accordance with Test Method A 275/A 275M.

S18.2 Unless otherwise agreed upon between the manufacturer and the purchaser the wet continuous method shall be used.

S18.2.1 The following conditions are subject to rejection or removal:

S18.2.1.1 Indications with major dimension exceeding 3⁄16 in. (4.8 mm).

S18.2.1.2 Four or more indications exceeding 1⁄16 in. (1.6 mm) in major dimensions that are aligned and separated by 1⁄16 in. or less end to end.

S18.2.1.3 Ten or more indications exceeding 1⁄16 in. (1.6 mm) in major dimensions contained in any 6 in.^{2} (39 cm^2) of surface, with the major dimension of this area not to exceed 6 in. (150 mm). The area shall be taken in the most unfavorable location relative to the indications being evaluated.

S19. Liquid Penetrant Examination

S19.1 All accessible surfaces of the finished forging shall be subject to liquid penetrant examination in accordance with Practice E 165. The penetrant system to be used shall be agreed upon between the manufacturer and purchaser.

S19.2 The following conditions are subject to rejection or removal.

S19.2.1 Indications with major dimensions exceeding 3⁄16 in. (4.8 mm).

S19.2.2 Four or more indications exceeding1⁄16 in. (1.6 mm) in major dimensions that are aligned and separated by 1⁄16 in. (1.6 mm) or less end to end.

S19.2.3 Ten or more indications exceeding 1⁄16 in. (1.6 mm) in major dimensions contained in any 6 in. (39 cm^2) of surface, with the major dimension in this area not to exceed 6 in. (150 mm). The area shall be taken in the most unfavorable location relative to the indications being evaluated.

S20. Ultrasonic Examination

S20.1 Ultrasonic examination of forgings shall be carried out in accordance with Practice A 388/A 388M.

S20.2 Unless otherwise agreed upon between the manufacturer and the purchaser, acceptance levels BR or DA shall be specified for the longitudinal wave examination and level S for shear wave examination.

Level BR—Longitudinal Wave

S20.2.1 The back reflection method of tuning shall be used in accordance with Practice A 388/A 388M.

S20.2.2 In addition to the reportable conditions of the Recording Section of Practice A 388/A 388M, indications exceeding the resultant back reflection shall be recorded.

S20.2.3 The following conditions are subject to rejection, or repair if applicable.

S20.2.3.1 Complete loss of back reflection accompanied by an indication of a discontinuity. For this purpose, a back reflection less than 5 % of full screen height shall be considered complete loss of back reflection.

S20.2.3.2 An indication equal in amplitude to that of the back reflection established in an indication-free portion of the forging.

Level DA—Longitudinal Wave

S20.2.4 Reference blocks of acoustically similar metal shall be used for calibration. Blocks shall meet one of the following requirements:

S20.2.4.1 A comparison of the back reflections between equivalent thicknesses of the reference block material and the actual forging to be tested, without change in instrument setting shall not show a variation in excess of 25 %.

S20.2.4.2 The reference blocks shall be manufactured from steel that is similar in chemistry and processing history to the production forging being tested. The reference blocks shall be fabricated in accordance with the procedures of Practice E 428.

S20.2.4.3 For test sections up to and including 12 in. (300 nm) thick, the reference blocks shall contain a ¼ in. (6.5 mm) diameter flat-bottom hole; for over 12 in. (300 mm) up to and including 18 in. (300 to 455 mm), the hole diameter shall be ⅜ in. (9.5 mm); and for over 18 in. (455 mm), it shall be ½ in. (13 mm).

S20.2.4.4 A distance-amplitude correction curve shall be established for the proper grade of steel and specified hole size.

S20.2.4.5 A forging containing one or more indications equal in amplitude to that of the applicable reference hole, when properly corrected for distance, is subject to rejection, or repair if applicable.

Level S–Shear Wave

S20.2.5 Calibration notches, calibration reference, and method of scanning shall be in accordance with Practice A 388/A 388M. Unless otherwise agreed upon, a 60° V-notch shall be used.

S20.2.6 A forging containing a discontinuity which results in an indication exceeding the amplitude of the reference line is subject to rejection.

S20.2.7 The report of the ultrasonic examination shall be in compliance with Practice A 388/A 388M.

S20.2.8 Additional nondestructive examination or trepanning may be employed to resolve questions of interpretation of ultrasonic indications. The manufacturer shall accept responsibility for injurious conditions which will not be removed in final machining.

S21. Additional Test Coupon Heat Treatment

S21.1 When subcritical heat treatment, applied to a completed forging during subsequent fabrication, may affect the mechanical properties of the forging, then coupons for the mechanical testing required by the product specification shall be given a laboratory heat treatment which simulates the anticipated subcritical heat treatment.

S21.2 The purchaser shall specify the required heat treatment temperature range, minimum time at temperature, and the rates of heating and cooling.

S21.3 The required number of test coupons shall be taken from the forging location described in the product specification.

S21.4 The test specimens shall meet the minimum mechanical test requirements of the product specification, as well as those of any additional tests agreed upon between producer and purchaser, after completion of the test coupon heat treatment.

S21.5 The forgings supplied in accordance with this supplementary requirement shall be marked in accordance with 17.1.7.

S21.6 The material test reports shall include the heat treatment of the as delivered material and the results of the mechanical tests from the test coupons subjected to the purchaser specified heat treatments which represent fabrication.

S22. Ultrasonic Examination from Bore Surface

S22.1 Bored cylindrical forgings shall be examined from the bored surface in accordance with Test Method A 939. The acceptance criteria shall be agreed upon between the purchaser and the producer.

S23. Magnetic Particle Examination Using AC Current

S23.1 The designated surfaces of ferromagnetic steel forgings shall be examined at the stage in machining specified by the purchaser in accordance with Test Method A 966/A 966M. The acceptance criteria for the examination shall be specified by the purchaser.

S24. J_{factor}

S24.1 The J_{factor}, calculated by means of the following equation, shall be established or each heat of steel used in forging manufacture:

$$J_{factor} = (Mn + Si)\,(P + Sn) \times 10^4$$

Has been found to be effective in reducing temper embrittlement effects.

S24.2 The purchaser shall specify the required maximum value of J_{factor} in both the inquiry and ordering documents.

S24.3 The determination of the tin content of the steel is necessary for the application of this supplementary requirement even if there is no chemical analysis requirement for tin in the product specification.

Note—In Dr. Paul Bates' paper[4], it was noted that the Fracture Appearance Transition Temperature (FATT) fell steadily from J_{factor} 120 to 60, but below 20, the drop in FATT was much less apparent.

S25. Positive Material Identification

S25.1 Forgings shall receive positive material identification to ensure that forgings are of the ordered material grade prior to shipment.

S25.2 Forgings shall receive a positive material identification in accordance with Guide E 1916.

S25.3 The entire ordered quantity of forgings shall be examined.

S25.4 Forgings not conforming to the ordered grade shall be rejected.

S25.5 Following this material identification examination, acceptable forgings shall be marked as agreed between the purchaser and producer.

[4] Bates P., "the Production of Safety Critical Forgings for Pressure Vessel Applications" *International Forgemasters Conference*, Wiesbaden, Germany, September 2000.

ANNEXES

(Mandatory Information)

A1. RECIRCULATION FACTOR

A1.1 The recirculation factor for the vacuum lift process is obtained as follows:

$$\frac{\text{Tons (kg) of Steel Lifted per Cycle} \times \text{Number of Cycles}}{\text{Heat Weight in Tons [kg]}}$$

A2. EXPLANATORY NOTE FOR WEIGHTED AVERAGE ANALYSIS

A2.1 A weighted average analysis is mandatory whenever an ingot is poured from the combination of two or more heats wherein the resultant chemistry of the ingot assumes an identity attributable to each heat involved in the combination. It is necessary to make this determination to ensure that each element in the official chemistry is represented by proportion to its amount in each individual furnace heat. An example of the determination of a weighted average analysis for an ingot made from a three-heat combination pour with varying weights and chemistry involved in each heat is shown below:

Furnace	Heat[A] Weight, tons	Individual Heat Chemistry, %								
		C	Mn	P	S	Si	Ni	Cr	Mo	V
A	25	0.20	0.50	0.010	0.020	0.34	0.92	0.32	0.12	0.03
B	50	0.25	0.50	0.013	0.015	0.38	0.98	0.32	0.12	0.02
C	50	0.25	0.50	0.015	0.018	0.38	0.94	0.34	0.13	0.02
	125[B]									

[A] This is individual heat contribution to the total ingot weight.
[B] Total ingot weight.

Step # 1—Determine furnace factor (FF) for each heat based on weight.

Furnace A = 25/125 = 20 %
Furnace B = 50/125 = 40 %
Furnace C = 50/125 = 40 %

$$FF = \frac{\text{(Individual Fnce Ht. Wt)}}{\text{(Combined Heat Weight)}} \times 100\ \%$$

Step # 2—Calculate the weighted average for each element. Examples for several elements shown below:

$$\text{Weighted avg} = \text{sum of (\% element in each furnace heat} \times \text{FF)}$$

° Weighted avg of Carbon (weighted avg):
Furnace A—0.20 % × 20 % = 0.04 %
Furnace B—0.25 % × 40 % = 0.10 %
Furnace C—0.25 % × 40 % = 0.10 %

Add to get weighted avg of 0.24 %

° Weighted avg of manganese:
Furnace A—0.50 % × 20 % = 0.10 %
Furnace B—0.50 % × 40 % = 0.20 %
Furnace C—0.50 % × 40 % = 0.20 %

Add to get weighted avg of 0.50 %

° Weighted avg of phosphorus:
Furnace A—0.010 % × 20 % = 0.002 %
Furnace B—0.013 % × 40 % = 0.0052 %
Furnace C—0.015 % × 40 % = 0.006 %

Add to get weighted avg of 0.013 %[A]

[A] (Round to significant figures in accordance with Practice E 380.)
° The same procedure is used for all of the other elements.

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since the last issue (A 788 – 03a) that may impact the use of this standard (approved June 10, 2003).

(1) Referenced Documents revised.
*(2)*The order of the melting processes was changed in 5.1.
*(3)*New paragraph 5.1.1 was added.
*(4)*Supplementary Requirement S7 was expanded and revised.

Committee A01 has identified the location of selected changes to this standard since the last issue (A 788 – 03) that may impact the use of this standard (approved April 10, 2003).

(1) "material specification" was changed to "product specification" throughout the document.

Committee A01 has identified the location of selected changes to this standard since the last issue (A 788 – 02) that may impact the use of this standard (approved April 10, 2002).

(1) Specification A 1021 and Guide E 1916 were added to Section 2.

(2) Supplementary requirement S25 was added.

Designation: A 833 – 84 (Reapproved 2001)

Standard Practice for Indentation Hardness of Metallic Materials by Comparison Hardness Testers[1]

This standard is issued under the fixed designation A 833; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the determination of indentation hardness of metallic materials using comparison hardness testers.

1.2 This practice applies only to those comparison hardness testers, normally portable, that use standardized test blocks in accordance with Test Method E 10 as a basis for comparison.

1.3 Calibration of comparative test bars (rods), used for comparison to determine hardness numbers, is also covered by this practice.

1.4 The indenting force used during comparison hardness testing is normally an impact load applied by striking a hammer at the appropriate areas as outlined in the manufacturer's instructions. Final indentation diameter in both the comparative test bar and material tested shall be within the range of the comparator used for the instrument.

1.5 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[2]

E 10 Test Method for Brinell Hardness of Metallic Materials[3]

3. Apparatus

3.1 Comparison hardness testers are used principally for testing articles that are too large or unwieldy to be tested in the usual types of testing machines, for testing parts of fixed structures, or for testing under any conditions that require that the indenting force be applied in a direction other than vertical.

3.1.1 Required equipment includes an apparatus that contains the Brinell ball and a slot or spacing to insert the calibration bar, the bar and an impacting tool, normally a hammer. This apparatus is designed to allow a ball impression to be produced on the standard rod simultaneously with one produced on the piece to be tested. Calibration tables (slide rule) are used to compare impression diameters and the hardness of the calibration bar to determine the hardness of the piece.

3.1.2 This apparatus is designed with a surface directly above the Brinell ball where impact is to occur. The apparatus may also be designed to include an extension for stabilization.

3.2 *Measuring Microscope*—The divisions of the micrometer scale on the microscope, or other measuring devices used for the measurement of the diameter of the impression, shall permit the direct measuring of the diameter to 0.1 mm and the estimation of the diameter to 0.02 mm. This requirement applies to the construction of the microscope only and is not a requirement for measurement of the impression.

4. Test Parts

4.1 Parts tested by this hardness testing practice vary greatly in form since it is frequently desirable to make the impression upon a part to be used in the finished product rather than upon a sample test specimen.

4.1.1 *Dimensions*—The thickness of the tested part shall be such that no bulge or other marking showing the effect of the load appears on the side of the piece opposite the impression. In any event, the thickness of the part shall be at least ten times the depth of the indentation. The minimum width shall be at least two and one half times the diameter of the indentation.

4.1.2 *Finish*—When necessary, the surface on which the impression is to be made shall be filed, ground, machined, or polished with abrasive material so that the edge of the impression shall be defined clearly enough to permit the measurement of the diameter to the specified accuracy. Take care to avoid overheating or cold working the surface. Sufficient metal shall be removed to eliminate decarburized metal.

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[1] This practice is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved Oct. 4, 1984. Published December 1984.

[2] *Annual Book of ASTM Standards*, Vol 01.03.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

4.2 *Support*—All parts to be tested shall be adequately supported to prevent any movement or deflection during application of the impact load.

5. Verification of Apparatus and Calibration of Comparative Bars

5.1 *Verification*—The hardness-testing apparatus and test bars shall be calibrated in accordance with Test Method E 10 prior to use when new, upon replacement of the ball indentor, and periodically during usage as deemed necessary.

5.2 *Comparative Bars*—Hardness of comparative bars (rods) shall be determined by the manufacturer on at least one face at approximately the mid-length of the bar. The ends of the bar shall be permanently marked with the hardness number by the manufacturer prior to shipment. The user shall check the hardness on each additional face to be used prior to testing in accordance with Test Method E 10. If the hardness of a face is not within ±2 % of the marked hardness number, the face shall not be used for part testing.

6. Procedure

6.1 Assemble the comparative bar into the apparatus making sure a minimum distance of no less than 5 mm will exist between diameter of the impression to be made and any other indentations on the face. Minimum distance of the indentation diameter from the edge of the part tested shall be 12.5 mm. If the apparatus is equipped with a presetting bar stop, ensure the fixture is properly in place. Place the apparatus on the surface of the component to be tested and apply the impact load. It is essential to apply a well guided, short blow in order to avoid a rebound and thus a double blow that may produce an erroneous result by damaging the sharp edge of the ball impression.

6.2 *Impression Diameter*—The diameter of the impression produced on the comparative bar should not exceed 4.2 mm. If a larger impression is produced, the comparative bar may give way laterally and the test result may be in error.

6.3 *Measurements*—Measurement of the impression diameters shall be in accordance with Test Methods and Definitions A 370.

6.4 *Determination of Part Hardness*—Employing the calibration device supplied by the manufacturer for the apparatus, determine the hardness of the part by comparing both impression diameters and the hardness of the comparative bar. Accuracy can be improved by using a comparative bar with a hardness number within thirty Brinell (HB) numbers of the part tested.

6.4.1 *Analytical Hardness Determination*—Analytically, the hardness of the part being tested may be determined from the following equation:

$$B_1 = B_2\,(10 - \sqrt{100 - D_1^{\,2}})/(10 - \sqrt{100 - D_2^{\,2}})$$

B_1 = indentation hardness of the part being tested,
B_2 = Brinell hardness of the comparative bar,
$D_1^{\,2}$ = diameter of impression in the comparative bar,
$D_2^{\,2}$ = diameter of impression in the part being tested.

7. Report

7.1 The report shall include the following information:

7.1.1 Indentation hardness number of the component and the Brinell hardness number of the comparative bar,

7.1.2 Identification of the manufacturer's equipment, and

7.1.3 Diameters of the indentations in the component and comparative bar.

Designation: A 837/A 837M – 03

Standard Specification for Steel Forgings, Alloy, for Carburizing Applications[1]

This standard is issued under the fixed designation A 837/A 837M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers alloy steel forgings for carburizing applications.

1.2 Forgings are considered weldable under proper conditions. Welding technique is of fundamental importance and it is presupposed that welding procedure and inspection shall be in accordance with approved methods for the class of material used.

1.3 This specification is expressed in both inch-pound units and in SI units. However, unless the order specifies the applicable *M* specification designation (SI units), the material shall be furnished to inch-pound units.

1.4 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings[2]

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings[2]

A 788 Specification for Steel Forgings, General Requirements[2]

E 527 Practice for Numbering Metals and Alloys (UNS)[3]

3. Ordering Information

3.1 Instructions for purchasing forgings to this specification are to be in accordance with Specification A 788.

3.2 In addition to the basic requirements of this specification, certain supplementary requirements are listed at the end of this specification. These supplementary requirements may be applicable when additional control, testing, or examination is required to meet end use requirements.

4. Heat Treatment

4.1 The forgings shall be given a normalize or normalize and temper heat treatment.

5. Machining

5.1 Rough machining before heat treatment may be performed at the option of the manufacturer.

6. Chemical Composition

6.1 The steel shall conform to the requirements for chemical composition prescribed in Table 1 unless otherwise modified in accordance with Supplementary Requirement S4.

7. Mechanical Properties

7.1 *Hardness*:

7.1.1 Maximum hardness of the forgings shall be 229 BHN.

7.1.2 Hardness tests shall be taken on prepared surfaces of the forging after machining to the purchaser's ordering requirements.

7.1.3 *Number and Location of Tests*:

7.1.3.1 For forgings not intended for gear applications, the number and location of hardness tests shall be by agreement between the purchaser and forger.

7.1.3.2 For gear applications on each forging 8 in. [200 mm] and over in diameter, four Brinell hardness tests shall be made on the outside surface of that portion of the forging on which teeth will be cut two tests being made on each helix 180° apart, and the tests on the two helices shall be 90° apart. On each forging under 8 in. [200 mm] in diameter two Brinell hardness tests shall be made, one on each helix 180° apart. On hollow, cylindrical forgings, one hardness test on each end shall be taken 180° apart. Hardness tests shall be performed at the quarter-face width of the tooth-portion diameter.

8. Other Requirements

8.1 Forgings supplied to this material specification shall conform to the latest issue of Specification A 788.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved June 10, 2003. Published July 2003. Originally approved in 1985. Last previous edition approved in 2001 as A 837 – 91 (2001).

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.01.

***A Summary of Changes section appears at the end of this standard.**

TABLE 1 Grade Designations and Chemical Compositions

UNS Designation[A]	Grade Designation[B]	Chemical Composition, Ranges and Limits, % Carbon	Manganese	Phosphorus, max	Sulfur, max	Silicon[C]	Nickel	Chromium	Molybdenum	Copper, max
G33106	E3310	0.08–0.13	0.45–0.60	0.025	0.025	0.15–0.35	3.25–3.75	1.40–1.75	0.10 max	0.35
G43200	4320	0.17–0.22	0.45–0.65	0.035	0.040	0.15–0.35	1.65–2.00	0.40–0.60	0.20–0.30	0.35
G46200	4620	0.17–0.22	0.45–0.65	0.035	0.040	0.15–0.35	1.65–2.00	0.25 max	0.20–0.30	0.35
G48150	4815	0.13–0.18	0.40–0.60	0.035	0.040	0.15–0.35	3.25–3.75	0.25 max	0.20–0.30	0.35
G86200	8620	0.18–0.23	0.70–0.90	0.035	0.040	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25	0.35
G93100	9310	0.07–0.13	0.40–0.70	0.035	0.040	0.15–0.35	2.95–3.55	1.00–1.45	0.08–0.15	0.35
S41000	410	0.15 max	1.00 max	0.040	0.030	1.00 max	0.50 max	11.50–13.50	0.10 max	0.35

[A] New designation established in accordance with Practice E 527.
[B] Grade designations correspond to the respective Practice E 527.
[C] When vacuum carbon deoxidation is used, silicon maximum shall be 0.10 %.

8.2 Specification A 788 covers forging terminology, melting processes, chemical analysis test methods, product analysis tolerances, mechanical testing methods, repair welding restrictions, marking, and certification requirements.

9. Keywords

9.1 alloy steel forgings; carburizing

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser on the order and agreed to by the manufacturer.

S1. Rough Turning and Boring

S1.1 The position of rough turning and boring in the sequence of manufacturing operations is specified.

S2. Magnetic Particle Examination

S2.1 Magnetic particle examination shall be specified in accordance with Test Method A 275/A 275M. Reporting and acceptance standards shall be a matter of agreement.

S3. Ultrasonic Examination

S3.1 Ultrasonic examination shall be specified in accordance with Practice A 388. Reporting and acceptance standards shall be a matter of agreement.

S4. Phosphorous and Sulfur Restriction

S4.1 Phosphorus shall not exceed 0.015 %, and the sulfur shall not exceed 0.018 % for all classes when determined in accordance with the heat analysis requirements of Specification A 788.

S5. Vacuum Degassing

S5.1 Vacuum treatment of the molten steel prior to or during the pouring of the ingot is required.

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes since A 837/A 837M – 91 (2001) that may impact the use of this standard.

(1) Added metric units in section 7.1.3.2.

Designation: A 859/A 859M – 04

An American National Standard

Standard Specification for Age-Hardening Alloy Steel Forgings for Pressure Vessel Components[1]

This standard is issued under the fixed designation A 859/A 859M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers requirements for low-carbon age-hardening nickel-copper-chromium-molybdenum-columbium alloy steel forgings for pressure vessel components.

1.2 Forgings under this specification are available as Grades A or B. Grade A may be ordered in one or two classes as follows:

1.2.1 *Grade A Class 1*—Normalized-and-precipitation-heat-treated, providing a minimum yield strength of 55 ksi [380 MPa] and a minimum tensile strength of 65 ksi [450 MPa].

1.2.2 *Grade A Class 2*—Quenched-and-precipitation-heat-treated, providing a minimum yield strength of 65 ksi [450 MPa] and a minimum tensile strength of 75 ksi [MPa].

1.2.3 Grade A was the original steel composition in this specification.

1.3 Although the material is readily weldable, welding procedures are of fundamental importance and must be such as not to affect adversely the properties of the material, especially in the heat-affected zone. It is presupposed that welding procedures will be suitable for the material being welded.

1.4 Supplementary requirements, including those applicable in Specification A 788, are provided for use when additional testing or inspection is desired. These shall apply only when specified individually by the purchaser in the order.

1.5 The values stated in either inch-pound or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.6 This specification is expressed in both inch-pound and SI units. However, unless the order specifies the applicable "M" specification designation [SI units], the material shall be furnished to inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings

A 788 Specification for Steel Forgings, General Requirements

E 208 Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels

E 604 Test Method for Dynamic Tear Testing of Metallic Materials

2.2 *ASME Standard:*

ASME[3] Boiler and Pressure Vessel Code—Section IX, Welding Qualifications

3. Ordering Information and General Requirements

3.1 In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order a detailed drawing, sketch, or written description of the forging and the method of selecting test location (see 6.3). When appropriate, the areas of significant loading in the forging shall be designated.

3.2 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved March 1, 2004. Published April 2004. Originally approved in 1986. Last previous edition approved in 2002 as A 859/A 859M – 02.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017.

***A Summary of Changes section appears at the end of this standard.**

3.3 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

4. Manufacture

4.1 *Melting Practice*—The steel shall be made to a killed, fine austenitic grain size, practice.

4.1.1 Vacuum degassing in accordance with Specification A 788 is highly recommended.

4.2 *Heat Treatment*:

4.2.1 Normalizing may, at the manufacturer's option, precede the prescribed heat treatment cycle.

4.2.2 Grade A Class 1 forgings shall be normalized at a temperature in the range from 1600 to 1725°F [870 to 940°C] and then precipitation hardened in the range from 1000 to 1225°F [540 to 665°C] for a time to be determined by the material manufacturer.

4.2.3 Grade A Class 2 forgings shall be liquid quenched from a temperature in the range from 1600 to 1725°F [870 to 940°C] and then precipitation hardened in the range from 1000 to 1225°F [540 to 665°C] for a time to be determined by the material manufacturer.

4.2.4 Grade B forgings shall be double quenched and tempered (liquid quenched twice) by austenitizing twice at a temperature in the range of 1600 tp 1725°F [870 to 940°C], and then precipitation hardened at a temperature in the range of 1000 to 1300°F [540 to 700°C] for a time to be determined by the manufacturer.

5. Chemical Composition

5.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 shall comply with Table 1.

5.2 *Product Analysis*—The purchaser may use the product analysis provision of Specification A 788 to obtain a product analysis from a forging representing each heat or multiple heat.

6. Mechanical Requirements

6.1 *Tensile Requirements*—The forgings, as represented by the tension test specimens, shall conform to the requirements of Table 2. The largest obtainable tension test specimen as specified in Test Methods and Definitions A 370 shall be used.

6.2 *Notch Toughness Requirements*:

6.2.1 For Grade A, Class 1 or 2 forgings, unless Supplementary Requirement S6 is specified, the Charpy impact test results shall conform to the requirements of Table 3. One set of three specimens shall be removed from each specimen location as specified in 6.3. The supplier may select a test temperature colder than that specified in the order, but in any case, the actual test temperature shall be reported with the test results.

6.2.2 For Grade B forgings two sets of Charpy impact specimens shall be removed from each test specimen location as specified in 6.3 and shall conform to the requirements of Table 3.

6.2.3 Full-size, 10 by 10 mm, Charpy V-notch specimens shall be used unless the material thickness or configuration makes it impossible to obtain full-size specimens. If the use of sub-size specimens is necessary, the largest standard sub-size specimen it is possible to obtain shall be used.

6.2.4 The acceptance values for sub-size specimens shall be reduced in direct ratio to the reduction of specimen width.

6.3 *Sampling*—The longitudinal axis and the mid-length of tension and impact test specimens shall be positioned in accordance with one of the following methods as specified by the purchaser:

6.3.1 *Method 1*—This method shall always be used when the maximum as-heat-treated thickness does not exceed 2 in. [50 mm]. Specimens shall be located in the production forging or test forging (as described in Method 4) at mid-thickness and at least 2 in. [50 mm] from other as-heat-treated surfaces.

6.3.2 *Method 2*—*T* by 2*T*, where *T* is the distance from the area of significant loading (see 3.1) to the nearest as-heat-treated surface. However, the specimen shall not be nearer to one as-heat-treated surface than ¾ in. [20 mm] and not nearer than 1½ in. [40 mm] to a second as-heat-treated surface. When this method of testing is employed, forgings are usually manufactured in accordance with a purchaser-approved drawing showing pre-heat-treatment dimensions and the location of test specimens.

TABLE 1 Chemical Requirements

	Composition, %	
Element	Grade A	Grade B
Carbon	0.07 max	0.02–0.04
Manganese	0.40–0.70	0.75–1.05
Phosphorus, max	0.025	0.015
Sulfur, max	0.025	0.002
Silicon, max	0.40	0.40
Chromium	0.60–0.90	0.45–0.75
Nickel	0.70–1.00	3.35–3.85
Molybdenum	0.15–0.25	0.55–0.65
Copper	1.00–1.30	1.15–1.75
Columbium	0.02 min	0.02–0.06
Vanadium max	...	0.008
Aluminum max	...	0.03
Titanium max	...	0.003
Tin max	...	0.03
Arsenic max	...	0.025
Antimony max	...	0.025
Nitrogen	...	report

TABLE 2 Tensile Requirements

Property	Grade A Class 1	Grade A Class 2	Grade B
Yield strength 0.2% offset ksi [MPa]	55 [380 min]	65 [450] min	100–115 [690–800]
Tensile Strength ksi [MPa]	65–85 [450–585]	75–95 [515–650]	105 [725] min
Elongation in 2 in. or 50 mm % min	20	20	16
Reduction of Area % min	45	45	45

TABLE 3 Charpy Impact Requirements

	Grade A Class1 −50°F [−45°C]	Grade A Class2 −50°F [−45°C]	Grade B 0°F [18°C]	Grade B —120°F [-85°C]
Test Average, ft/lb [J][A]	20 [27]	20 [27]	80 [110]	60 [80]
Minimum single value, ft/lb [J]	15 [20]	15 [20]	75 [100]	55 [75]

[A] Not more than one specimen from a set may be below this value.

6.3.3 *Method 3*—¼ *T* by *T*, where *T* is the maximum thickness of the forging as-heat-treated. When this method of testing is employed for Class 2, the maximum as-heat-treated thickness shall not exceed 8 in. [200 mm] unless otherwise agreed.

6.3.4 *Method 4*—Test specimens shall be taken from a representative separate test forging or bar made from the same heat of steel that shall receive substantially the same reduction and type of hot working as the production forgings which it represents; except that a longitudinally forged bar may be used to represent a rolled ring of similar cross section. It shall be of the same nominal thickness as the as-heat-treated production forgings and shall be heat treated in the same furnace charge and under the same conditions as the production forgings. Test specimens shall be removed using the ¼ *T* by *T* procedure referenced in Method 3 with the same limitation on forging thickness as in 6.3.3. This method shall be limited to forgings with a rough machined weight of not more than 1000 lb [500 kg].

6.4 *Metal Buffers*—The required distances from as-heat-treated surfaces may be obtained with metal buffers instead of integral extensions. Buffer material may be carbon or low-alloy steel and shall be joined to the forging with a partial penetration weld that seals the buffered surface. Specimens shall be located at least ½ in. [13 mm] from the buffered surface of the forging. Buffers shall be removed and the welded areas subjected to magnetic particle test to ensure freedom from cracks unless the welded areas are completely removed by subsequent machining.

6.5 Samples shall be removed from forgings after heat treatment. The sample material shall be subjected to a simulated post-weld heat-treatment if Supplementary Requirement S1 is specified.

6.6 *Orientation*—For upset disk forgings, the longitudinal axis of all test specimens shall be oriented in the tangential direction. For all other forgings, the longitudinal axis of the specimens shall be oriented in the direction of maximum working of the forging unless Supplementary Requirements S11 or S14 are imposed.

6.7 *Number of Tests*:

6.7.1 *Forgings Under 500 lb [250 kg] As-Heat-Treated*—For duplicate forgings weighing less than 500 lb [250 kg] as-heat-treated, one tension test and one impact test (three specimens) shall be made to represent each heat in each heat-treatment charge. When heat-treatment is performed in continuous-type furnaces with suitable temperature control and equipped with recording pyrometers so that complete heat-treatment records are available, a heat-treatment charge shall be considered as any continuous run not exceeding any 8-h duration.

6.7.2 *Forgings Weighing 500 to 10 000 lb [250 to 5000 kg] As-Heat-Treated*—One tension and one impact test (three specimens) shall be made for each forging.

6.7.3 Each forging weighing over 10 000 lb [5000 kg] shall require two tension tests and two impact tests, located at opposite ends if the length, excluding test prolongations, exceeds 80 in. [2000 mm], or located 180° apart for shorter length forgings.

7. Workmanship, Finish, and Appearance

7.1 The forgings shall conform to the dimensions specified by the purchaser. The finishes shall permit adequate visual inspection for surface imperfections. If a dimension varies from that specified, the forging may be offered to the purchaser for acceptance.

8. Repair Welding

8.1 Repair welding of forgings shall be permitted only with the approval of the purchaser.

8.2 Preparation for repair welding shall include inspection to ensure complete removal of the defect.

8.3 Repairs shall be made using welding procedures qualified in accordance with ASME Boiler and Pressure Vessel Code Section IX and repair welding shall be done by welders or welding operators meeting the qualification requirements of that code.

9. Test Reports

9.1 A test report shall be furnished and shall include certification that the material was manufactured and tested in accordance with this specification. The report shall include the results of all required tests, including heat analysis, mechanical test results, the type of heat treatment, and the test sampling method.

10. Keywords

10.1 precipitation hardening steel; pressure containing parts; pressure vessel service; steel forgings—alloy

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser on the order. Details of these supplementary requirements shall be agreed upon by the manufacturer and purchaser.

S1. Simulated Post-Weld Heat Treatment of Mechanical Test Coupons

S1.1 All test coupons shall be subjected to single or multiple heat treatments at subcritical temperatures prior to testing. Such treatments are intended to simulate post-weld or other thermal treatments to which the forgings will be subjected during subsequent fabrication. The purchaser shall furnish the manufacturer with details of the desired heat treatment for the test coupons, including temperatures, times, and cooling rates.

S2. Ultrasonic Examination

S2.1 The forgings shall be ultrasonically examined in accordance with the procedures of Practice A 388/A 388M.

S2.1.1 *Longitudinal Wave Test:*

S2.1.1.1 Unless otherwise specified, the back-reflection method of tuning shall be used in accordance with 7.2.2.1 of Practice A 388/A 388M.

S2.1.1.2 In addition to the reportable conditions of Section 8 of Practice A 388/A 388M, indications exceeding the resultant back reflection shall be recorded.

S2.1.1.3 The following conditions are subject to rejection:

(a) Complete loss of back reflection accompanied by an indication of a discontinuity. For this purpose, a back reflection less than 5 % of full screen height shall be considered complete loss of back reflection.

(b) An indication equal in amplitude to that of the back reflection established in an indication-free portion of the forging.

S2.1.2 *Angle Beam Test:*

S2.1.2.1 Calibration notches, calibration reference, and method of scanning shall be in accordance with 7.3 of Practice A 388/A 388M.

S2.1.2.2 A forging that contains a discontinuity that results in an indication exceeding the amplitude of the reference line is subject to rejection.

S2.1.3 The report of the ultrasonic examination shall be in compliance with Section 9 of Practice A 388/A 388M.

S2.1.4 Additional nondestructive examination or trepanning may be employed to resolve questions of interpretation of ultrasonic indications. The manufacturer shall accept responsibility for injurious conditions that will not be removed in final machining.

S3. Magnetic Particle Examination

S3.1 Each forging shall be examined by magnetic particle methods described in Test Method A 275/A 275M. Acceptance standards shall be specified by the purchaser.

S3.2 Alternatively the purchaser may specify that Supplementary Requirement S18 of Specification A 788 shall be used as the basis for the magnetic particle examination.

S4. Charpy V-Notch Impact Transition Curve

S4.1 Sufficient impact test shall be made from the forging test material to establish a temperature/absorbed-energy curve. The test temperature range shall be wide enough to establish the upper and lower shelf foot-pound-force [Joule] energies, with sufficient testing at intermediate temperatures to permit plotting a reasonably smooth curve.

S5. Additional Charpy V-Notch Test Data

S5.1 The percent shear fracture and mils [mm] of lateral expansion shall be reported for each specimen tested.

S6. Charpy V-Notch Test

S6.1 For Grade A, Class 1 or 2 forgings the specified test temperature for the Charpy V-Notch tests required in Section 6 of this specification shall be a temperature lower than −50°F [−45°C]. The specified test temperature shall be stated in the order.

S6.2 The charpy impact test temperature used shall be included in the forging certification and marking.

S7. Drop-Weight Test

S7.1 Drop-weight tests shall be conducted in accordance with Test Method E 208. The fracture plane of the specimen shall coincide with the location required for other mechanical test specimens as specified by the purchaser in accordance with 6.3. However, since the drop-weight specimen can be taken in any orientation, the fracture plane of the specimen when tested to Method 2 (see 6.3.2) shall be a minimum distance of 7⁄16 in. [10 mm] from the nearest quenched surface, and 1½ in. [40 mm] from any second surface. The purchaser may specify either duplicate no-break performance when tested 10°F [5°C] warmer than a specified temperature or request a determination of the Nil-Ductility temperature.

S8. Rings and Hollow Cylindrically-Shaped Parts

S8.1 Tests shall be removed in the tangential (circumferential) direction regardless of the direction of maximum working.

S9. Alternative Test Specimen Orientation

S9.1 The longitudinal axis of all test specimens shall be oriented in a direction transverse to the direction of maximum working of the forging.

Dynamic Tear Test

S10.1 For Grade B material, dynamic tear testing shall be carried out in accordance with Test Method E 604. Unless otherwise specified by the purchaser the test temperature shall be –20±3°F [-30±2°C]. Acceptance criteria shall be in accordance with the purchase order requirements.

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 859/A 859M-02 (Approved Sept. 10, 2002) that may impact the use of this standard.

(1) Existing material was named Grade A, new material was named Grade B.
(2) Tables 1, 2, and 3 were revised to include the new grade.
(3) Reference to the original grade was included in the Scope.
(4) Sections 4 and 6 were revised to accomodate Grade B.
(5) SI units were rationalized in 6.3.4 and 6.7.
(6) Supplementary Requirement S6 was revised to reference Grade A.
(7) Supplementary Requirement S10 was added.
(1) Supplementary Requirement S3 revised

Designation: A 866 – 01

Standard Specification for Medium Carbon Anti-Friction Bearing Steel[1]

This standard is issued under the fixed designation A 866; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers medium carbon bearing quality steel to be used in the manufacture of anti-friction bearings.

1.2 Supplementary requirements of an optional nature are provided and when desired shall be so stated in the order.

1.3 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products[3]

E 45 Practice for Determining the Inclusion Content of Steel[4]

E 112 Test Methods for Determining Average Grain Size[4]

E 381 Test Method for Macrotech Testing, Inspection and Rating Steel Products, Comprising Bars, Billets, Blooms, and Forgings[4]

E 1019 Test Methods for Determination of Carbon, Sulfur, Nitrogen, Oxygen, and Hydrogen in Steel and in Iron, Nickel, and Cobalt Alloys[5]

E 1077 Test Method for Estimating the Depth of Decarburization of Steel Specimens[4]

2.2 *ISO Standard:*

ISO 683 Part 17: Ball and Roller Bearing Steels

3. Ordering Information

3.1 Orders for material under this specification should include the following information:

3.1.1 Quantity (weight or pieces),

3.1.2 Grade identification,

3.1.3 ASTM designation and year of issue,

3.1.4 Dimensions, and

3.1.5 Supplementary requirements, if included.

4. Materials and Manufacture

4.1 *Process:*

4.1.1 The steel shall be made by a process that is capable of providing a high quality product meeting the requirements of this specification.

5. Chemical Composition and Analysis

5.1 Typical examples of chemical composition are shown in Table 1. Other compositions may be specified.

5.2 An analysis of each heat of steel shall be made by the steel manufacturer in accordance with Test Methods, Practices, and Terminology A 751. The chemical composition thus determined shall conform to the requirements specified in Table 1 for the ordered grade or to other requirements agreed upon between the manufacturer and the purchaser.

5.3 Product analysis may be made by the purchaser in accordance with Test Methods, Practices, and Terminology A 751. Permissible variations in product analysis shall be in accordance with Specification A 29/A 29M.

6. Sizes, Shapes, and Dimensional Tolerances

6.1 The physical size and shape of the material shall be agreed upon between the manufacturer and the purchaser.

6.2 Dimensional tolerances for hot-rolled or hot-rolled and annealed bars, in straight lengths or coils, and cold-finished bars 0.500 in. (12.7 mm) and larger in diameter furnished under this specification shall conform to the requirements specified in the latest edition of Specification A 29/A 29M.

6.3 Dimensional tolerances for cold-finished coils for ball and roller material shall be as shown in Table 2.

6.4 Coil tolerances also apply to cold-finished straight lengths under 0.500 in. in diameter.

7. Quality Tests

7.1 The supplier shall be held responsible for the quality of the material furnished and shall make the necessary tests to ensure this quality. The supplier shall be required to report on the results of the macroetch and micro-inclusion rating tests

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.28 on Bearing Steels.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] *Annual Book of ASTM Standards*, Vol 03.06.

TABLE 1 Chemical Composition[A,B]

Number[C]	Name	C	Mn	P (max)	S (max)	Si	Cr	Mo	V	Cu (max)	O (max)[D]	Al (max)
. . .	1030	0.28 to 0.34	0.60 to 0.90	0.025	0.025	0.15 to 0.35	. . .	. . .	. . .	0.30	0.0020	0.050
. . .	1040	0.37 to 0.44	0.60 to 0.90	0.025	0.025	0.15 to 0.35	. . .	. . .	. . .	0.30	0.0020	0.050
. . .	1050	0.48 to 0.55	0.60 to 0.90	0.025	0.025	0.15 to 0.35	. . .	. . .	. . .	0.30	0.0020	0.050
. . .	1541	0.36 to 0.44	1.35 to 1.65	0.025	0.025	0.15 to 0.35	. . .	. . .	. . .	0.30	0.0020	0.050
. . .	1552	0.47 to 0.55	1.20 to 1.50	0.025	0.025	0.15 to 0.35	. . .	. . .	. . .	0.30	0.0020	0.050
. . .	4130	0.28 to 0.33	0.40 to 0.60	0.025	0.025	0.15 to 0.35	0.80 to 1.10	0.15 to 0.25	. . .	0.30	0.0020	0.050
. . .	4140	0.38 to 0.43	0.75 to 1.00	0.025	0.025	0.15 to 0.35	0.80 to 1.10	0.15 to 0.25	. . .	0.30	0.0020	0.050
. . .	4150	0.48 to 0.53	0.75 to 1.00	0.025	0.025	0.15 to 0.35	0.80 to 1.10	0.15 to 0.25	. . .	0.30	0.0020	0.050
. . .	5140	0.38 to 0.43	0.70 to 0.95	0.025	0.025	0.15 to 0.35	0.70 to 0.90	. . .	. . .	0.30	0.0020	0.050
. . .	5150	0.48 to 0.53	0.70 to 0.90	0.025	0.025	0.15 to 0.35	0.70 to 0.90	. . .	. . .	0.30	0.0020	0.050
. . .	6150	0.48 to 0.53	0.70 to 0.90	0.025	0.025	0.15 to 0.35	0.80 to 1.10	. . .	0.15 min	0.30	0.0020	0.050
B40	C56E2	0.52 to 0.60	0.60 to 0.90	0.025	0.015	0.40 max	. . .	. . .	. . .	0.30	0.0020	0.050
B41	56Mn4	0.52 to 0.60	0.90 to 1.20	0.025	0.015	0.40 max	. . .	. . .	. . .	0.30	0.0020	0.050
B43	43CrMo4	0.40 to 0.46	0.60 to 0.90	0.025	0.015	0.40 max	0.90 to 1.20	0.15 to 0.30	. . .	0.30	0.0020	0.050

[A] Elements not quoted shall not be intentionally added to the steel without the agreement of the purchaser.
[B] Intentional additions of calcium or calcium alloys for deoxidation or inclusion shape control are not permitted unless specifically approved by the purchaser.
[C] Steels B40, B41, and B43 meet the requirements of ISO 683, Part 17, Second Edition, Table 3.
[D] Oxygen content applies to product analysis and shall be determined in accordance with Test Methods E 1019.

TABLE 2 Dimensional Tolerances for Cold-Finished Coils

Size, in. (mm)	Total Tolerance, in. (mm)
Through 0.096 (2.44)	0.002 (0.05)
Over 0.096 (2.44) to 0.270 (6.86), incl	0.003 (0.08)
Over 0.270 (6.86) to 0.750 (19.1), incl	0.004 (0.10)

detailed below. Quality tests shown in 7.2 through 7.4 are based upon procedures established in Practice E 45.

7.2 *Sampling*—Samples taken in accordance with the following paragraphs shall be obtained from 4 by 4 in. (102 by 102 mm) rolled billets or forged sections. Tests may be made on smaller or larger sections by agreement with the purchaser. A minimum 3 to 1 reduction of rolled billets or forged sections is required for strand cast products.

7.2.1 For top poured products, a minimum of six samples representing the top and bottom of the first, middle, and last usable ingots shall be examined.

7.2.2 For bottom poured products, a minimum of six samples shall be examined and they shall represent the top and bottom of three ingots. One ingot shall be taken at random from the first usable plate poured, one ingot, at random, from the usable plate poured nearest to the middle of the heat, and one ingot, at random, from the last usable plate poured. When two usable plates constitute a heat, two of the sample ingots shall be selected from the second usable plate poured. Where a single usable plate constitutes a heat, any three random ingots may be selected. Other methods of sampling shall be as agreed upon by manufacturer and purchaser.

7.2.3 For strand cast products, a minimum of six samples representing the first, middle, and last portion of the heat cast shall be examined. At least one sample shall be taken from each strand.

7.3 *Macroetch*—Specimens representative of cross sections of billets shall be macroetched and rated in accordance with Test Method E 381 in hydrochloric acid and water (1:1) at a temperature of 160 to 180°F (71 to 82°C). Such specimens shall not exceed S2, R2, and C2 of Test Method E 381.

7.4 *Inclusion Rating*—The specimens shall be ⅜ by ¾ in. (9.5 by 19.1 mm) and shall be taken from an area halfway between the center and outside of the billet. The polished face shall be longitudinal to the direction of rolling. The scale used for rating the specimens shall be the Jernkontoret chart described in Practice E 45, Plate I-r. Fields with sizes or numbers of all types of inclusions intermediate between configurations shown on the chart shall be classified as the lesser of the rating number. The worst field of each inclusion type from each specimen shall be recorded as the rating for the specimen. Two thirds of all specimens and at least one from each ingot tested, or from the first, middle, and last portion of the strands tested, as well as the average of all specimens, shall not exceed the rating specified in Table 3.

8. Grain Size

8.1 The grain size shall be from 5 to 8 as defined in Test Methods E 112 (see Plate 4, Austenitic Grain Size in Steels), with occasional grains as large as No. 3 permissible. Material not meeting this requirement may be normalized at 1700°F (925°C) or above, and retested.

9. Decarburization and Surface Imperfections

9.1 Decarburization and surface imperfections shall not exceed the limits specified in Tables 4 and 5. Decarburization shall be measured using the microscopical methods described in Test Method E 1077.

10. Microstructure and Hardness

10.1 Material may be ordered as hot rolled or thermally treated. When thermally treated, the acceptance criteria for microstructure and hardness shall be agreed upon between the manufacturer and the purchaser. No hardness limits shall apply for as-hot-rolled materials.

TABLE 3 Inclusion Rating

Rating Units	
Thin Series	Heavy Series
A 2.5	A 1.5
B 2.0	B 1.0
C 0.5	C 0.5
D 1.0	D 1.0

TABLE 4 Decarburization and Surface Imperfections for Coils and Bars for Balls and Rollers

Size, in. (mm)	Decarburization or Surface Imperfections per Side, max, in. (mm)	
	Hot-Rolled or Hot-Rolled Annealed	Cold-Finished Annealed
Through 0.250 (6.35)	0.005 (0.13)	0.003 (0.08)
Over 0.250 (6.35) to 0.500 (12.7), incl	0.006 (0.15)	0.004 (0.10)
Over 0.500 (12.7) to 0.750 (19.1), incl	0.008 (0.20)	0.006 (0.15)
Over 0.750 (19.1) to 1.000 (25.4), incl	0.010 (0.25)	0.008 (0.20)

TABLE 5 Decarburization and Surface Imperfections for Bars and Tubes

Size, in. (mm)	Decarburization or Surface Imperfections per Side, max, in. (mm)				
	Hot-Rolled Bars	Hot-Rolled Annealed		Cold-Finished Annealed	
		Bars	Tubes	Bars	Tubes
Through 1.000 (25.4)	0.012 (0.31)	0.015 (0.38)	0.012 (0.31)	0.012 (0.31)	0.010 (0.21)
Over 1.000 (25.4) to 2.000 (50.8), incl	0.017 (0.43)	0.022 (0.56)	0.020 (0.51)	0.015 (0.38)	0.014 (0.36)
Over 2.000 (50.8) to 3.000 (76.2), incl	0.025 (0.64)	0.030 (0.76)	0.030 (0.76)	0.025 (0.64)	0.019 (0.48)
Over 3.000 (76.2) to 4.000 (101.6), incl	0.035 (0.89)	0.045 (1.14)	0.035 (0.89)		0.024 (0.61)
Over 4.000 (101.6) to 5.000 (127.0), incl	0.055 (1.40)	0.065 (1.65)	0.040 (1.02)		0.028 (0.71)

11. Inspection

11.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Mill inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspections shall be made at the place of manufacture, unless otherwise agreed to.

12. Certification and Reports

12.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification, together with a report of the test results, shall be furnished at the time of shipment. Special requirements agreed to at the time of purchase must be noted on the certification.

SUPPLEMENTARY REQUIREMENTS

One or more of the supplementary requirements described below apply when included in the purchaser's order or contract. When so included, a supplementary requirement shall have the same force as if it were in the body of the specification. Supplementary requirements' details not fully described shall be agreed upon between the purchaser and the supplier, but shall not negate any of the requirements in the body of the specification.

S1. Titanium Content

S1.1 The purchaser may specify that the analysis of titanium be provided by agreement with the steel manufacturer.

S2. Residual Elements

S2.1 The purchaser may specify that the analysis of titanium, aluminum, and/or oxygen (Test Methods E 1019) be provided by agreement with the steel manufacturer. The number and location of samples shall be by agreement between the purchaser and the manufacturer.

S3. "SAM'' Inclusion Rating System

S3.1 The purchaser may specify that the "SAM'' inclusion rating described in Method E of Practice E 45, be used in addition to the micro-inclusion rating method described in 7.4.

S3.2 *Sampling*—See 7.2.

S3.3 *Limits*—The "SAM'' rating for B-type inclusions shall not exceed fifteen. The "SAM'' rating for D-type inclusions shall not exceed ten.

S4. Magnetic Particle Method

S4.1 The purchaser may specify that the magnetic particle method described below be used in addition to the microinclusion rating system described in 6.4. The magnetic particle method measures bearing steel cleanliness by evaluating the total length of macro-inclusions for a stated area or per unit area. Results are commonly expressed in mm/m^2.

S4.2 *Sampling*—See 6.2.

S4.3 Test specimens shall be straight cylinder quarter section samples prepared and examined in accordance with the magnetic particle method of Practice E 45.

S4.4 For purposes of calculation, an inclusion length shall be taken as the mean length of the length bracket into which it falls; that is, an inclusion in the 1⁄16 to 1⁄8 in. bracket shall be taken as being 3⁄32 in. in length. The sum of all lengths for each specimen shall be determined and expressed as total length per area inspected. The average total length per area inspected of all six specimens shall not exceed 200 mm/m^2 (or equivalent).

S5. Sulfur Requirement for Machinability

S5.1 The sulfur content shall be 0.015–0.030 %.

S5.2 The sulfide (Type A) rating units in Table 2 shall be 3.0 thin and 2.0 heavy.

S5.3 The manufacturer's certification shall state that material was produced to this supplementary requirement when applicable.

S6. Sample Reduction Ratio

S6.1 For the sampling described in 7.2, the purchaser may specify that the reduction ratio from as-cast section to test section be provided.

Designation: A 891 – 98

Standard Specification for Precipitation Hardening Iron Base Superalloy Forgings for Turbine Rotor Disks and Wheels[1]

This standard is issued under the fixed designation A 891; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers precipitation hardening iron base superalloy forgings which are primarily intended for use as turbine rotor disks and wheels.

1.2 Two heat treatments are covered. Selection will depend upon design, service conditions, mechanical properties, and elevated temperature characteristics.

1.3 All of the provisions of Specification A 788, apply, except as amended herein.

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 788 Specification for Steel Forgings, General Requirements[2]

E 112 Test Methods for Determining the Average Grain Size[3]

E 139 Practice for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials[3]

E 165 Practice for Liquid Penetrant Examination[4]

E 292 Practice for Conducting Time-for-Rupture Notch Tension Tests of Materials[3]

3. Ordering Information

3.1 Orders for material under this specification shall include the information specified in Specification A 788 and the following:

3.1.1 *Condition*—See Section 4.

3.1.2 *Stress Rupture Test*—Parameters for material furnished in condition 2 of 8.3.3.

3.1.3 *Forging Drawing*—Each forging shall be manufactured in accordance with a drawing furnished by the purchaser showing the dimensions of the forging and the location of mechanical test specimens.

4. Condition

4.1 The forgings covered in this specification may be ordered in two different solution treated and aged conditions:

4.1.1 *Type 1*:

4.1.1.1 Solution anneal at 1650 ± 25°F (900 ± 14°C) for 2 to 5 h at temperature liquid quench.

4.1.1.2 Precipitation harden at 1420 ± 15°F (770 ± 8°C) for 16 h at temperature air cool; 1200 ± 15°F (650 ± 8°C) for 16 h at temperature air cool.

4.1.2 *Type 2*:

4.1.2.1 Solution anneal at 1800 ± 25°F (980 ± 14°C) for 2 to 5 h at temperature liquid quench.

4.1.2.2 Precipitation harden at 1420 ± 15°F (770 ± 8°C) for 16 h at temperature air cool; 1200 ± 15°F (650 ± 8°C) for 16 h at temperature air cool.

5. Manufacture

5.1 The material shall be made by vacuum melting followed by consumable electrode vacuum arc or electroslag remelting as agreed upon between producer and user.

5.2 The forgings shall be upset forged so that the axis of the disk corresponds with that of the ingot.

6. Chemical Requirements

6.1 *Heat Analysis*—Each heat shall be analyzed by the manufacturer in accordance with Specification A 788. The chemical composition shall conform to the requirements specified in Table 1.

7. Heat Treatment

7.1 The forgings shall be heat treated in accordance with 4.1.

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[1] This specification is under the jurisdiction of Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] *Annual Book of ASTM Standards*, Vol 03.03.

TABLE 1 Chemical Composition

Element	Heat and Product Analyses Range, Percentage	Product Analysis Tolerance—Over or Under
Carbon	0.05 max	0.01
Manganese	0.50 max	0.03
Silicon	0.50 max	0.05
Phosphorus	0.025 max	0.005
Sulfur	0.015 max	0.005
Chromium	13.50–16.00	0.20
Nickel	24.00–27.00	0.20
Molybdenum	1.00–1.50	0.05
Titanium	1.90–2.35	0.07
Boron	0.003–0.010	0.001 over 0.0004 under
Vanadium	0.10–0.50	0.03
Aluminum	0.35 max	0.05
Iron	remainder	

TABLE 3 Stress Rupture Requirements

	Test Temp, °F [°C]	Stress, ksi [MPa]	Min h	Min Elongation in 4, %
Type 1	1200 [649]	56 [385]	100	15
Type 2				
Test A	1200 [649]	56 [385]	100	8
Test B	1200 [649]	65 [450]	30	10

TABLE 4 Creep Requirements

Temperature, °F [°C]	Stress, ksi [MPa]	Time, h	Creep Strain, %
1000 [538]	85 [585]	100	0.1–2.0

8. Mechanical Properties

8.1 The forgings shall conform to the mechanical property requirements specified in Table 2 after heat treatment as prescribed in 4.1.

8.2 *Tension and Hardness*—Tension and hardness testing shall be conducted in accordance with Specification A 788.

8.3 *Stress Rupture*:

8.3.1 Combination smooth and notched bar specimens using 0.252 in. [6.4 mm] diameter bars shall be tested to rupture in accordance with Practice E 292. Rupture must occur in the smooth section of each specimen. After 100 h, samples may be uploaded in 5-ksi [35-MPa] increments in 8 to 16 h intervals.

8.3.2 Material supplied as Type 1 shall meet the stress rupture requirements specified in Table 3.

8.3.3 Material supplied as Type 2 shall meet the stress rupture requirements of either Test A or Test B of Table 3 as specified by the purchaser.

8.4 *Creep*:

8.4.1 A creep test shall be performed in accordance with Practice E 139 on a 0.252 in. [6.4 mm] diameter smooth bar.

8.4.2 The material shall meet the requirements specified in Table 4 after heat treatment as prescribed in 4.1.

8.5 *Number of Tests*—The testing frequency shall be as follows with a lot being defined as not more than 50 pieces of the same part made from the same heat of material to the same forging parameters, forged within an 8 h period, and heat treated together:

8.5.1 For forgings weighing less than 500 lb [227 kg] each, one tension, stress rupture, and creep test shall be made on one forging per lot. In addition, two hardness tests shall be made on each piece in the lot.

TABLE 2 Mechanical Property Requirements

	Type 1	Type 2
Tensile Strength, min, ksi [MPa]	140 [965]	130 [895]
0.2 % Offset Yield Strength, min, ksi [MPa]	95 [655]	85 [585]
Elongation in 4, min, %	12	15
Reduction of Area, min, %	15	20
Hardness, HB	277–363	248–341

8.5.2 For forgings weighing 500 lb to 2000 lb [227 kg to 907 kg] one tension, stress rupture, and creep test, and two hardness tests shall be made on each forging.

8.5.3 For forgings weighing over 2000 lb [907 kg] testing shall be performed as covered in 8.5.1.2 or in Supplementary Requirement S1. In addition, one tangential tension, stress rupture, and creep test shall be run on material taken from the forging hub.

8.6 *Test Location*:

8.6.1 The tension, stress rupture, and creep specimens covered in 8.5.1 and 8.5.2 shall be machined from tangential bars taken from the forging rim.

8.6.2 Hardness tests shall be taken on both the rim and hub.

9. Microstructure

9.1 The forgings shall have an average grain size of number 4 or finer as determined in accordance with Test Methods E 112. The material shall be of a uniform microstructure, free of phase or compound formations such as a continuous grain boundary film.

9.2 One test per lot is required for forgings weighing less than 500 lb [227 kg] each. One test per forging is required on all other forgings.

9.3 The microstructural examination may be performed on material taken from the non-deformed grip section of a peripheral tensile test specimen or on a separate sample taken from the peripheral area of a forging.

10. Non-Destructive Examinations

10.1 *Ultrasonic Examination*:

10.1.1 Each forging shall be subjected to ultrasonic examination.

10.1.2 The method of ultrasonic examination and acceptance level shall be agreed upon between the purchaser and manufacturer.

10.2 *Liquid Penetrant Examination*—Each forging shall be subjected to liquid penetrant examination using one of the methods outlined in Practice E 165. The specific test procedure and acceptance level shall be as agreed upon by the purchaser and manufacturer.

11. Quality

11.1 The forgings shall be uniform in quality and condition, clean, sound, and free of cracks, seams, laps, shrinkage, and other injurious imperfections.

12. Retests

12.1 If any test specimen fails to meet specified requirements because of defective machining or a flaw other than a rupture, crack, or flake, a single retest shall be allowed.

12.2 If the results of any test lot are not in conformance with the requirements of this specification, such lots may be retreated by the manufacturer with the agreement of the purchaser. The material shall be acceptable if the results of the retests on the retreated material are within the requirements of this specification.

13. Certification and Reports

13.1 Certifications shall be furnished in accordance with Specification A 788.

13.2 The report shall include the results of the chemical analysis(ses), microstructural examination, the date, drawing number, melt practice used, ingot number and position or serial number and the name of the manufacturer. It shall also include the test parameters and results of the tensile, creep, stress-rupture, and hardness testing as well as the ultrasonic and liquid penetrant examination results.

14. Product Marking

14.1 Each forging shall be legibly stamped by the manufacturer in accordance with Specification A 788. Markings shall include the ingot number and position or serial number, part number, and purchase order number.

15. Keywords

15.1 age hardened; creep; elevated temperature service; forging; alloy steel—turbine disk; forging; alloy steel—turbine wheel; precipitation hardened; stress rupture; superalloy

SUPPLEMENTARY REQUIREMENTS

The following supplemental requirements shall apply only when specified by the purchaser on the order and agreed to by the manufacturer.

S1. Number of Test

S1.1 Two tension and stress rupture tests shall be made on each forging weighing less than 2000 lb [907 kg]. Each set of tests shall be machined from tangential bars located 180° apart on the forging rim.

S1.2 One creep test shall be made on each forging weighing less than 2000 lb [907 kg]. Test material shall be taken from the same location as that for one of the sets of test bars covered in S1.1.

S1.3 One microstructural examination shall be performed on each forging in accordance with 9.1.

S1.4 A product analysis of each forging shall be made by the manufacturer in accordance with Specification A 788 and shall conform to the requirements of Table 1.

S2. Stress Rupture

S2.1 The stress rupture tests conditions shall be 1200°F [650°C], 65 ksi [450 MPa], 30 h minimum, no upload, with a 15 % minimum elongation.

Standard Guide for Defining and Rating the Microstructure of High Carbon Bearing Steels[1]

This standard is issued under the fixed designation A 892; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers the description of carbide structures in annealed high carbon bearing steels.

1.2 Included is a guide for rating steel specimens by a graded series of photomicrographs showing the incidence of certain conditions.

1.3 The reference photomicrographs are graded illustrations of annealed carbides categorized by size, network and lamellar content (shape).

1.4 This guide is to facilitate communication and description of microstructure. It does not establish limits of acceptability. Such limits are a matter of agreement between user and producer.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 3 Methods of Preparation of Metallographic Specimens[2]

E 407 Practice for Microetching Metals and Alloys[2]

3. Apparatus

3.1 In order to adequately compare the structure of a specimen with the photomicrographs, it will be necessary to view a properly prepared sample at 1000× magnification with good resolution.

4. Specimen Preparation

4.1 Samples which represent a portion of the cross section of the material shall be prepared using the practices described in Methods E 3. The size of the sample shall be negotiated between the user and the producer. It may be a full cross section but should not be too large for practical handling in the polishing operation.

4.2 The properly polished specimens shall be etched in a suitable etchant which will clearly delineate the annealed carbide structure of the material being examined as described in Test Methods E 407. Nital (2 %) will frequently be an adequate etchant for routine examination. When critical or detailed analysis of structures is required, the recommended etchant is Picral (saturated).

5. Description

5.1 The reference photomicrographs are arranged into three categories as follows: carbide size (CS), carbide network (CN), and lamellar content (LC).

5.2 Six photomicrographs for each category are provided and are identified by category and number, for example, CS1-CS6, CN1-CN6, and LC1-LC6 as shown in Figs. 1-3. Higher numbers indicate a larger number or greater degree of severity of the category being rated.

5.2.1 Actual counted number of carbides per 400 μm^2 determined from the carbide size series of photomicrographs is as follows: (Reported counts are the average of three measurements.)

CS1	508
CS2	419
CS3	324
CS4	234
CS5	165
CS6	115

6. Procedure for Evaluation

6.1 Using an optical metallograph and a magnification of 1000×, examine a properly prepared and etched specimen. Select a field which is representative of the category to be graded and compare it to the photomicrographs which are part of this method. The rating will be the number of that photo which most closely resembles the appearance of the specimen. A separate field may be used for each category or a single field may be rated for more than one category. An example rating is: CS4, CN2, LC1.

7. Keywords

7.1 antifriction bearings; bearing steel; chromium alloy steel; metallography

[1] This guide is under the jurisdiction of Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.28 on Bearing Steels.

Current edition approved Dec. 30, 1988. Published February 1989.

[2] *Annual Book of ASTM Standards*, Vol 03.01.

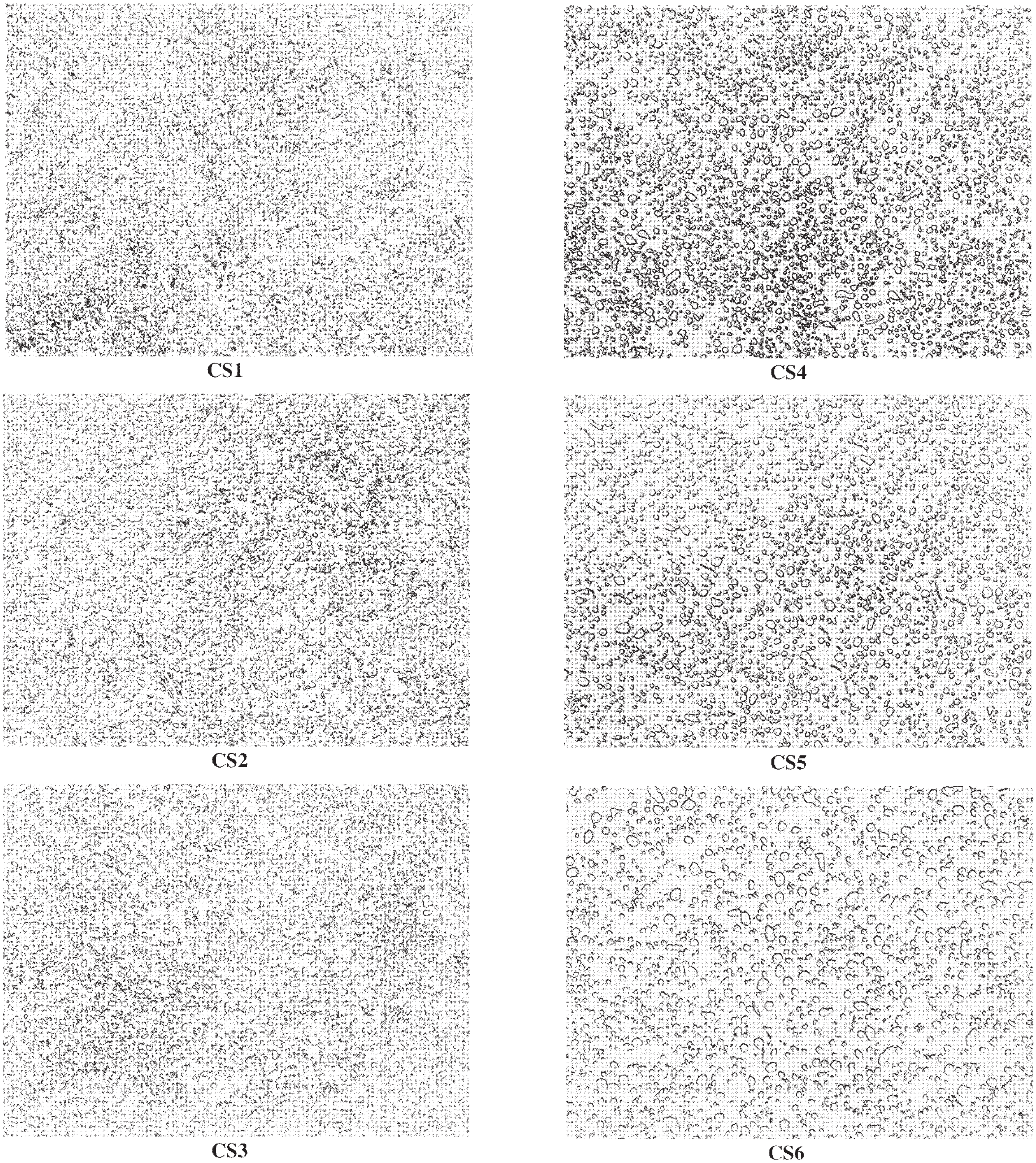


FIG. 1 Carbide Size

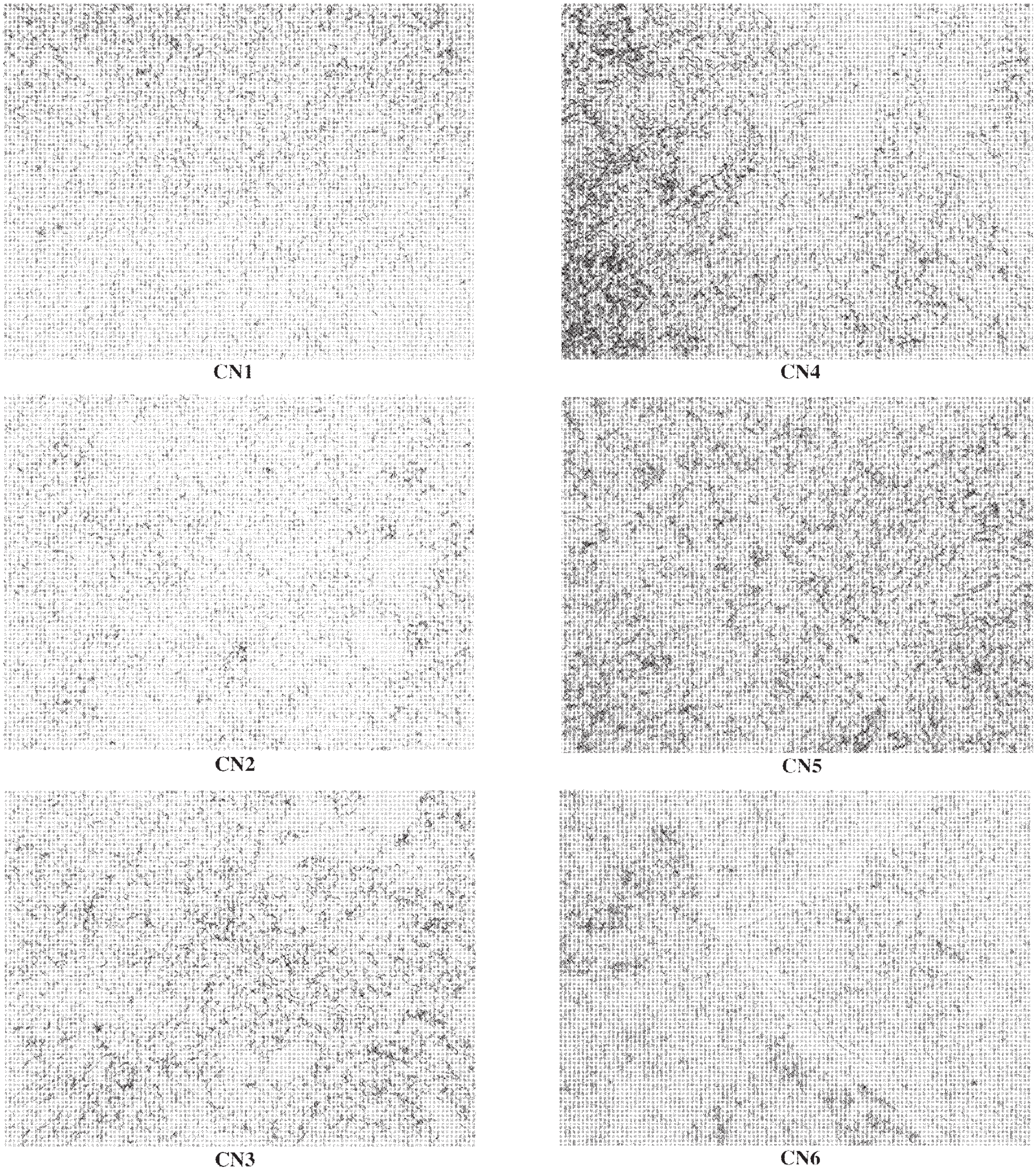


FIG. 2 Carbide Network

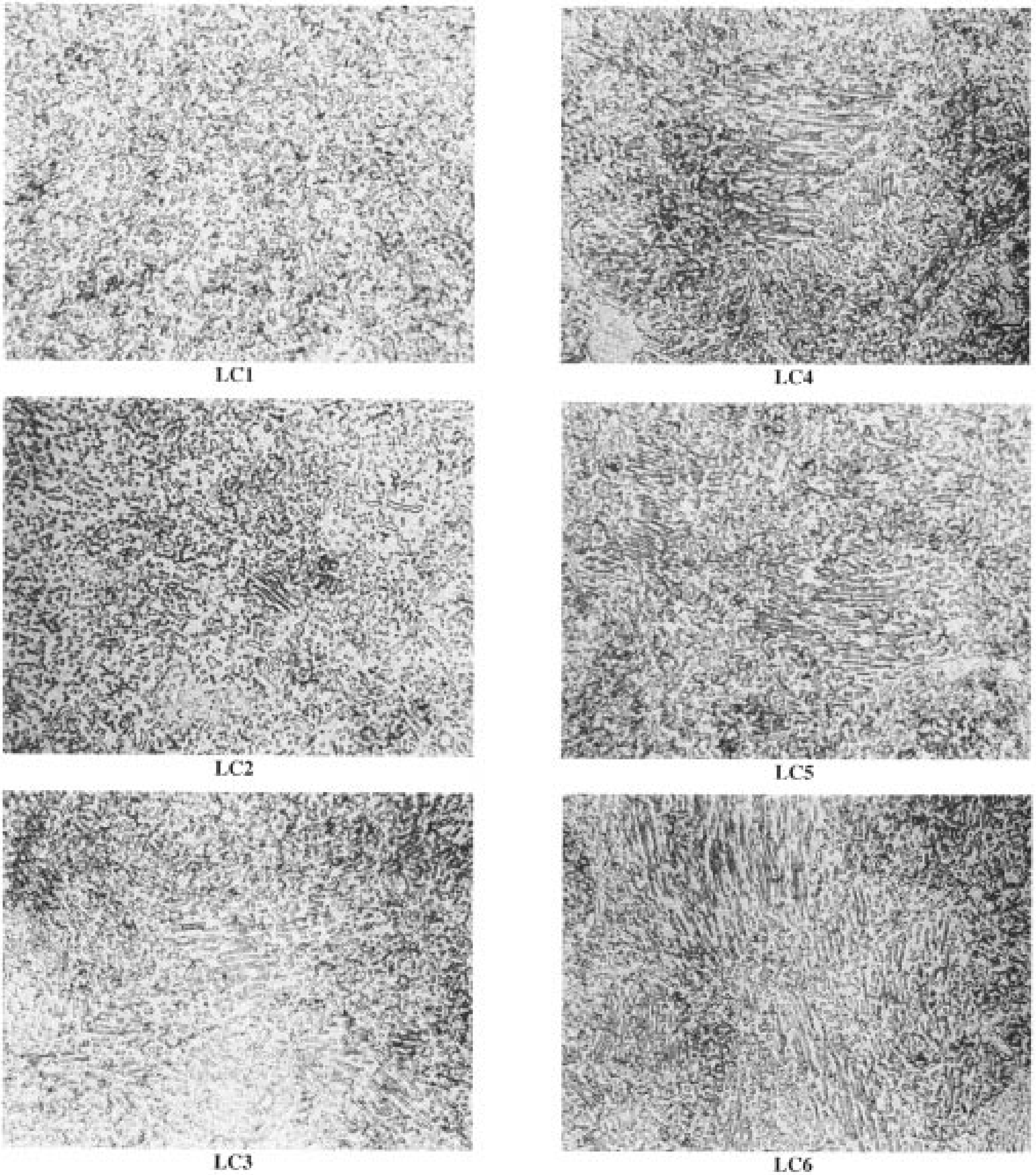


FIG. 3 Lamellar Content

Designation: A 906/A 906M – 02

Standard Specification for Grade 80 and Grade 100 Alloy Steel Chain Slings for Overhead Lifting[1]

This standard is issued under the fixed designation A 906/A 906M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers the requirements and method of rating and testing for alloy chain slings. Slings shall be assembled using components manufactured in accordance with Specification A 391/A 391M for Grade 80 chain, A 973/A 973M for Grade 100 chain, and A 952/A 952M for other components. This specification covers welded and mechanically assembled slings.

1.2 This specification does not cover slings used at elevated temperatures (above 400°F [200°C]), in harmful or corrosive environmental conditions or for applications such as nonsymmetrical legs or loading.

1.3 This specification is a performance and assembly specification. Other standards, such as OSHA 1910.184, ASME B30.9, and ASME B30.10, apply to the use of the products in this specification.

1.4 The values stated in either inch-pound units or SI units shall be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore each system shall be used independently of the other, without combining values in any way.

2. Referenced Documents

2.1 *ASTM Standards:*

A 391/A 391M Specification for Alloy Steel Chain[2]

A 952/A 952M Specification for Forged Grade 80 and Grade 100 Steel Lifting Components and Welded Attachment Links[2]

A 973/A 973M Specification for Grade 100 Alloy Steel Chain[2]

2.2 *Other Standards:*

OSHA 1910.184 [3]

ASME B30.9 Slings[4]

ASME B30.10 Hooks[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *chain sling*—an assembly consisting of alloy steel chain or chains joined to suitable upper and lower fittings, according to the provisions of this specification, for attaching loads to be lifted by a crane or lifting machine.

3.1.2 *coupling link*—a link fitted to the end of the chain to connect to another component of the sling. See Fig. 1.

3.1.3 *master coupling link (secondary or intermediate link)*—a link used on three and four leg slings to connect the legs to a master link. See Fig. 1.

3.1.4 *master link*—a link used as the upper end component of a chain sling and by means of which the sling is attached to a crane or other lifting machine. See Fig. 1.

3.1.5 *overhead lifting*—that process of lifting which would elevate a freely suspended load to such a position that dropping the load would present a possibility of bodily injury or property damage.

3.1.6 *proof test*—a term designating a quality control test applied to a sling or to components of a sling. It is the minimum force in pounds or newtons which the sling and components have withstood under a test in which a constantly increasing force has been applied in direct tension.

3.1.7 *length (reach)*—the distance from the bearing point of the upper end fitting to the bearing point of the lower end fitting. See Fig. 1.

3.1.8 *sling angle*—that angle measured between the horizontal plane and the leg (legs) of the sling. See Tables 1-3.

3.1.9 *working load limit (WLL)*—the maximum load which a sling is designed to support in direct tension without shock loading at a designated sling angle of lift.

4. Classification

4.1 There are two grades of chain slings covered under this specification. The size of a sling is denoted by the size of the

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.27 on Steel Chain.

Current edition approved May 10, 2002. Published June 2002. Originally published as A 906–91. Last previous edition A 906–99.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] Available from Occupational Safety and Health Administration (OSHA), Office of the Federal Register National Archives and Records Administration, Washington, DC.

[4] Available from American Society of Mechanical Engineers (ASME), 3 Park Ave., New York, NY 10016–5990.

***A Summary of Changes section appears at the end of this standard.**

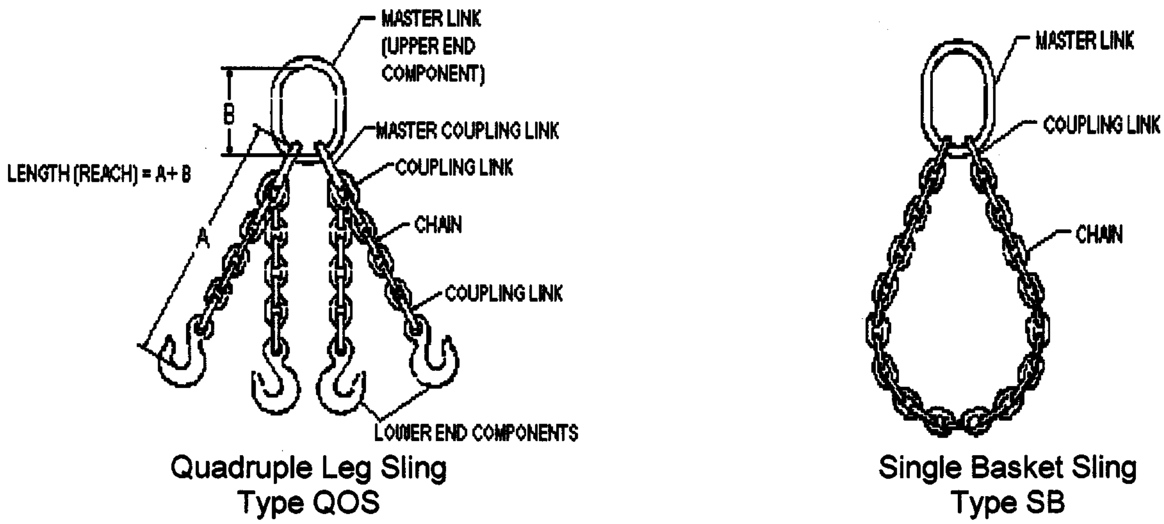
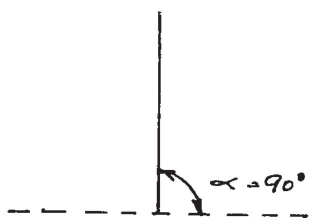


FIG. 1 Chain Sling Major Components

TABLE 1 Chain and Single Leg Grade 80 Sling WLL Data



Grade 80 Chain Size		Single Leg WLL (max)	
in.	mm	lb	kg
7⁄32	5.5	2100	950
9⁄32	7	3500	1600
5⁄16	8	4500	2000
3⁄8	10	7100	3200
1⁄2	13	12 000	5400
5⁄8	16	18 100	8200
3⁄4	20	28 300	12 800
7⁄8	22	34 200	15 500
1	26	47 700	21 600
1 1⁄4	32	72 300	32 800

chain used in its manufacture. The grade of a sling is denoted by the lowest grade component used in its manufacture.

4.1.1 Grade 80.

4.1.2 Grade 100.

5. Ordering Information

5.1 It shall be the responsibility of the purchaser to specify all requirements that are necessary for material ordered under this specification. Such requirements to be considered include, but are not limited to, the following:

5.1.1 Conformance to ASTM designation A 906 or A 906M and year of issue,

5.1.2 Size of sling in inches [millimetres],

5.1.3 Grade of sling,

5.1.4 Type of sling(s) as designated by the symbols depicted in Table 7, if possible,

5.1.5 Quantity ordered,

5.1.6 Reach of sling(s),

5.1.7 Sling angle, and

5.1.8 Certification of proof test(s), if required.

6. Manufacture

6.1 *Assembly*:

6.1.1 Only component parts compatible with alloy chain shall be used.

6.1.2 Slings assembled by welding shall be fabricated by the electric or gas welding process, or both.

6.1.3 Mechanically assembled slings shall be assembled in accordance with component manufacturer's recommendations.

6.1.4 Components shall be assembled so as to ensure free articulation of the sling.

7. Mechanical Requirements

7.1 *Proof Test*:

7.1.1 All components of a sling, either individually or as an assembly, shall be proof tested as required in 7.1.2-7.1.4.

7.1.2 The proof test load for single leg slings and components attached to single legs shall be twice the working load limit for the size and grade chain.

7.1.3 The proof test load for components attached to two legs of a sling shall be four times the working load limit for the size and grade chain.

7.1.4 The proof test load for components attached to three or four legs of a sling shall be six times the working load limit for the size and grade chain.

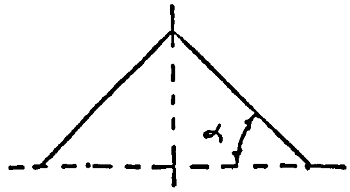
7.1.5 All sling components shall withstand the proof test load without loss of integrity or detrimental dimensional changes. Components that do not withstand the proof test shall be discarded.

8. Tolerances

8.1 When constructing the sling, a tolerance of −0 + 2 links is permissible on the nominal reach ordered by a purchaser. In the completed sling, the difference between the longest and shortest legs of a multi-leg sling shall not exceed 5⁄16 in. (8 mm) for legs up to 6 1⁄2 ft (2 m) in length. For slings in excess of 6 1⁄2

TABLE 2 Double Leg and Single Basket Grade 80 Alloy Chain Sling WLL Data at 60°, 45°, and 30° Sling Angles

NOTE 1—[WLL (double leg) = 2 x WLL (single leg) x sin α]

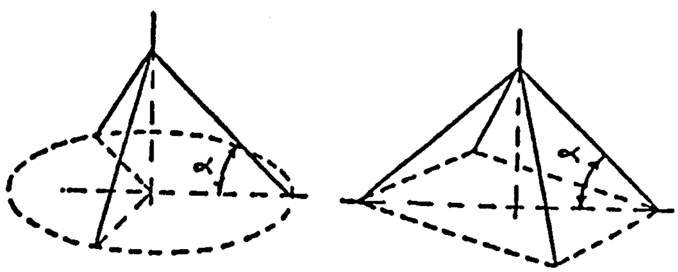


DOUBLE LEG

Grade 80 Chain Size		WLL at Sling Angle α of					
		60°		45°		30°	
in.	mm	lb	kg	lb	kg	lb	kg
7⁄32	5.5	3600	1650	3000	1350	2100	950
9⁄32	7	6100	2750	4900	2250	3500	1600
5⁄16	8	7800	3550	6400	2900	4500	2000
3⁄8	10	12 300	5500	10 000	4500	7100	3200
1⁄2	13	20 800	9450	17 000	7700	12 000	5400
5⁄8	16	31 300	14 200	25 600	11 600	18 100	8200
3⁄4	20	49 000	22 250	40 000	18 150	28 300	12 800
7⁄8	22	59 200	26 850	48 400	21 900	34 200	15 500
1	26	82 600	37 500	67 400	30 600	47 700	21 600
1 1⁄4	32	125 200	56 800	102 200	46 400	72 300	32 800

TABLE 3 Triple and Quadruple Leg and Double Basket Grade 80 Alloy Chain Sling WLL Data at 60°, 45°, and 30° Sling Angles

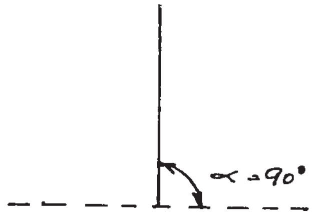
NOTE 1— [WLL (3 or 4 leg) = 3 x WLL (single leg) x sin α]



THREE LEG FOUR LEG

Grade 80 Chain Size		WLL at Sling Angle α of					
		60°		45°		30°	
in.	mm	lb	kg	lb	kg	lb	kg
7⁄32	5.5	5500	2450	4400	2000	3200	1450
9⁄32	7	9100	4150	7400	3400	5200	2400
5⁄16	8	11 700	5350	9500	4350	6800	3100
3⁄8	10	18 400	8300	15 100	6800	10 600	4800
1⁄2	13	31 200	14 150	25 500	11 550	18 000	8200
5⁄8	16	47 000	21 300	38 400	17 400	27 100	12 300
3⁄4	20	73 500	33 400	60 000	27 250	42 400	19 300
7⁄8	22	88 900	40 250	72 500	32 900	51 300	23 250
1	26	123 900	56 250	101 200	45 950	71 500	32 500
1 1⁄4	32	187 800	85 200	153 400	69 600	108 400	49 200

TABLE 4 Chain and Single Leg Grade 100 Sling WLL Data



Grade 100 Chain Size		Single Leg WLL (max)	
in.	mm	lb	kg
7/32	5.5	2700	1200
9/32	7	4300	1950
5/16	8	5700	2600
3/8	10	8800	4000
1/2	13	15 000	6800
5/8	16	22 600	10 300
3/4	20	35 300	16 000
7/8	22	42 700	19 400

ft (2 m), the difference between the longest and shortest legs may be increased by 5/32 in. (4 mm) for each additional 3¼ ft (1 m).

9. Working Load Limit (WLL)

9.1 *Working Load Limit*—The working load limits given in Tables 1-6 are for symmetrically loaded slings manufactured with components of equal or higher working load limits than the chain.

9.2 Slings containing any Grade 80 component shall be rated at Grade 80 working load limits.

9.3 Working load limits shall conform to the values shown in Tables 1-3 for Grade 80 slings and Tables 4-6 for Grade 100 slings.

NOTE 1—The working load limit values in Tables 1-6 have been rounded to the nearest 100 lb [50 kg].

NOTE 2—Rigging and hitch conditions may lower the working load limit of the sling.

9.4 Working load limits for sling angles not listed in Tables 1-6 shall be calculated as follows:

9.4.1 The working load limit for double leg and single basket slings = 2 × single leg sling working load limit × sine of horizontal angle.

9.4.2 The working load limit for triple and quadruple leg and double basket slings = 3 × chain single leg sling working load limit × sine of horizontal angle.

9.4.3 *Nominal Rating*—The nominal rating of any multi-branch sling shall be the working load limit for that sling when applied at an angle of 60° from the horizontal.

10. Workmanship, Finish, and Appearance

10.1 The manufacturer may apply a surface treatment or coating of his own choice for identification or corrosion resistance unless the customer specifies otherwise.

11. Certification

11.1 A manufacturer's certification of proof test shall be furnished, if requested. The certificate shall include the information on the tag, the proof load, and date of issue.

11.2 For mechanically assembled slings, the appropriate certification of sling component parts shall be made available to the user if requested.

12. Product Marking

12.1 *Identification Tag*—There shall be an identification tag permanently affixed to each sling chain bearing the following information:

12.1.1 Size,

12.1.2 Length (reach),

12.1.3 Working load limit and angle upon which it is based,

12.1.4 Serial number,

12.1.5 Manufacturer's name or symbol, and chain grade, and

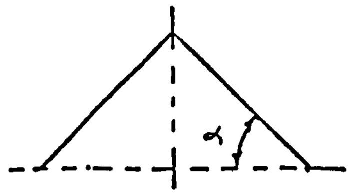
12.1.6 Sling type (number of legs) as described in Table 7.

13. Keywords

13.1 chain; steel chain

TABLE 5 Double Leg and Single Basket Grade 100 Alloy Chain Sling WLL Data at 60°, 45°, and 30° Sling Angles

NOTE—[WLL (double leg) = 2 × WLL (single leg) × sin α].

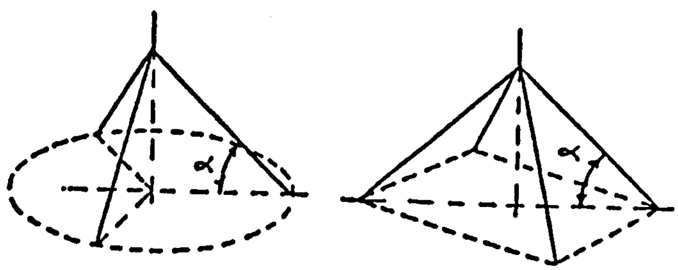


DOUBLE LEG

Grade 100 Chain Size		WLL at Sling Angle α of					
		60°		45°		30°	
in.	mm	lb	kg	lb	kg	lb	kg
7⁄32	5.5	4700	2150	3800	1750	2700	1200
9⁄32	7	7400	3400	6100	2750	4300	1950
5⁄16	8	9900	4500	8100	3700	5700	2600
3⁄8	10	15 200	6950	12 400	5650	8800	4000
1⁄2	13	26 000	11 800	21 200	9600	15 000	6800
5⁄8	16	39 100	17 750	32 000	14 500	22 600	10 300
3⁄4	20	61 100	27 700	49 900	22 650	35 300	16 000
7⁄8	22	74 000	33 500	60 400	27 350	42 700	19 400

TABLE 6 Triple and Quadruple Leg and Double Basket Grade 100 Alloy Chain Sling WLL Data at 60°, 45°, and 30° Sling Angles

NOTE—[WLL (3 or 4 leg) = 3 × WLL (single leg) × sin α].



THREE LEG FOUR LEG

Grade 100 Chain Size		WLL at Sling Angle α of					
		60°		45°		30°	
in.	mm	lb	kg	lb	kg	lb	kg
7⁄32	5.5	7000	3250	5700	2650	4000	1900
9⁄32	7	11 200	5050	9100	4150	6400	2950
5⁄16	8	14 800	6750	12 100	5500	8500	3900
3⁄8	10	22 900	10 400	18 700	8500	13 200	6000
1⁄2	13	39 000	17 650	31 800	14 450	22 500	10 200
5⁄8	16	58 700	26 650	47 900	21 750	33 900	15 400
3⁄4	20	91 700	41 550	74 900	33 950	53 000	24 000
7⁄8	22	110 900	50 250	90 600	41 050	64 000	29 050

TABLE 7 Sling Designation

NOTE 1—This table is not complete in that manufacturers employ special designations for special, miscellaneous, and adjustable sling styles.

First Symbol (Basic Sling Type)		Second Symbol (Upper End Fitting)[A]	
Symbol	Description	Symbol	Description
S	Single Leg	O	Oblong Master Link
C	Single Choker with Master Links—no hooks	P	Pear Shaped Master Link
D	Double Leg	S	Sling Hook
T	Triple Leg	G	Grab Hook
Q	Quadruple Leg	F	Foundry Hook
SB	Single Basket		
DB	Double Basket		

Third Symbol (End (Terminal) Fitting(s))	
Symbol	Description
S	Sling Hook
G	Grab Hook
F	Foundry Hook

[A] The absence of a designation in the second symbol position indicates no top fitting present. Such would be the case in a single leg with grab hook at one end designated SG.

SUMMARY OF CHANGES

(1) Revised 1.1.
(2) Global throughout standard: changed "fitting" to "component," "fittings" to "components" and "reach" to "length."
(3) Revised definition 3.1.2 for "coupling link," deleted definitions for "end fitting" and "qualified person," and renamed defintion 3.1.5 "reach" to "length (reach)."
(4) Added Note 2 under 9.3.
(5) Revised standard to include single and double basket slings (Revised 1, Tables 2, 3, 5, 6, and 7).
(6) Removed prior Note on 30° sling angle in Tables 2, 3, 5, and 6.

Designation: A 909 – 03

Standard Specification for Steel Forgings, Microalloy, for General Industrial Use[1]

This standard is issued under the fixed designation A 909; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers wrought, microalloyed carbon steel forgings for industrial use. Microalloyed steels develop their properties by the addition of small amounts of microalloying elements such as vanadium, columbium, titanium, or molybdenum. The properties may be influenced also by control of the hot working process and temperature and by control of the subsequent cooling rate.

1.2 The forgings shall be furnished to chemical composition and mechanical property requirements as specified herein. Chemical composition is based on standard carbon steel grades modified to include microalloying elements. Strength level is specified based on desired mechanical properties in the forgings. Depending on the forging process, different strength classes may be attainable from a single chemical composition. Conversely, mechanical properties of a given strength class may be achieved using different chemical compositions. The manufacturer should be consulted if development of chemical composition is necessary.

1.3 For the purpose of this specification, forgings with maximum section thickness of 4 in. (102 mm) are to be considered.

1.4 Supplementary Requirements S1 to S8 are provided for use when additional controls or requirements are desired. These shall apply only when specified on the purchase order.

1.5 The values stated in either inch-pound units or SI (metric) units are to be regarded separately as standard. Within the text and tables, SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with this specification.

1.6 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 576 Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products

A 788 Specification for Steel Forgings, General Requirements

A 921 Specification for Steel Bars, Microalloy, Hot-Wrought, Special Quality, for Subsequent Hot Forging

E 10 Test Method for Brinell Hardness of Metallic Materials

E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials

E 45 Test Methods for Determining the Inclusion Content of Steel

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *microalloy forgings*—forgings from microalloyed steels produced by effectively controlling the thermomechanical components of the forging process to achieve required mechanical properties with no post-forging heat treatment.

3.1.2 *microalloy forging procedure*—the written thermomechanical processing parameters to be followed during the production of a microalloy forging. It would include, but is not limited to: starting stock size; chemical composition, including

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard.**

any optional microalloying additions; reheat practice; forging temperature range; method of heating; cooling methods; and lot size definition.

4. Ordering Information

4.1 Orders for material supplied to this specification should include the information specified in 4.1 of Specification A 788. The purchaser should refer to Specification A 788 for information not contained in this specification.

4.1.1 The type (see 6.1), grade (see 6.1), and the remainder of the chemical composition (see 6.2 to 6.5) should be included.

4.2 The information contained in 4.2 of Specification A 788 should be specified, as necessary, to adequately describe the desired material.

4.3 In addition to the requirements of 4.1 and 4.2 of Specification A 788, the following should be included in the purchase order, as applicable:

4.3.1 From Table 1, strength class or method of testing, or both, including test location on the forging.

4.3.2 Definition of lot size including the number of mechanical tests to be performed per lot.

4.3.3 Any supplementary requirements.

5. Materials and Manufacture

5.1 *Melting Practice*—The steel shall be produced in accordance with the applicable methods for primary and secondary melting outlines in Specification A 788.

5.2 The steel shall be killed.

5.3 *Hot Forging*—The forging shall be brought as close as practical to finish size by hot mechanical working. Controlled hot working and cooling practices shall be applied to develop specified mechanical properties.

5.4 *Microalloy Forge Procedure*—When requested by the purchaser, a written forge procedure shall be made available to the purchaser by the manufacturer.

6. Chemical Composition

6.1 Carbon, manganese, phosphorus, and sulfur analyses shall conform to the table on Grade Designations and Chemical Requirements of Hot-Wrought Carbon Steel Bars in Specification A 576 for the grade specified, to such other limits that may be specified using the ranges and limits in the table on Grade Designations and Chemical Requirements of Hot-Wrought Carbon Steel Bars in Specification A 576, or to the ranges and limits set forth in Table 1 of Specification A 921.

NOTE 1—For improved machinability, alternative sulfur ranges may be specified by agreement between the purchaser and the producer. Additional machinability-enhancing elements such as lead, bismuth, selenium, or tellurium may also be specified by agreement.

6.2 Silicon analysis shall be 0.15/0.35 %. Silicon content up to 0.80 % maximum may be furnished by agreement between purchaser and producer.

6.3 Vanadium, columbium (niobium), titanium, or molybdenum may be specified singly or in combination, subject to the limits shown in Table 2. The elements and ranges specified shall be by agreement between the purchaser and the producer.

6.4 Nitrogen may be specified as a supplement to vanadium, columbium, or titanium. When nitrogen is specified as a supplement to vanadium, the minimum ratio of vanadium to nitrogen shall be 4 to 1. The nitrogen content shall not exceed 0.03 % and shall be reported.

6.5 Sampling for heat and product analysis shall be in accordance with the requirements of Specification A 788. Chemical Analyses shall be in accordance with Specification A 751.

7. Metallurgical Requirements

7.1 *Grain Size*—The steel shall conform to the fine grain size requirement of Specification A 29/A 29M. The grain refining element may be specified in accordance with one of the following types:

7.1.1 *Type A—Aluminum*—The total aluminum analysis shall be 0.020 % or greater, and shall be reported.

7.1.2 *Type B*—The grain refining element shall be specified in accordance with 5.1.2.3 of Specification A 29/A 29M.

7.2 *Microstructure*—The microstructure shall consist of a minimum of 90 % ferrite-pearlite or 90 % bainite as agreed between producer and purchaser.

8. Mechanical Properties

8.1 The mechanical properties of the forgings shall conform to the requirements listed in Table 1 for the strength class specified.

8.2 Test specimens shall be prepared for testing from the forging in its as forged condition unless otherwise specified.

8.3 Test specimens shall be oriented parallel to the longitudinal axis of the forging and removed from a full thickness section or may be removed and produced in accordance with the requirements of Test Methods and Definitions A 370. If conforming to Test Methods and Definitions A 370, test specimens shall be removed from a position midway between the center and the surface of the forging.

8.4 Test specimens for shapes and flats may be machined in accordance with the requirements of Test Methods and Definitions of A 370 or with both edges parallel. Test specimens for material over 1.5 in. (40 mm) in thickness or diameter may be machined to a thickness or diameter of at least ¾ in. (19 mm)

TABLE 1 Mechanical Property Requirements

Class	Yield Strength, min		Tensile Strength, min		Elongation, min, %		Hardness, BHN, min
	ksi	MPa	ksi	MPa	in 8 in. (200 mm)	in 2 in. (50 mm)	
60	60	415	75	515	16	18	167
80	80	550	95	655	13	15	201
100	100	690	125	860	8	10	269
120	120	825	150	1030	6	8	321

TABLE 2 Chemical Requirements (Microalloy Elements)

Element	Chemical Ranges and Limits, %	
	Heat Analysis	Product Analysis
Vanadium	0.02 to 0.20	0.01 to 0.21
Columbium (Niobium)	0.005 to 0.07	0.004 to 0.08
Molybdenum	0.01 to 0.30	0.31 max
Titanium	0.030 max	0.040 max

for a length of at least 9 in. (230 mm), or they may conform to requirements of Test Methods and Definitions A 370.

8.5 At least two tension tests shall be made from each heat and forging lot.

8.6 If so specified by the purchaser, forgings may be specified on the basis of hardness tests alone. If this option is exercised, the class shall be identified with the letter "H," that is, "60H," "80H," and so on. Hardness testing shall be performed in accordance with Specifications E 10 or E 18.

9. Workmanship, Finish, and Appearance

9.1 The forgings shall conform to the requirements specified on the purchaser's drawing and shall have a good, workmanlike appearance, free of any injurious imperfections.

10. Retreatment

10.1 Forgings above the specified hardness range or with ductility values below specified limits may be tempered and retested, upon approval by purchaser or in accordance with the approved forging procedure. Forgings below specified hardness minimums or tensile and yield requirements may be heat treated upon approval by the purchaser.

11. Certification and Test Reports

11.1 When specified by the purchaser, the manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the heat analysis for the specified elements and for copper, chromium, nickel, molybdenum, vanadium and columbium shall be furnished. When the amount of an element present is less than 0.02 %, the heat analysis may be reported as <0.02 % except for titanium and nitrogen. When specified, these elements shall be reported to three decimal places. The certification requirements of Specification A 788 shall also apply.

11.2 The report shall include the results of any mechanical tests performed in accordance with this specification, including supplementary requirements, if any.

12. Keywords

12.1 forging procedure; microalloyed; steel forgings

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser.

S1. Restricted Chemical Composition

S1.1 Restricted heat analysis limits or ranges or restricted product analysis tolerances on one or more elements shall be specified by the purchaser.

S2. Restricted Incidental Elements

S2.1 The steel shall not exceed the limits for copper, nickel, chromium, molybdenum, or other elements as shown on the purchase order.

S3. Nonmetallic Inclusions

S3.1 A microscopical examination of longitudinal sections to determine the nature and frequency of nonmetallic inclusions shall be made as prescribed in Practice E 45. The acceptance limits shall be specified by the purchaser.

NOTE S1—In resulfurized steels, much of the sulfur is present as sulfide inclusions. For this reason, maximum sulfide inclusion level should not be specified.

S4. Calcium Treatment

S4.1 The steel shall be calcium treated.

S5. Stress Relieving

S5.1 The steel shall be stress relieved by a cycle specified by the purchaser or selected by the manufacturer.

NOTE S2—Stress relieving may affect mechanical properties and this should be considered when specifying this requirement.

S6. Notch Toughness Tests

S6.1 Charpy V-notch tests shall be performed in sets of three. The absorbed energy requirement and the test temperature shall be agreed upon between producer and purchaser.

S6.2 Testing frequency shall be as for tension testing (see 8.5). The specimens shall be taken adjacent to the tension test specimen and shall be located as near as practicable midway between surface and center of the forging diameter or thickness and width. The longitudinal axis of specimen shall be parallel to the longitudinal axis of the forging. The length of the notch shall be perpendicular to the nearest surface of the forging. Testing procedure and acceptance criteria shall be in accordance with Test Methods and Definitions A 370.

S7. Cleaning

S7.1 The surface of the forgings shall be descaled by pickling or shot blasting or other suitable means.

S8. Magnetic Particle Testing

S8.1 Magnetic particle testing of the forgings shall be specified in accordance with Test Method A 275. Acceptance requirements shall be as agreed upon between the purchaser and the producer.

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 909 – 94(1999) that may impact the use of this standard.

(1) Revised section 2 and paragraphs 6.1, 6.5, and 8.6.

Standard Specification for Steel Bars Subject to Restricted End-Quench Hardenability Requirements[1]

This standard is issued under the fixed designation A 914/A 914M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

ϵ^1 NOTE—Fig. 19 was editorially replaced with the correct information on Hardenability Band 8620 RH in February 2002.

1. Scope

1.1 This specification covers hot-worked alloy and carbon-boron steels designed to attain restricted depth of hardening in the end-quench test. These steel compositions are identified by the suffix letter "RH" added to the conventional grade number.

1.2 In general, steels with restricted hardenability (RH steels) will exhibit a hardness range not greater than 5 HRC at the initial position on the end-quench hardenability bar and not greater than 65 % of the hardness range for standard H-band steels (Specification A 304) in the inflection region. Generally the restricted hardenability band follows the middle of the corresponding standard H-band. An example of the RH band compared with the H band is given for Grade 4140 in Fig. 1.

1.3 This specification is expressed in both inch-pound units and SI units. However, the material will be supplied to inch-pound units unless the purchase order specifies the "M" specification designation.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold Finished, General Requirements for[2]

A 255 Test Methods for Determining Hardenability of Steel[2]

A 304 Specification for Steel Bars, Alloy, Subject to End-Quench Hardenability Requirements[2]

E 112 Test Method for Determining Average Grain Size[3]

E 527 Practice for Numbering Metals and Alloys (UNS)[4]

2.2 *SAE Standards:*[5]

J 406 Methods of Determining Hardenability of Steels

J 1268 Hardenability Bands for Carbon and Alloy H Steels

J 1868 Restricted Hardenability Bands for Selected Alloy Steels

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *hardenability*—the relative ability of a steel to harden under heat treatment becomes apparent in the degree to which the material hardens when quenched at different cooling rates.

3.1.1.1 *Discussion*— Hardenability is measured quantitatively, usually by noting the extent or depth of hardening of a standard size and shape test specimen in a standardized quench. In the end-quench test the depth of hardening is the distance along the specimen from the quenched end to a given hardness.

4. Ordering Information

4.1 Orders for material under this specification should include the following information, in proper sequence:

4.1.1 Quantity (weight),
4.1.2 Name of material (alloy or carbon-boron steel),
4.1.3 Cross-sectional shape,
4.1.4 Size,
4.1.5 Length,
4.1.6 Grade,
4.1.7 End-quenched hardenability (see Section 9),
4.1.8 Report of heat analysis, if desired (see Section 7),
4.1.9 Special straightness, if required,
4.1.10 ASTM designation and date of issue, and
4.1.11 End use or special requirements.

NOTE 1—A typical ordering description is as follows: 10 000 lb, alloy bars, round, 4.0-in. diameter by 10 ft, Grade 4140RH, heat analysis required, complete hardenability data required, ASTM AXXX, [AXXXM] dated _____ worm gear.

4.2 The purchaser shall specify the desired grade, including the suffix letters "RH", in accordance with Table 1.

4.3 Band limits are shown graphically and as tabulations in Figs. 2-23, inclusive. For specification purposes, one must use tabulated values of Rockwell hardness (HRC) as a function of distance from the quenched end of the hardenability bar, either

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] *Annual Book of ASTM Standards*, Vol 01.01.

[5] Available from Society of Automotive Engineers, 400 Commonwealth Dr., Warrendale, PA 15096.

in inch-pound units (sixteenths of an inch) or in SI units (millimetres). Values below 20 HRC are not specified because such values are not accurate.

4.3.1 Band limits shown graphically are so depicted for convenience in estimating the hardness values at various intermediate locations on the end quench test bar for quick comparisons of the various RH grades. The values of "Approximate Diameter of Rounds with Same As-Quenched Hardness" shown above each RH-band, were selected from ranges appearing in Fig. 7 of SAE J406. The RH-bands are presented graphically, with distances from the quenched end in both inch-pound units and also SI units.

4.4 For specification purposes, RH-band steels shall exhibit hardness within the minimum and maximum HRC range specified at the J1 (J1.5-mm) position and shall meet one additional minimum and one additional maximum value. In this specification, the two additional hardness values shall represent the approximate hardness for 50 % martensite for the minimum and maximum specified carbon content, respectively (except where hardenability is too high; then the two additional hardness control values shall be five HRC points below the maximum hardness value specified at the J1 (J1.5-mm) position).

4.4.1 In general, these points define the critical locations of the Jominy hardenability band for purposes of characterizing heat treatment response. The four specification points are circled in the tables of hardness versus Jominy distance and on the RH-bands. For all other Jominy positions, a tolerance of two points HRC is permitted for a maximum consecutive 3⁄16 -in. or 5-mm Jominy distance on the restricted hardenability band.

4.4.2 For example, referring to Fig. 9, a hardenability test bar of a steel meeting the requirements for 4140RH must exhibit a hardness at J1 not less than 54 HRC, nor more than 59 HRC. At J12, the test bar must exhibit hardness not less than 43 HRC, but the maximum hardness can be as high as 52 HRC (or even 54 HRC if the region of the test bar is chosen as the exception). At J20, the bar must exhibit hardness not greater than 47 HRC, but the minimum hardness can be as low as 37 HRC (or as low as 35 HRC if this region of the test bar is chosen as the exception).

4.4.3 A similar example, referring to Fig. 9, for 4140RH with distances from the quenched end in millimetres would limit hardness at J1.5 mm to not less than 54 HRC nor more than 59 HRC. At J20 mm, the test bar must exhibit hardness not less than 42 HRC. At J30 mm, the test bar must exhibit hardness not greater than 48 HRC.

5. Manufacture

5.1 *Melting Practice*—The steel shall be made by one or more of the following primary processes: open-hearth, basic-oxygen, or electric furnace. The primary melting may incorporate separate degassing or ladle refining and may be followed by secondary melting using electroslag remelting or vacuum arc remelting. Where secondary melting is employed, the heat shall be defined as all the ingots remelted from a single primary heat.

5.2 *Slow Cooling*—Immediately after hot working, the bars shall be allowed to cool when necessary to a temperature below the critical range under suitable conditions, to prevent injury by too rapid cooling.

6. General Requirements

6.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 29/A 29M, unless otherwise provided for herein.

7. Chemical Requirements

7.1 The heat analysis shall conform to the requirements as to chemical composition prescribed in Table 1 for the grade specified by the purchaser.

8. Grain Size Requirements

8.1 The steel shall have an austenitic grain size of five to eight. The grain structure shall be considered satisfactory when a minimum of 70 % of the rated grains are within the specified size limits.

8.2 Hardenability values specified are based on fine-grain steels and are not applicable to coarse-grain steel.

9. End-Quench Hardenability Requirements

9.1 The end-quench hardenability shall conform to the requirements specified on the purchase order.

9.2 Hardenability values shall be specified in accordance with the applicable values in Figs. 2-23, inclusive, for the grade specified.

10. Test Specimens

10.1 *Number and Location*—The number and location of test specimens shall be in accordance with the manufacturer's standard practice and shall adequately represent the hardenability of each heat.

10.2 *Thermal Treatment*—All forged and rolled hardenability test specimens must be normalized prior to testing. Cast specimens need not be normalized.

11. Test Methods

11.1 *Grain Size*—Test Method E 112.

11.2 *End-quench Hardenability*—Test Methods A 255.

12. Certification and Reports of Testing

12.1 The hardenability shall be reported by listing hardness values at the following distances from the quenched end of the test specimen:

12.1.1 For inch-pound units (J distance in sixteenths of an inch): 1 through 16 sixteenths, then 18, 20, 22, 24, 28, and 32 sixteenths of an inch.

12.1.2 For SI units (J distance in millimetres): 1.5, 3, 5, 7, 9, 11, 13, 15, 20, 25, 30, 35, 40, 45, and 50 mm.

13. Keywords

13.1 bars; restricted hardenability

TABLE 1 Chemical Requirements of Restricted Hardenability Steels

NOTE 1—Phosphorus and sulfur in open-hearth steel is 0.035 %, max, and 0.040 %, max respectively. Phosphorus and sulfur in electric-furnace steel is 0.025 %, max.

NOTE 2—Small quantities of certain elements are present in alloy steels which are not specified or required. These elements are considered as incidental and may be present to the following maximum amounts: copper, 0.35 %; nickel, 0.25 %; chromium, 0.20 %; molybdenum, 0.06 %.

NOTE 3—Chemical ranges and limits shown in this table are subject to the permissible variation for product analysis shown in Specification A 29/A 29M.

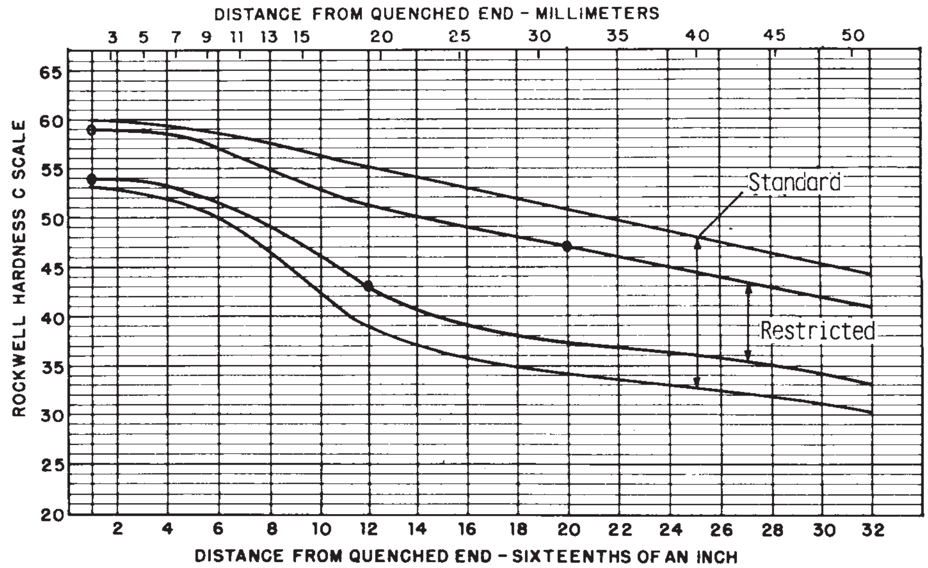
Grade Designation	Chemical Composition, %					
	Carbon	Manganese	Silicon	Nickel	Chromium	Molybdenum
15B21RH[A]	0.17–0.22	0.80–1.10	0.15–0.35			
15B35RH[A]	0.33–0.38	0.80–1.10	0.15–0.35			
3310RH	0.08–0.13	0.40–0.60	0.15–0.35	3.25–3.75	1.40–1.75	
4027RH	0.25–0.30	0.70–0.90	0.15–0.35	. . .	. . .	0.20–0.30
4118RH	0.18–0.23	0.70–0.90	0.15–0.35	. . .	0.40–0.60	0.08–0.15
4120RH	0.18–0.23	0.90–1.20	0.15–0.35	. . .	0.40–0.60	0.13–0.20
4130RH	0.28–0.33	0.40–0.60	0.15–0.35	. . .	0.80–1.10	0.15–0.25
4140RH	0.38–0.43	0.75–1.00	0.15–0.35	. . .	0.80–1.10	0.15–0.25
4145RH	0.43–0.48	0.75–1.00	0.15–0.35	. . .	0.80–1.10	0.15–0.25
4161RH	0.56–0.64	0.75–1.00	0.15–0.35	. . .	0.70–0.90	0.25–0.35
4320RH	0.17–0.22	0.45–0.65	0.15–0.35	1.65–2.00	0.40–0.60	0.20–0.30
4620RH	0.17–0.22	0.45–0.65	0.15–0.35	1.65–2.00	. . .	0.20–0.30
4820RH	0.18–0.23	0.50–0.70	0.15–0.35	3.25–3.75	. . .	0.20–0.30
50B40RH[A]	0.38–0.43	0.75–1.00	0.15–0.35	. . .	0.40–0.60	
5130RH	0.28–0.33	0.70–0.90	0.15–0.35	. . .	0.80–1.10	. . .
5140RH	0.38–0.43	0.70–0.90	0.15–0.35	. . .	0.70–0.90	. . .
5160RH	0.56–0.64	0.75–1.00	0.15–0.35	. . .	0.70–0.90	. . .
8620RH	0.18–0.23	0.70–0.90	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25
8622RH	0.20–0.25	0.70–0.90	0.15–0.35	0.40–0.70	0.40–0.60	0.15–0.25
8720RH	0.18–0.23	0.70–0.90	0.15–0.35	0.40–0.70	0.40–0.60	0.20–0.30
8822RH	0.20–0.25	0.75–1.00	0.15–0.35	0.40–0.70	0.40–0.60	0.30–0.40
9310RH	0.08–0.13	0.45–0.65	0.15–0.35	3.00–3.50	1.00–1.40	0.08–0.15

[A] These steels can be expected to have 0.0005 to 0.003 % boron.

HARDENABILITY BAND

4140 H/RH

	%C	%Mn	%Si	%Ni	%Cr	%Mo	
H	0.37/0.44	0.65/1.10	0.15/0.35	--	0.75/1.20	0.15/0.25	
RH	0.38/0.43	0.75/1.00	0.15/0.35	--	0.80/1.10	0.15/0.25	



HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE MILLIMETERS	MAX HRC		MIN HRC	
	4140 H	4140 RH	4140 RH	4140 H
1.5	60	59	54	53
3	60	59	54	52
5	60	59	59	52
7	59	59	53	51
9	59	58	52	50
11	58	56	50	48
13	57	55	49	46
15	57	54	47	43
20	55	51	42	38
25	53	49	39	35
30	51	48	38	33
35	49	46	37	32
40	48	44	36	32
45	46	43	35	31
50	45	41	33	30

HEAT TREATING TEMPERATURES

*NORMALIZE	870°C
AUSTENITIZE	845°C

*For forged or rolled specimens only

HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	MAX HRC		MIN HRC	
	4140 H	4140 RH	4140 RH	4140 H
1	60	59	54	53
2	60	59	54	53
3	60	59	54	52
4	59	59	53	51
5	59	58	52	51
6	58	57	51	50
7	58	56	50	48
8	57	55	49	47
9	57	54	48	44
10	56	53	46	42
11	56	52	44	40
12	55	52	43	39
13	55	51	42	38
14	54	50	41	37
15	54	50	40	36
16	53	49	39	35
18	52	48	38	34
20	51	47	37	33
22	49	46	37	33
24	48	45	36	32
26	47	44	35	32
28	46	43	35	31
30	46	42	34	31
32	44	41	33	30

HEAT TREATING TEMPERATURES

*NORMALIZE	1600 °F
AUSTENITIZE	1550 °F

*For forged or rolled specimens only

FIG. 1 Comparison of H-Band and RH-Band for 4140 Steel[A]

HARDENABILITY BAND

15B21 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	%B
0.17/0.22	0.80/1.10	0.15/0.35	--	--	--	*

* can be expected to contain 0.0005/0.003 percent boron.

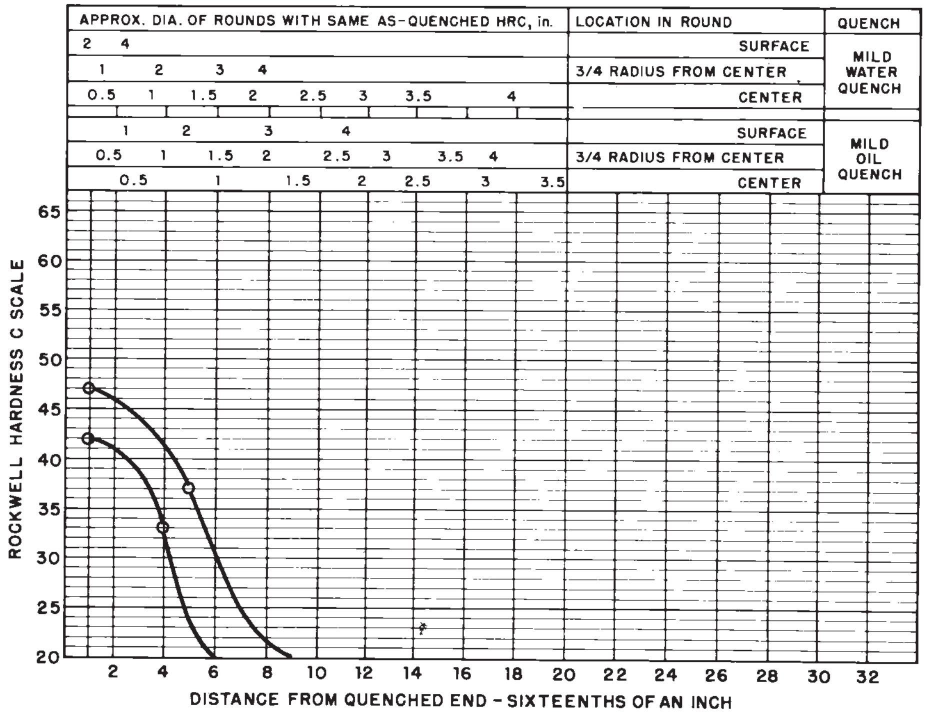
HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	47	42
2	46	41
3	44	39
4	42	33
5	37	24
6	30	20
7	24	--
8	22	--
9	20	--
10	--	--
11		
12		
13		
14		
15		
16		
18		
20		
22		
24		
26		
28		
30		
32		

HEAT TREATING TEMPERATURES

*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN.
1.5	47	42
3	46	41
5	44	39
7	40	31
9	34	23
11	24	--
13	22	--
15	20	--
20	--	--
25		
30		
35		
40		
45		
50		

HEAT TREATING TEMPERATURES

*NORMALIZE 925 °C
AUSTENITIZE 925 °C

*For forged or rolled specimens only

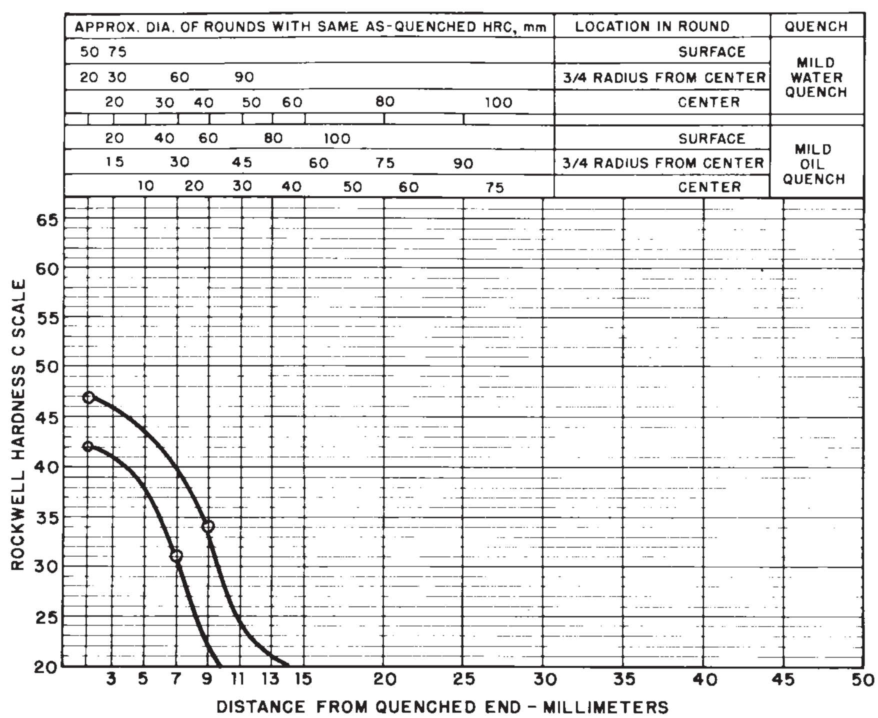


FIG. 2 Limits for Hardenability Band 15B21 RH

HARDENABILITY BAND

15B35 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	%B
0.33/0.38	0.80/1.10	0.15/0.35	--	--	--	*

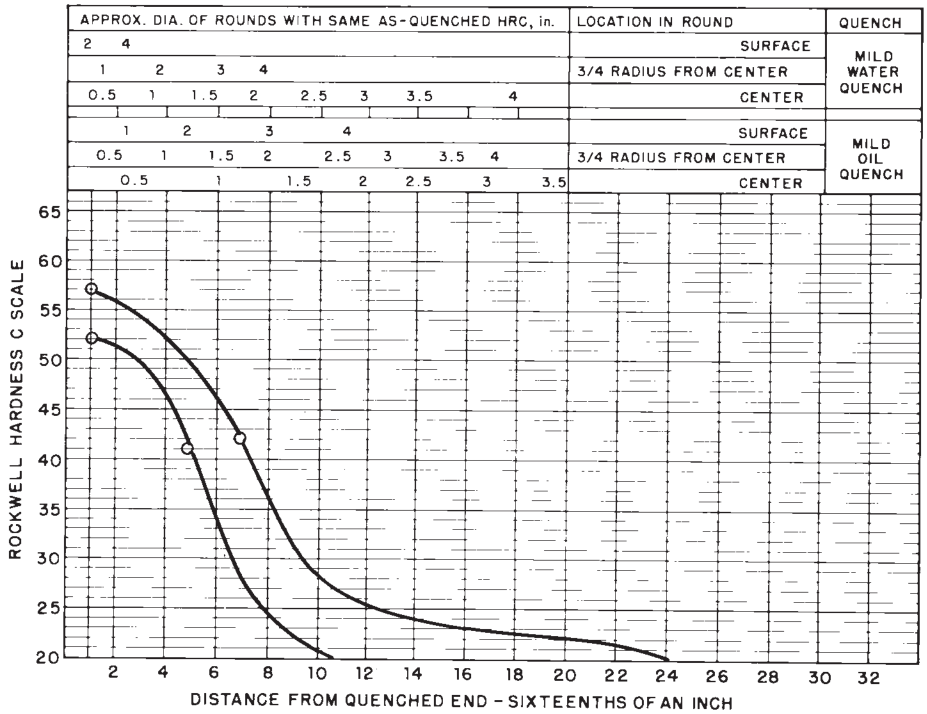
* can be expected to contain 0.0005/0.003 percent boron.

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	HRC	
	MAX.	MIN.
1	57	52
2	55	51
3	54	50
4	53	49
5	50	41
6	46	33
7	42	28
8	36	24
9	32	23
10	28	21
11		
12	25	--
13		
14	24	--
15		
16	23	--
18		
20	22	--
22		
24	20	--
26		
28	--	--
30		
32		

HEAT TREATING TEMPERATURES

*NORMALIZE	1600 °F
AUSTENITIZE	1550 °F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE MILLIMETERS	HRC	
	MAX.	MIN.
1.5	57	52
3	55	51
5	54	50
7	51	47
9	46	37
11	42	28
13	35	24
15	30	21
20	25	--
25	23	--
30	22	--
35	21	--
40	20	--
45		
50		

HEAT TREATING TEMPERATURES

*NORMALIZE	870 °C
AUSTENITIZE	845 °C

*For forged or rolled specimens only

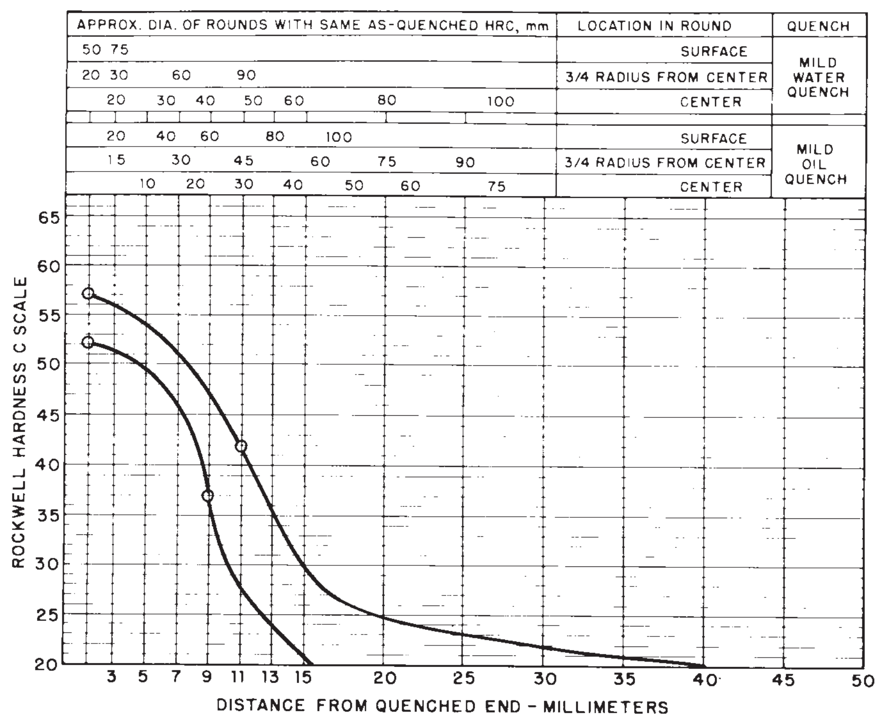


FIG. 3 Limits for Hardenability Band 15B35 RH

HARDENABILITY BAND

3310 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.08/0.13	0.40/0.60	0.15/0.35	3.25/3.75	1.40/1.75	--	

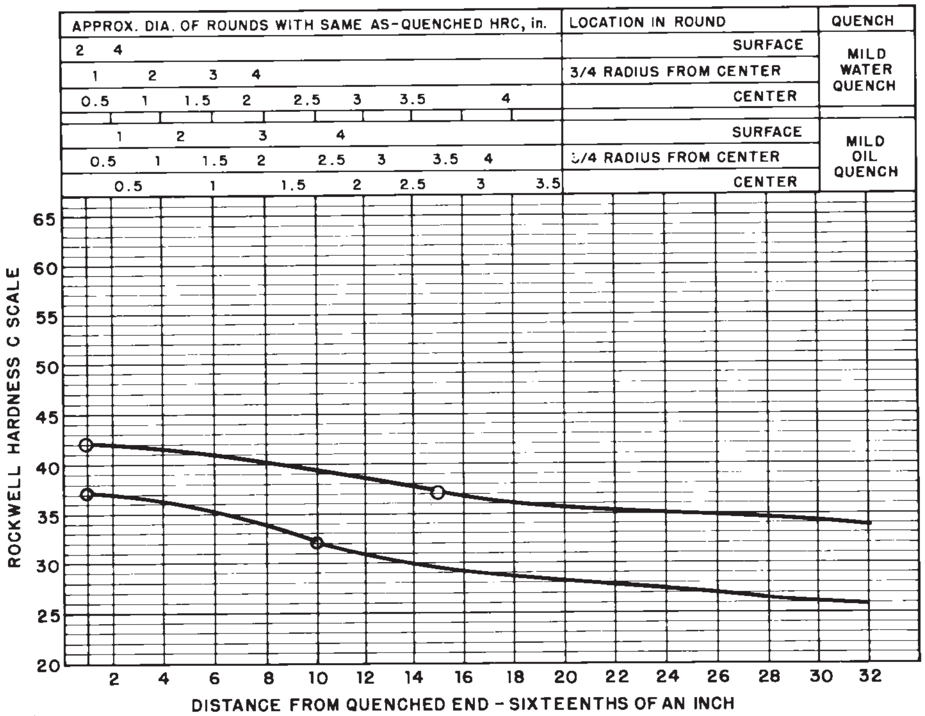
HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	42	37
2	42	37
3	42	37
4	41	36
5	41	36
6	41	35
7	40	34
8	40	33
9	39	32
10	39	32
11	39	31
12	39	31
13	38	30
14	38	30
15	37	29
16	37	29
18	36	28
20	36	28
22	35	27
24	35	27
26	35	27
28	34	26
30	34	26
32	34	26

HEAT TREATING TEMPERATURES

*NORMALIZE	1700 °F
AUSTENITIZE	1550 °F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN.
1.5	42	37
3	42	37
5	42	37
7	41	36
9	41	35
11	40	34
13	40	33
15	39	32
20	38	30
25	37	29
30	36	28
35	35	27
40	35	27
45	34	26
50	34	26

HEAT TREATING TEMPERATURES

*NORMALIZE	925 °C
AUSTENITIZE	845 °C

*For forged or rolled specimens only

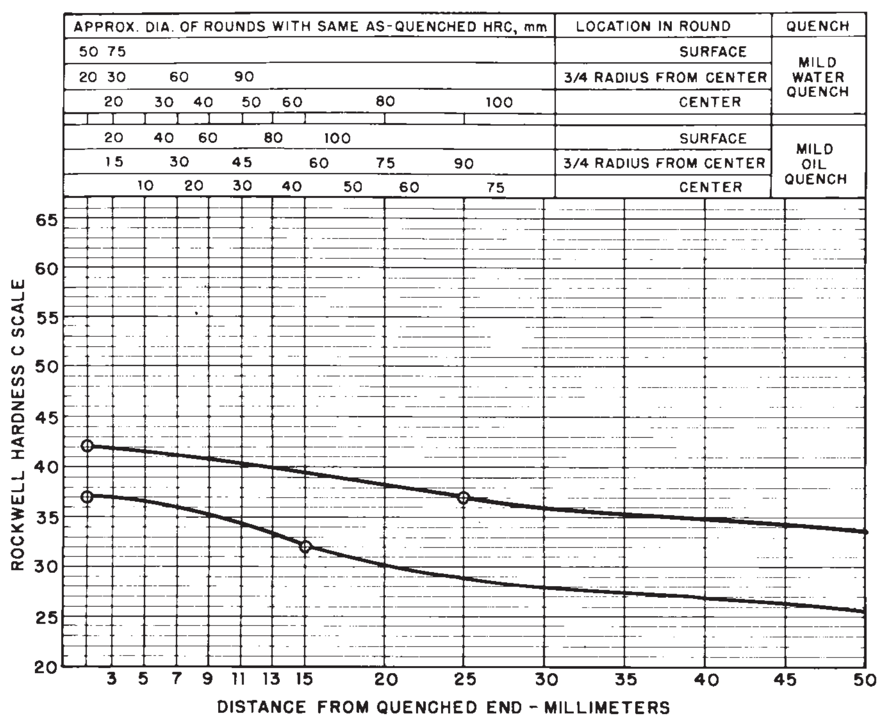


FIG. 4 Limits for Hardenability Band 3310 RH

HARDENABILITY BAND

4027 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.25/0.30	0.70/0.90	0.15/0.35	--	--	0.20/0.30	

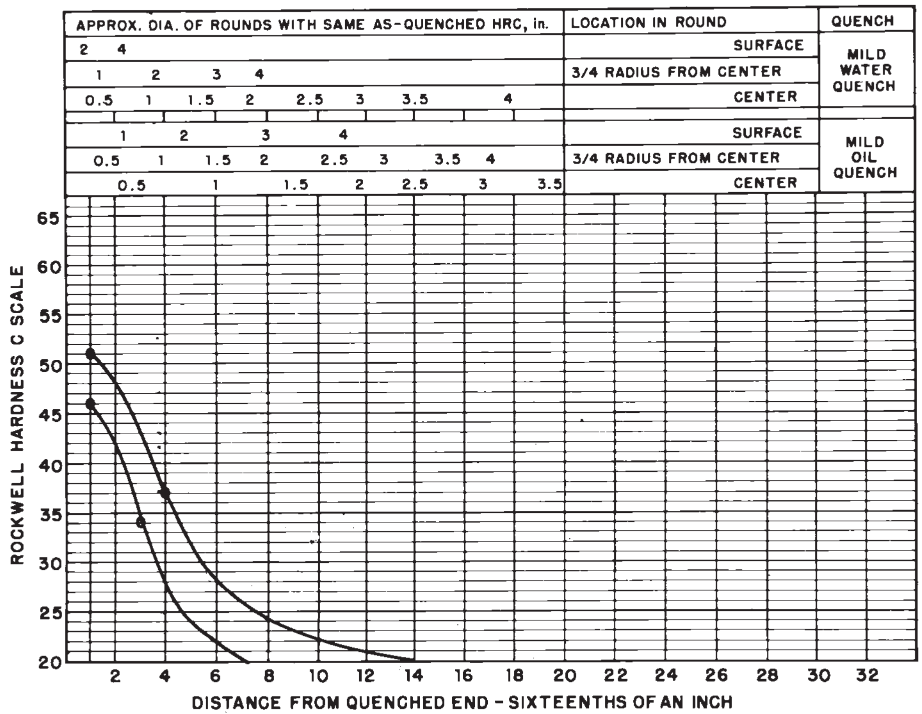
HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	51	46
2	48	42
3	43	34
4	37	28
5	32	24
6	28	22
7	26	20
8	24	--
9	23	--
10	22	--
11	22	--
12	21	--
13	21	--
14	20	--
15	--	--
16		
18		
20		
22		
24		
26		
28		
30		
32		

HEAT TREATING TEMPERATURES

*NORMALIZE	1650	°F
AUSTENITIZE	1600	°F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN
1.5	51	46
3	48	42
5	42	33
7	35	26
9	29	23
11	26	20
13	24	--
15	23	--
20	21	--
25	--	--
30		
35		
40		
45		
50		

HEAT TREATING TEMPERATURES

*NORMALIZE	900	°C
AUSTENITIZE	870	°C

*For forged or rolled specimens only

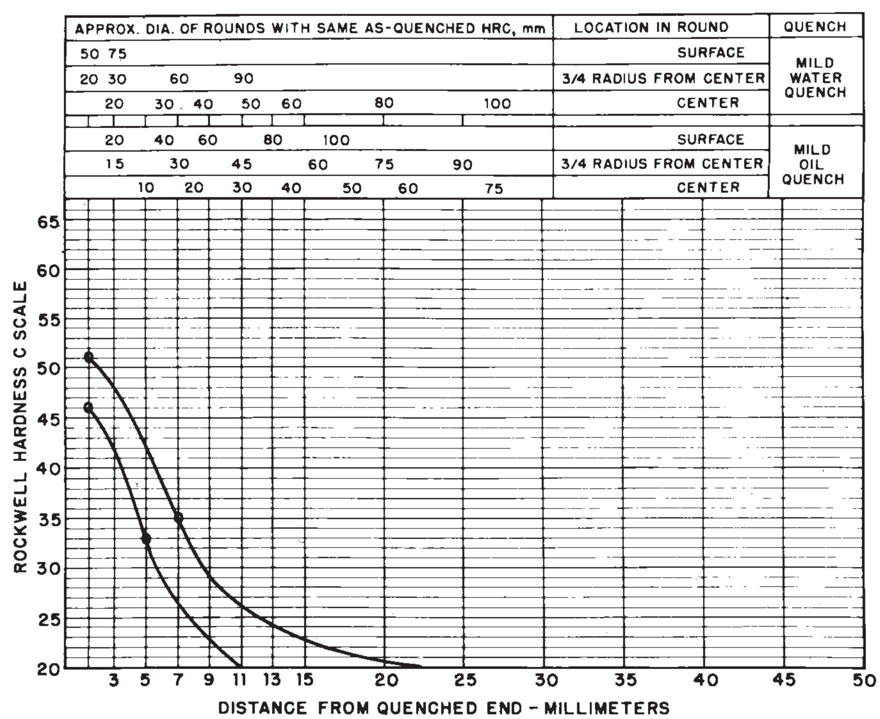


FIG. 5 Limits for Hardenability Band 4027 RH

HARDENABILITY BAND

4118 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.18/0.23	0.70/0.90	0.15/0.35	--	0.40/0.60	0.08/0.15	

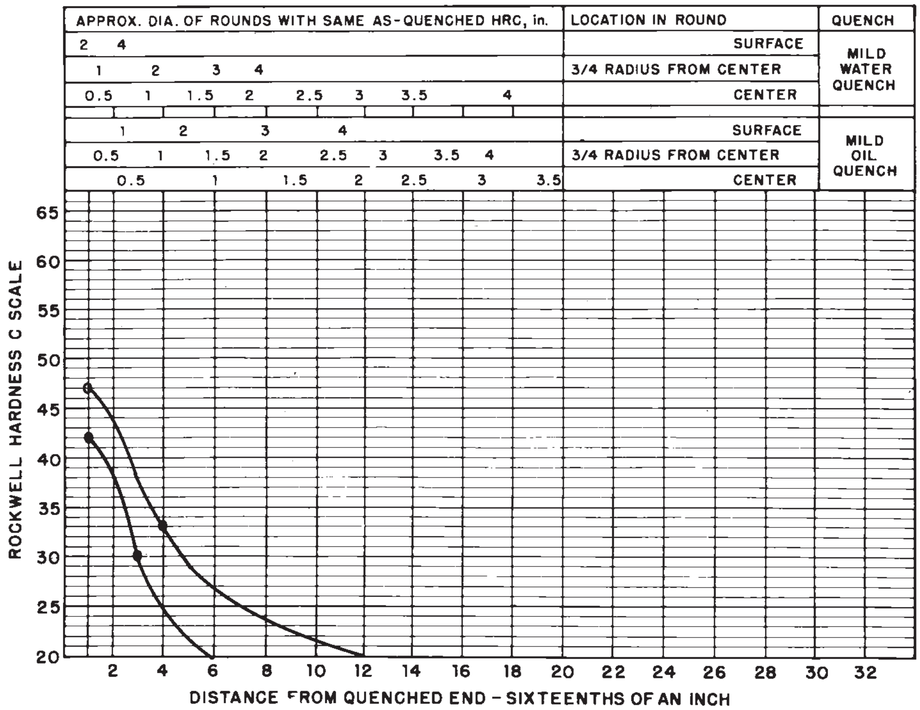
HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	47	42
2	44	38
3	38	30
4	33	25
5	29	22
6	27	20
7	25	--
8	24	--
9	23	--
10	22	--
11	21	--
12	20	--
13	--	--
14		
15		
16		
18		
20		
22		
24		
26		
28		
30		
32		

HEAT TREATING TEMPERATURES

*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN.
1.5	47	42
3	44	38
5	37	29
7	31	24
9	28	21
11	25	20
13	24	--
15	23	--
20	20	--
25	--	--
30		
35		
40		
45		
50		

HEAT TREATING TEMPERATURES

*NORMALIZE 925 °C
AUSTENITIZE 925 °C

*For forged or rolled specimens only

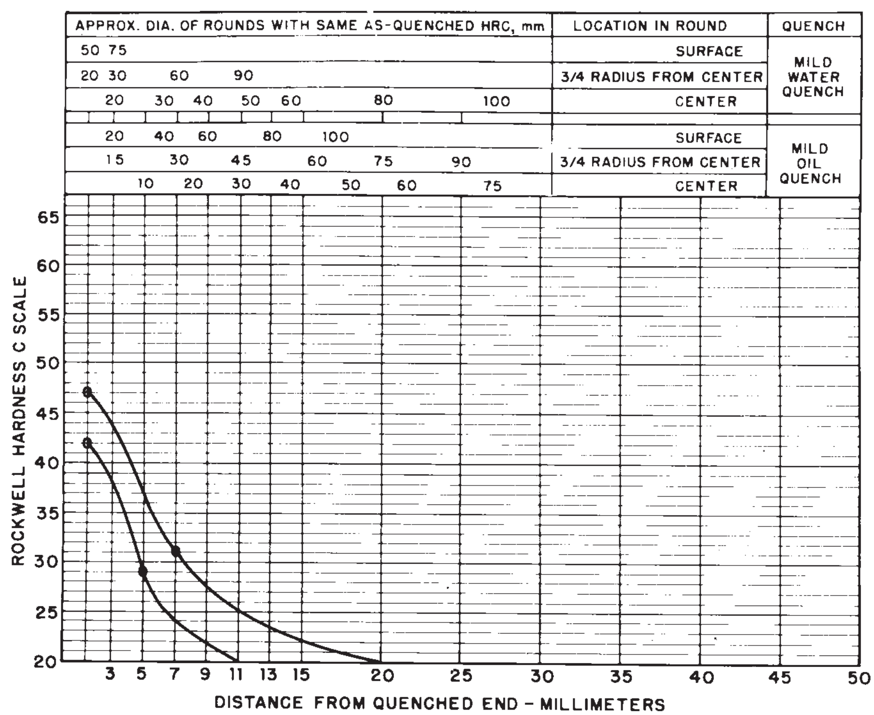


FIG. 6 Limits for Hardenability Band 4118 RH

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	HRC	
	MAX.	MIN.
1	47	42
2	45	39
3	41	35
4	38	30
5	34	26
6	31	24
7	29	22
8	28	21
9	26	20
10	25	--
11	24	--
12	23	--
13	23	--
14	22	--
15	22	--
16	21	--
18	20	--
20	--	--
22		
24		
26		
28		
30		
32		

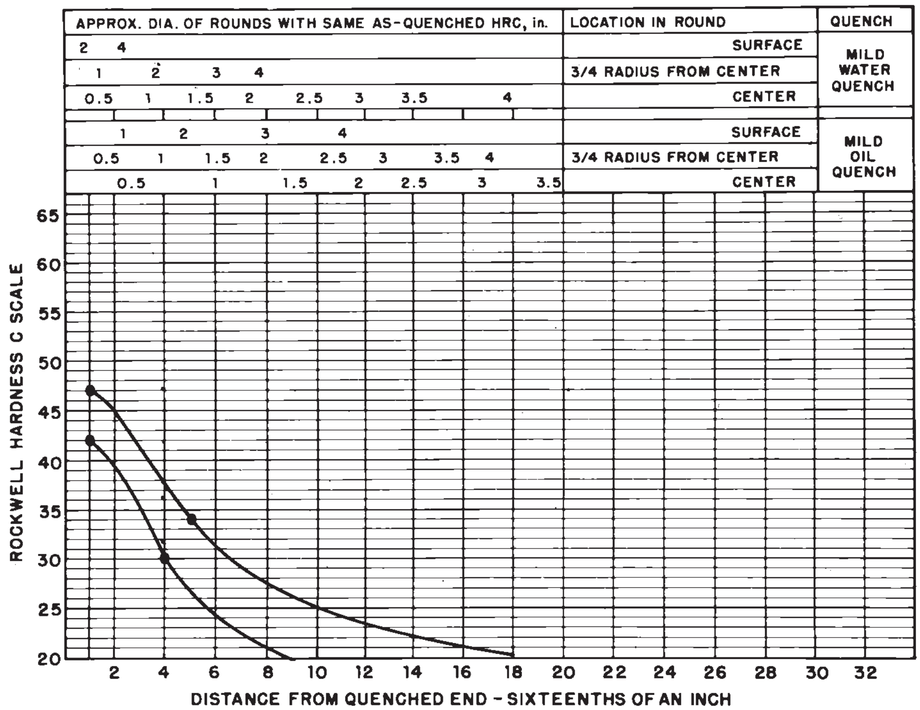
HEAT TREATING TEMPERATURES

*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F

*For forged or rolled specimens only

HARDENABILITY BAND 4120 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.18/0.23	0.90/1.20	0.15/0.35	--	0.40/0.60	0.13/0.20	



HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE MILLIMETERS	HRC	
	MAX.	MIN.
1.5	47	42
3	45	39
5	41	34
7	36	28
9	32	25
11	29	22
13	28	21
15	26	20
20	23	--
25	21	--
30	--	--
35		
40		
45		
50		

HEAT TREATING TEMPERATURES

*NORMALIZE 925 °C
AUSTENITIZE 925 °C

*For forged or rolled specimens only

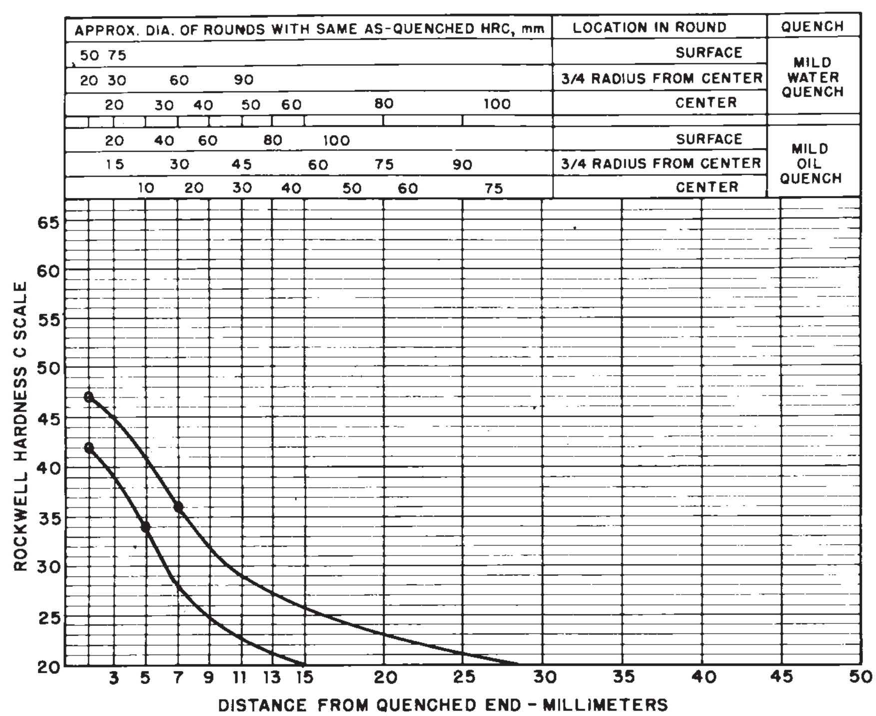


FIG. 7 Limits for Hardenability Band 4120 RH

HARDENABILITY BAND 4130 RH

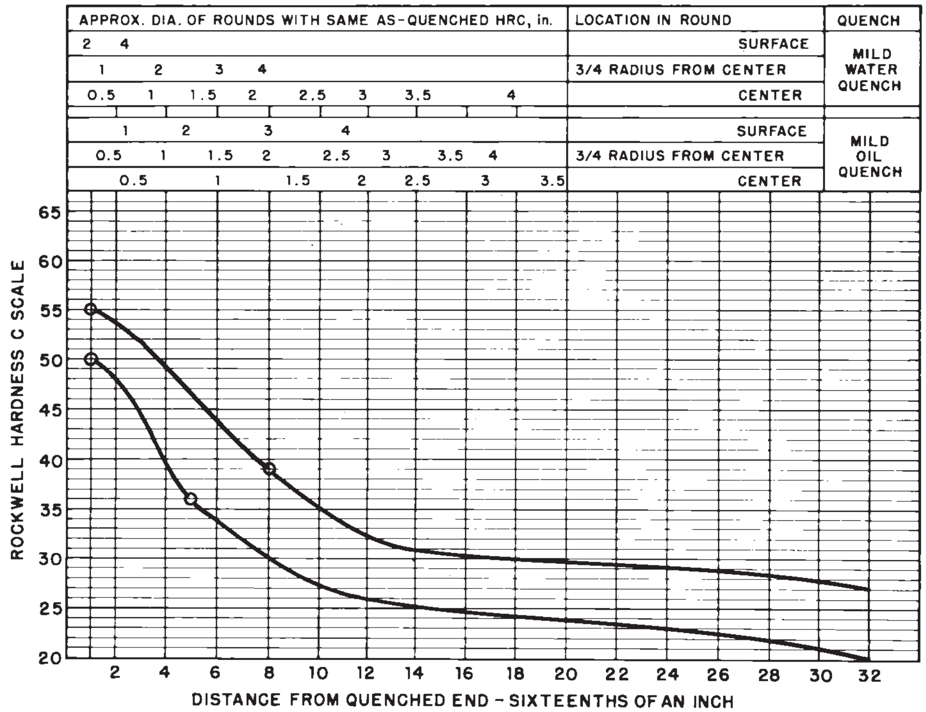
%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.28/0.33	0.40/0.60	0.15/0.35	--	0.80/1.10	0.15/0.25	

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	55	50
2	54	48
3	52	44
4	49	40
5	46	36
6	44	34
7	41	32
8	39	30
9	37	28
10	35	27
11	33	26
12	32	26
13	32	26
14	31	25
15	31	25
16	31	25
18	30	24
20	30	23
22	30	23
24	29	22
26	29	22
28	28	21
30	28	21
32	27	20

HEAT TREATING TEMPERATURES

*NORMALIZE 1650 °F
AUSTENITIZE 1600 °F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN.
1.5	55	50
3	54	48
5	52	44
7	48	38
9	45	35
11	41	32
13	39	30
15	36	27
20	32	26
25	31	25
30	30	24
35	30	23
40	29	22
45	28	21
50	27	20

HEAT TREATING TEMPERATURES

*NORMALIZE 900 °C
AUSTENITIZE 870 °C

*For forged or rolled specimens only

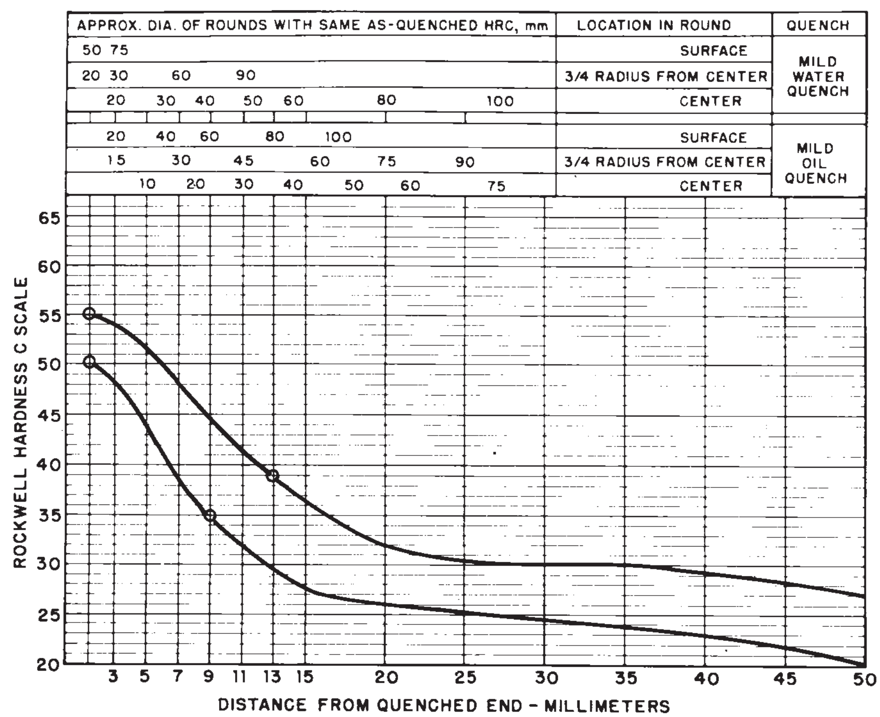


FIG. 8 Limits for Hardenability Band 4130 RH

HARDENABILITY BAND 4140 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.38/0.43	0.75/1.00	0.15/0.35	--	0.80/1.10	0.15/0.25	

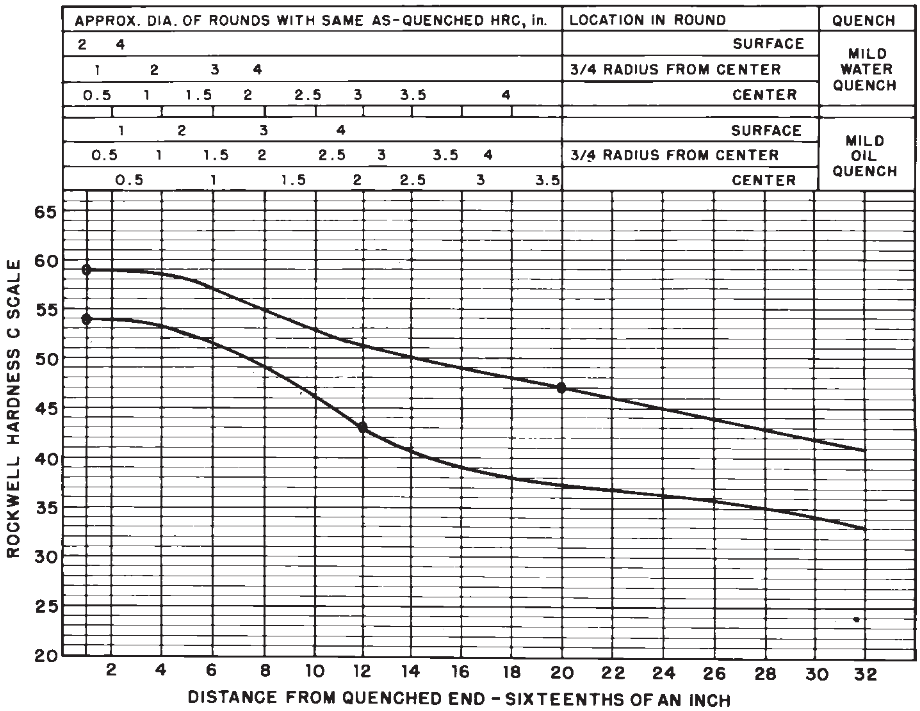
HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	59	54
2	59	54
3	59	54
4	59	53
5	58	52
6	57	51
7	56	50
8	55	49
9	54	48
10	53	46
11	52	44
12	52	43
13	51	42
14	50	41
15	50	40
16	49	39
18	48	38
20	47	37
22	46	37
24	45	36
26	44	35
28	43	35
30	42	34
32	41	33

HEAT TREATING TEMPERATURES

*NORMALIZE	1600	°F
AUSTENITIZE	1550	°F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN.
1.5	59	54
3	59	54
5	59	54
7	59	53
9	58	52
11	56	50
13	55	49
15	54	47
20	51	42
25	49	39
30	48	38
35	46	37
40	44	36
45	43	35
50	41	33

HEAT TREATING TEMPERATURES

*NORMALIZE	870	°C
AUSTENITIZE	845	°C

*For forged or rolled specimens only

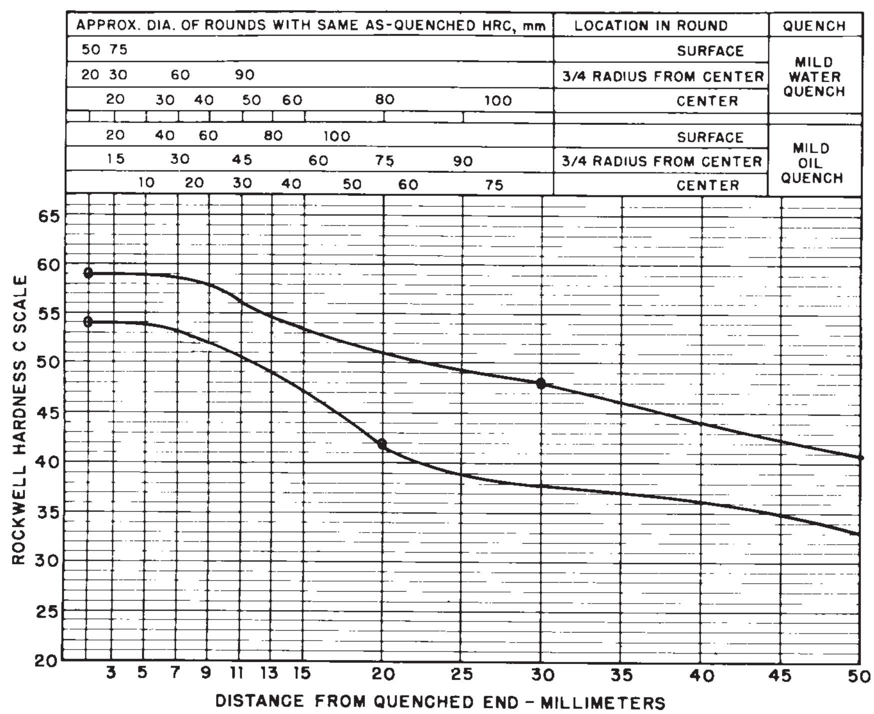


FIG. 9 Limits for Hardenability Band 4140 RH

HARDENABILITY BAND

4145 RH

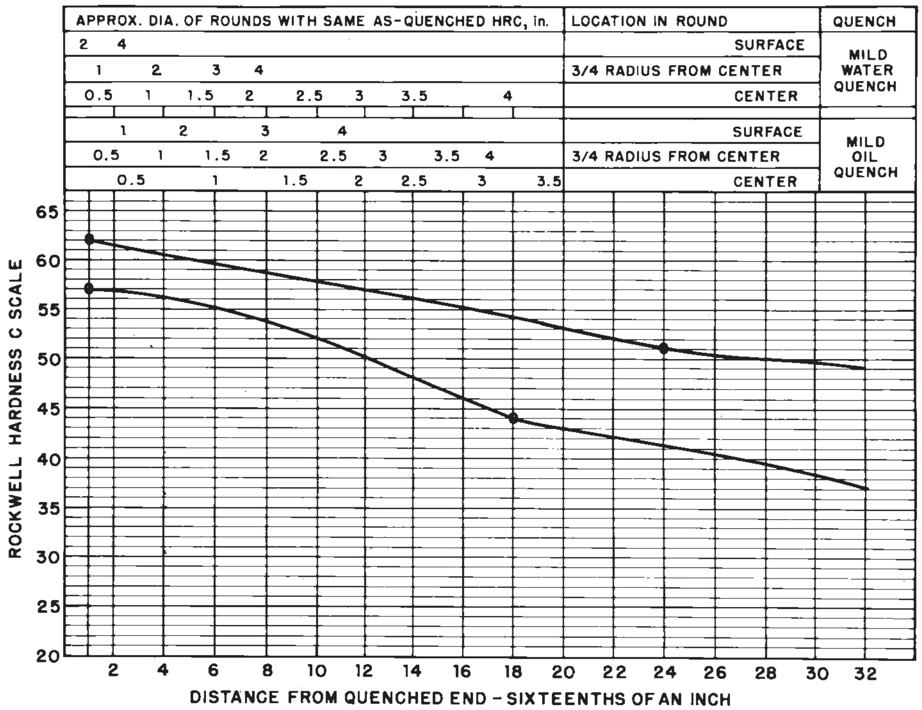
%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.43/0.48	0.75/1.00	0.15/0.35	--	0.80/1.10	0.15/0.25	

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	HRC	
	MAX.	MIN.
1	62	57
2	62	57
3	61	56
4	61	56
5	60	55
6	60	55
7	59	54
8	59	53
9	58	52
10	58	52
11	58	51
12	57	50
13	57	49
14	56	48
15	56	47
16	55	46
18	54	44
20	53	43
22	52	42
24	51	40
26	51	40
28	50	39
30	50	38
32	49	37

HEAT TREATING TEMPERATURES

*NORMALIZE	1600	°F
AUSTENITIZE	1550	°F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE MILLIMETERS	HRC	
	MAX.	MIN.
1.5	62	57
3	62	57
5	61	56
7	61	56
9	60	55
11	59	54
13	59	53
15	58	52
20	57	49
25	55	46
30	54	44
35	52	42
40	51	40
45	50	39
50	49	37

HEAT TREATING TEMPERATURES

*NORMALIZE	870	°C
AUSTENITIZE	845	°C

*For forged or rolled specimens only

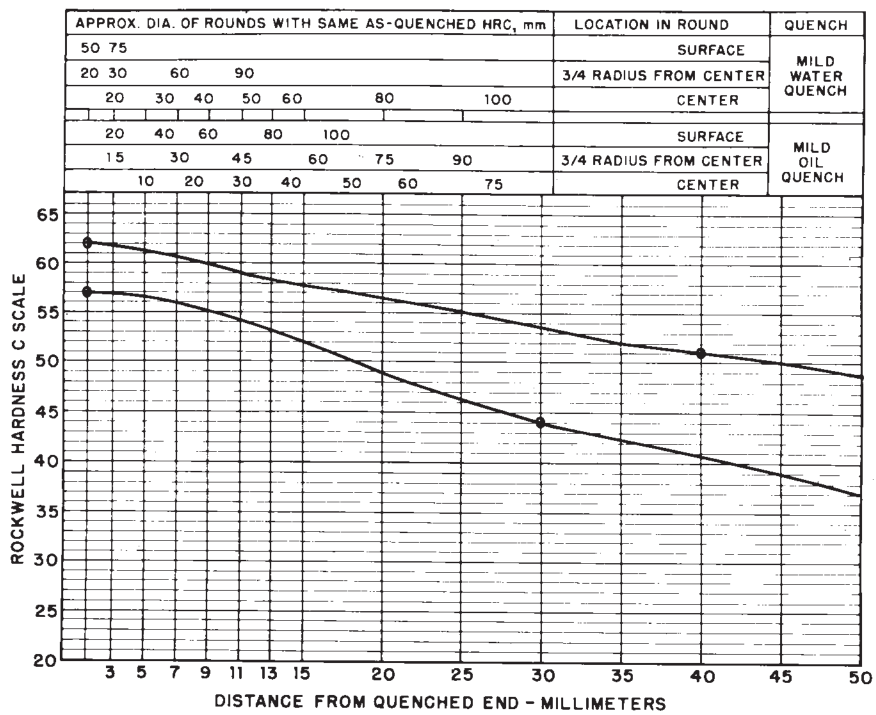


FIG. 10 Limits for Hardenability Band 4145 RH

HARDENABILITY BAND

4145 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.43/0.48	0.75/1.00	0.15/0.35	--	0.80/1.10	0.15/0.25	

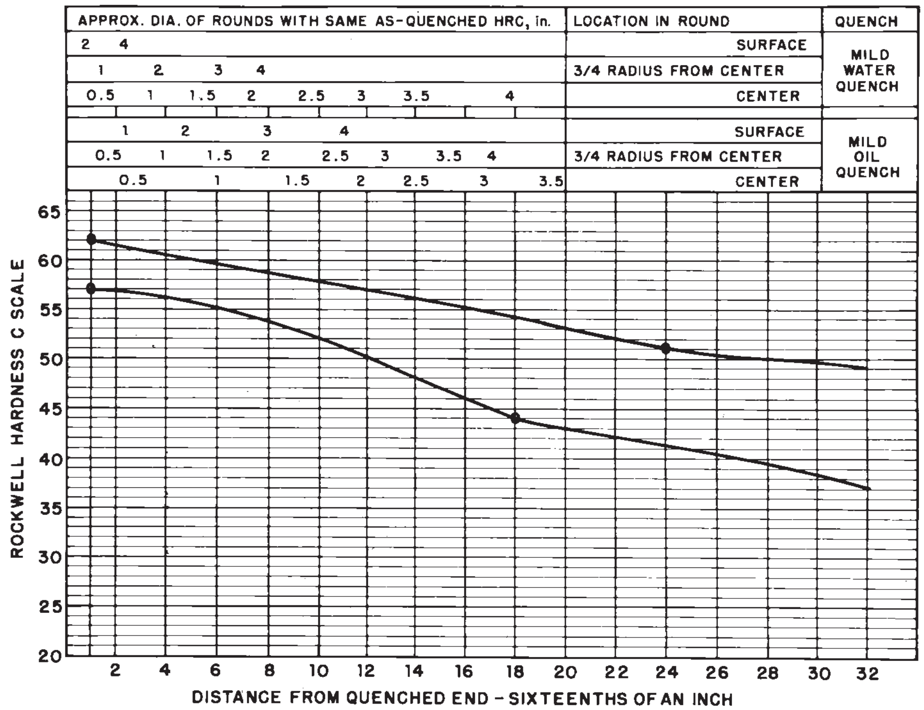
HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	62	57
2	62	57
3	61	56
4	61	56
5	60	55
6	60	55
7	59	54
8	59	53
9	58	52
10	58	52
11	58	51
12	57	50
13	57	49
14	56	48
15	56	47
16	55	46
18	54	44
20	53	43
22	52	42
24	51	40
26	51	40
28	50	39
30	50	38
32	49	37

HEAT TREATING TEMPERATURES

*NORMALIZE	1600	°F
AUSTENITIZE	1550	°F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN.
1.5	62	57
3	62	57
5	61	56
7	61	56
9	60	55
11	59	54
13	59	53
15	58	52
20	57	49
25	55	46
30	54	44
35	52	42
40	51	40
45	50	39
50	49	37

HEAT TREATING TEMPERATURES

*NORMALIZE	870	°C
AUSTENITIZE	845	°C

*For forged or rolled specimens only

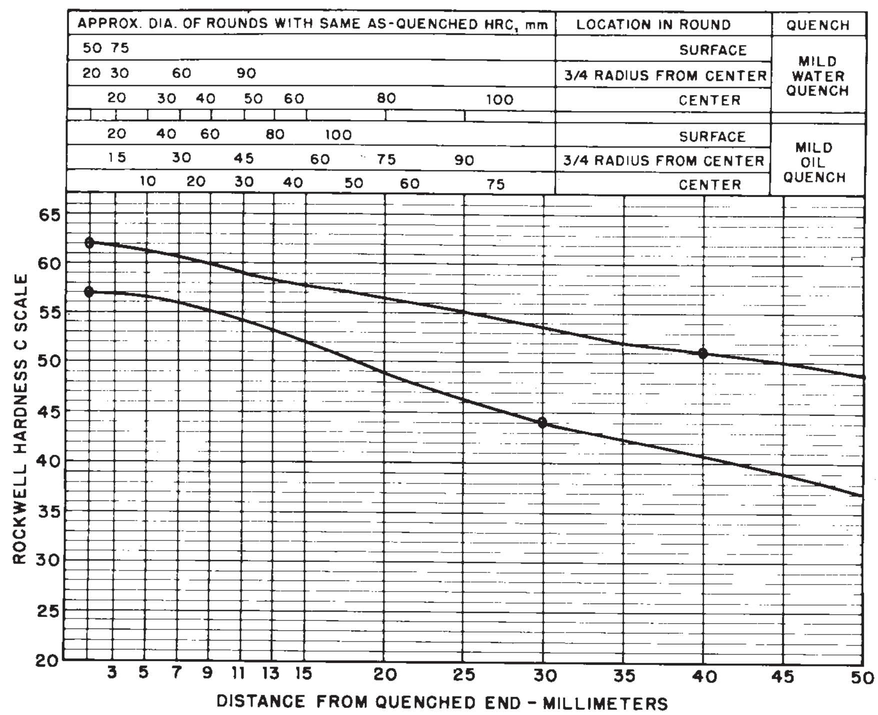


FIG. 11 Limits for Hardenability Band 4161 RH

HARDENABILITY BAND 4320 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.17/0.22	0.45/0.65	0.15/0.35	1.65/2.00	0.40/0.60	0.20/0.30	

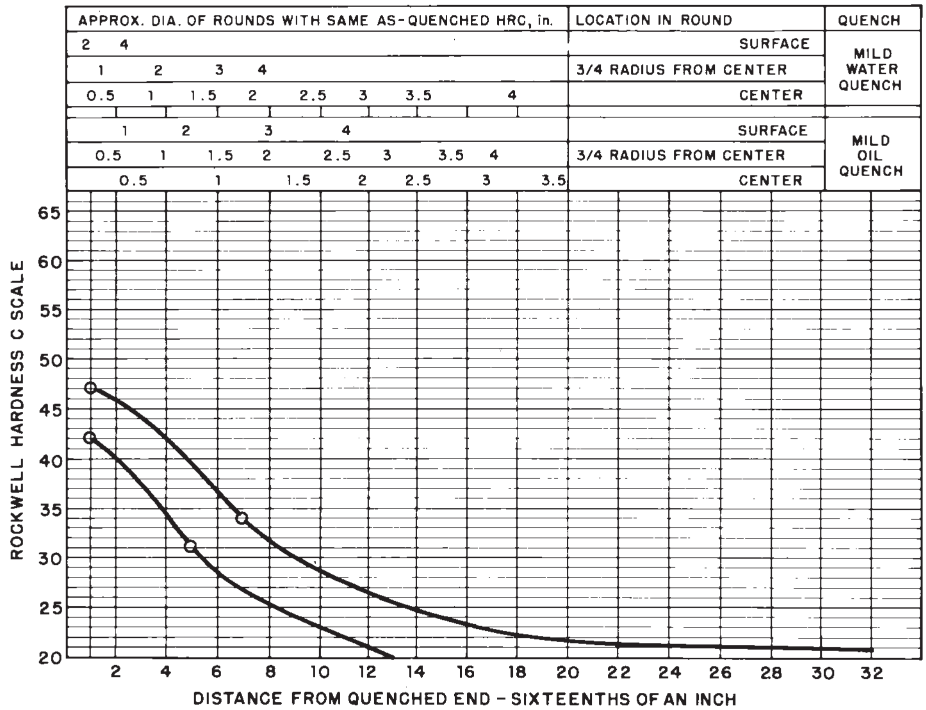
HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	47	42
2	46	40
3	44	37
4	41	34
5	39	31
6	36	29
7	34	27
8	32	25
9	31	24
10	29	23
11	28	22
12	26	21
13	25	20
14	24	--
15	24	--
16	23	--
18	22	--
20	22	--
22	21	--
24	21	--
26	21	--
28	21	--
30	21	--
32	21	--

HEAT TREATING TEMPERATURES

*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN.
1.5	47	42
3	46	40
5	44	37
7	40	32
9	37	30
11	34	27
13	31	25
15	29	23
20	25	20
25	23	--
30	22	--
35	21	--
40	21	--
45	21	--
50	21	--

HEAT TREATING TEMPERATURES

*NORMALIZE 925 °C
AUSTENITIZE 925 °C

*For forged or rolled specimens only

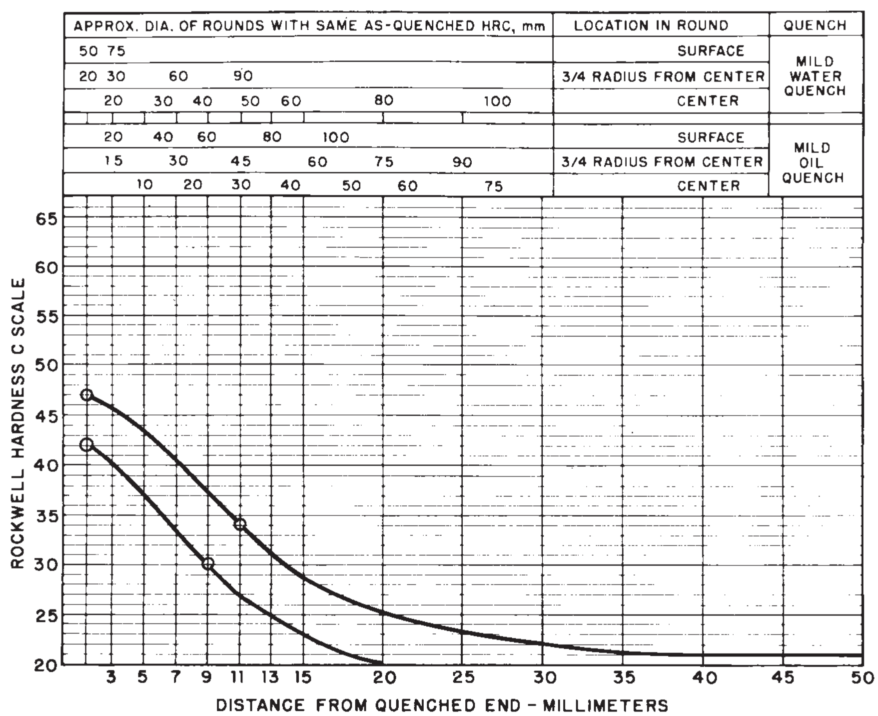


FIG. 12 Limits for Hardenability Band 4320 RH

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	HRC	
	MAX.	MIN.
1	47	42
2	44	37
3	40	30
4	37	27
5	32	24
6	29	21
7	27	20
8	25	--
9	24	--
10	23	--
11	22	--
12	21	--
13	20	--
14	--	--
15		
16		
18		
20		
22		
24		
26		
28		
30		
32		

HEAT TREATING TEMPERATURES

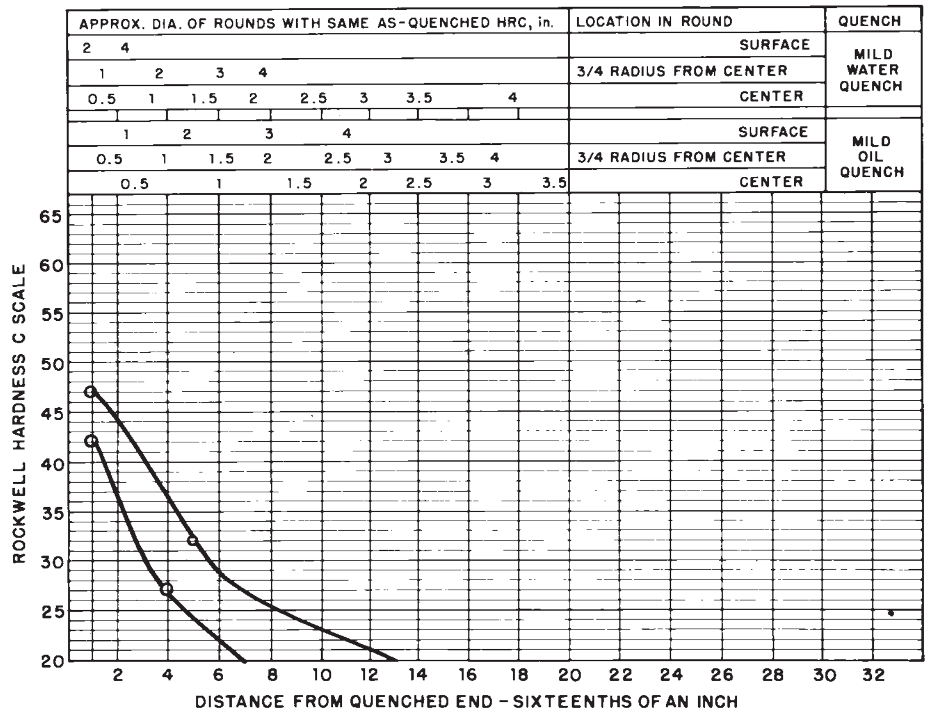
*NORMALIZE	1700 °F
AUSTENITIZE	1700 °F

*For forged or rolled specimens only

HARDENABILITY BAND

4620 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.17/0.22	0.45/0.65	0.15/0.35	1.65/2.00	--	0.20/0.30	



HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE MILLIMETERS	HRC	
	MAX.	MIN.
1.5	47	42
3	45	38
5	39	30
7	34	25
9	31	22
11	27	20
13	25	--
15	23	--
20	21	--
25	--	--
30		
35		
40		
45		
50		

HEAT TREATING TEMPERATURES

*NORMALIZE	925 °C
AUSTENITIZE	925 °C

*For forged or rolled specimens only

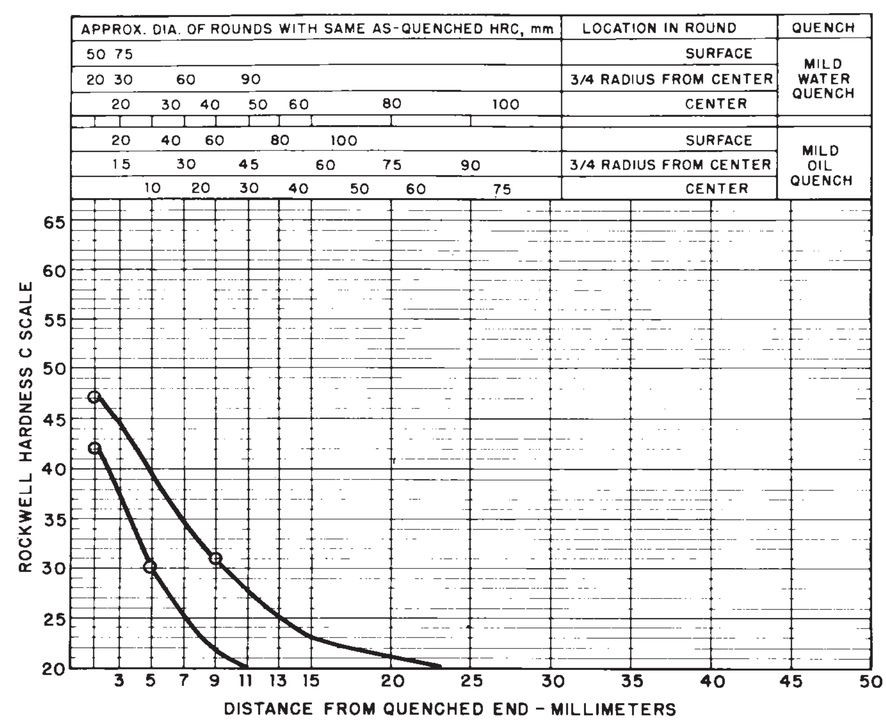


FIG. 13 Limits for Hardenability Band 4620 RH

HARDENABILITY BAND 4820 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.18/0.23	0.50/0.70	0.15/0.35	3.25/3.75	--	0.20/0.30	

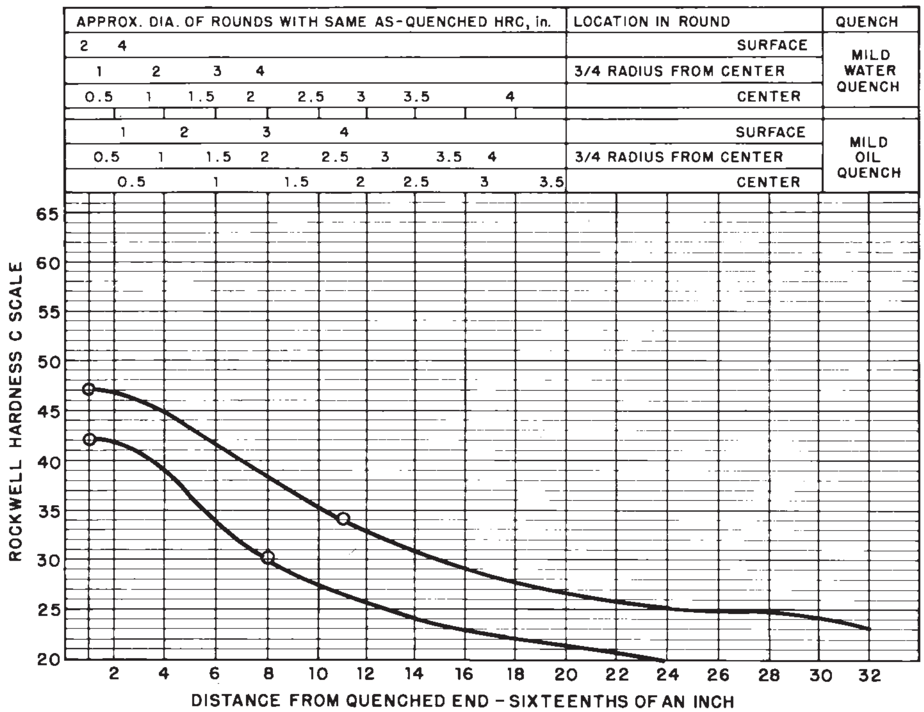
HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	47	42
2	47	42
3	46	41
4	45	40
5	43	36
6	41	33
7	40	32
8	38	30
9	36	28
10	35	27
11	34	26
12	33	25
13	32	24
14	31	24
15	30	23
16	29	23
18	28	22
20	27	22
22	26	21
24	25	20
26	25	20
28	25	--
30	24	--
32	23	--

HEAT TREATING TEMPERATURES

*NORMALIZE	1700°F
AUSTENITIZE	1550°F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN.
1.5	47	42
3	47	42
5	46	41
7	44	38
9	42	34
11	40	32
13	37	29
15	35	27
20	32	24
25	29	22
30	27	21
35	26	21
40	25	20
45	24	--
50	23	--

HEAT TREATING TEMPERATURES

*NORMALIZE	925 °C
AUSTENITIZE	845 °C

*For forged or rolled specimens only

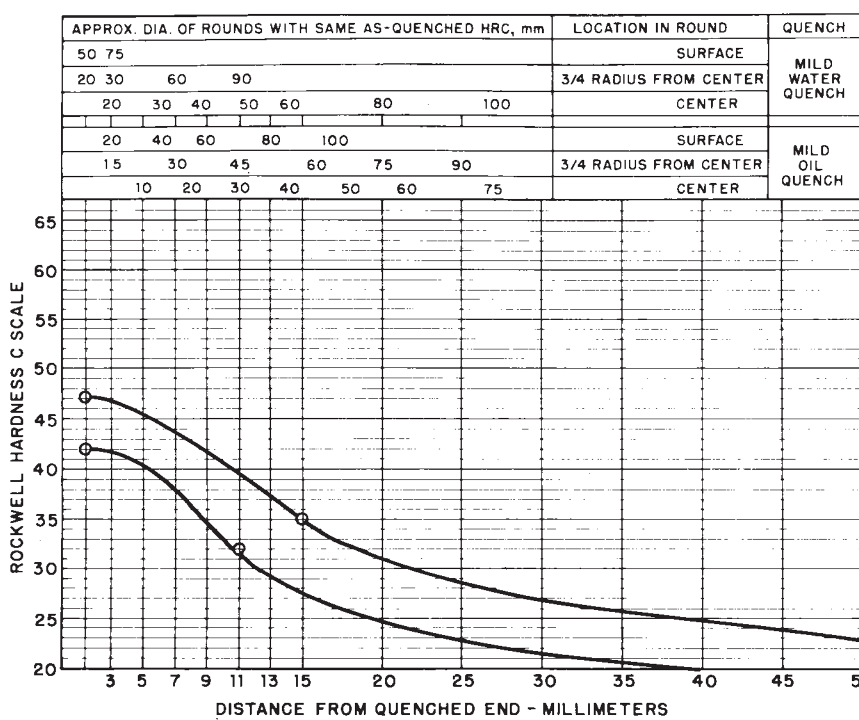


FIG. 14 Limits for Hardenability Band 4820 RH

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	59	54
2	59	54
3	58	53
4	58	53
5	57	52
6	56	50
7	55	47
8	54	43
9	52	38
10	50	35
11	49	33
12	47	32
13	45	31
14	44	30
15	41	29
16	38	28
18	36	26
20	34	24
22	33	23
24	32	22
26	31	21
28	30	20
30	29	--
32	28	--

HEAT TREATING TEMPERATURES

*NORMALIZE 1600°F

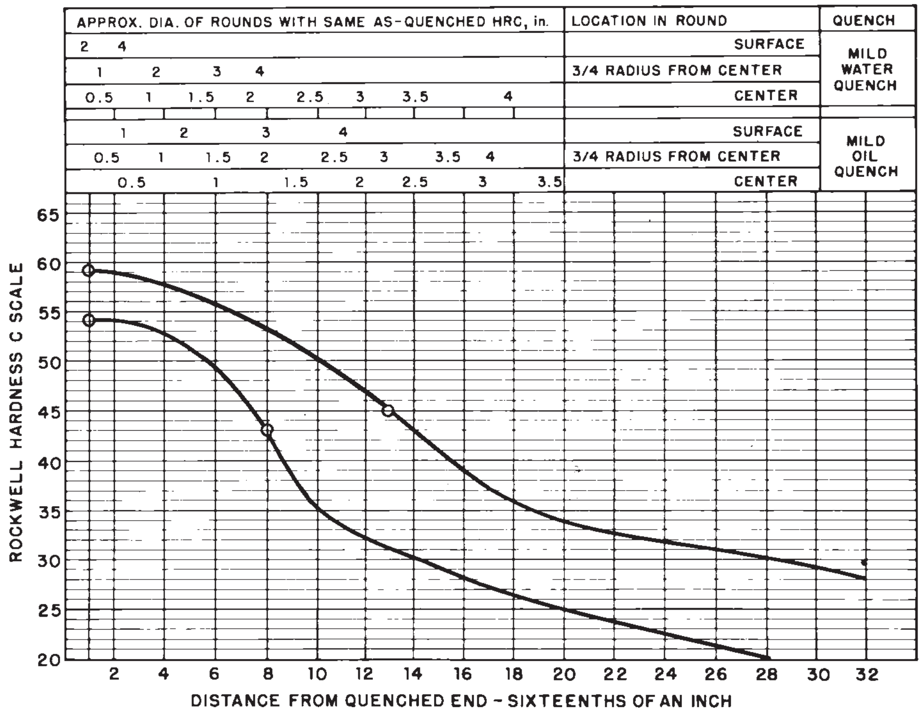
AUSTENITIZE 1550°F

*For forged or rolled specimens only

HARDENABILITY BAND 50B40 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	%B
0.38/0.43	0.75/1.00	0.15/0.35	--	0.40/0.60	--	*

* can be expected to contain 0.0005/0.003 percent boron.



HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN.
1.5	59	54
3	59	54
5	58	53
7	57	52
9	56	51
11	55	47
13	53	41
15	51	36
20	46	31
25	39	28
30	35	25
35	33	23
40	31	21
45	29	20
50	28	--

HEAT TREATING TEMPERATURES

*NORMALIZE 870°C

AUSTENITIZE 845°C

*For forged or rolled specimens only

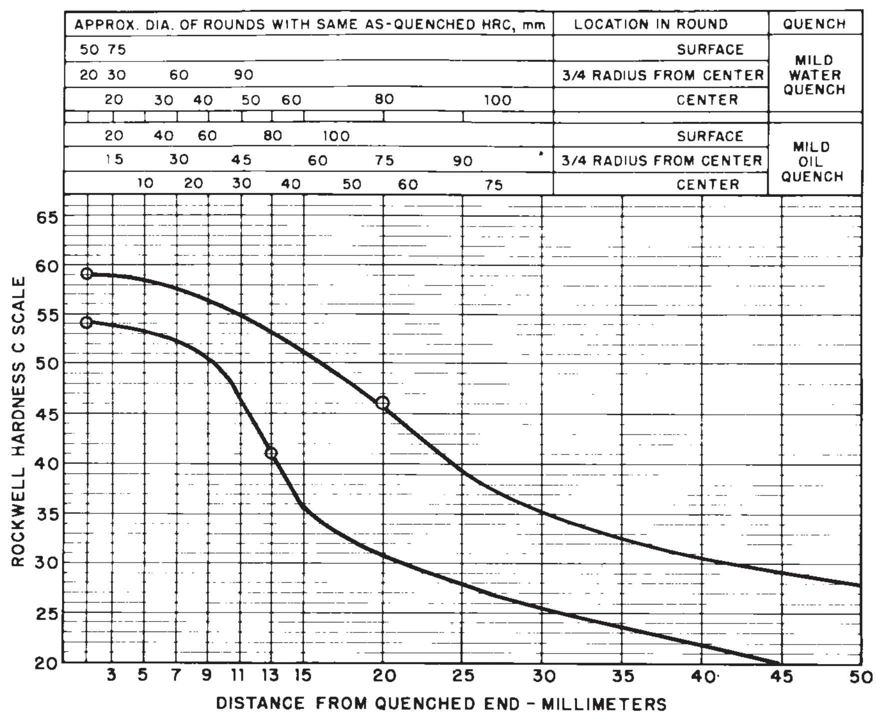


FIG. 15 Limits for Hardenability Band 50B40 RH

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	HRC	
	MAX.	MIN.
1	55	50
2	53	47
3	51	44
4	49	41
5	46	37
6	44	35
7	42	33
8	39	31
9	37	29
10	35	27
11	34	26
12	33	25
13	32	24
14	31	23
15	30	22
16	29	21
18	28	20
20	27	--
22	26	--
24	25	--
26	24	--
28	23	--
30	22	--
32	21	--

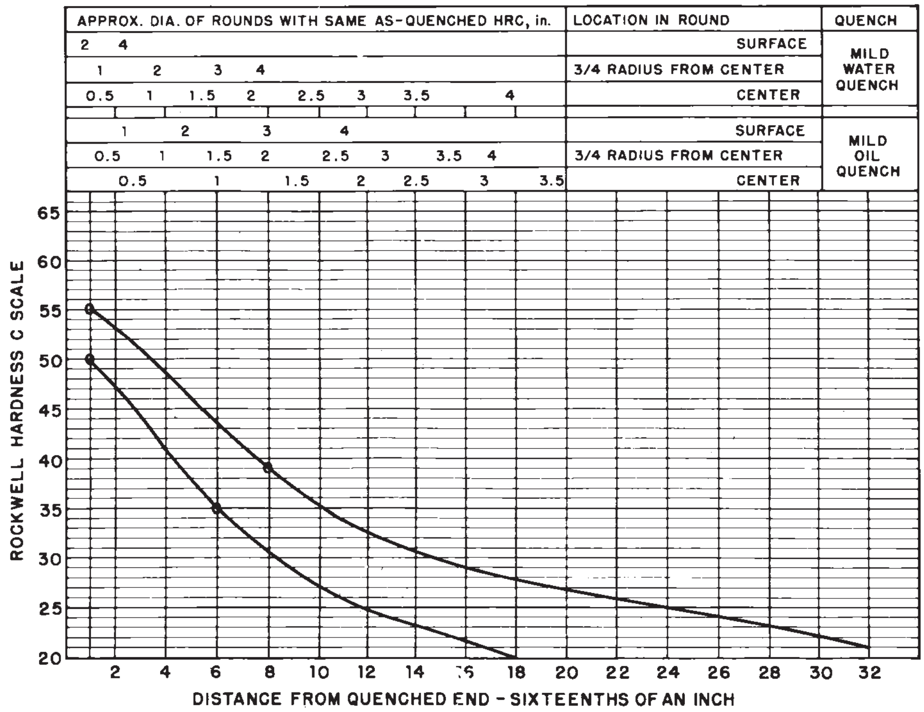
HEAT TREATING TEMPERATURES

*NORMALIZE	1650	°F
AUSTENITIZE	1600	°F

*For forged or rolled specimens only

HARDENABILITY BAND 5130 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.28/0.33	0.70/0.90	0.15/0.35	--	0.80/1.10	--	



HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE MILLIMETERS	HRC	
	MAX.	MIN.
1.5	55	50
3	53	47
5	51	44
7	48	39
9	45	36
11	42	33
13	39	31
15	36	28
20	32	24
25	29	21
30	28	20
35	26	--
40	24	--
45	23	--
50	21	--

HEAT TREATING TEMPERATURES

*NORMALIZE	900	°C
AUSTENITIZE	870	°C

*For forged or rolled specimens only

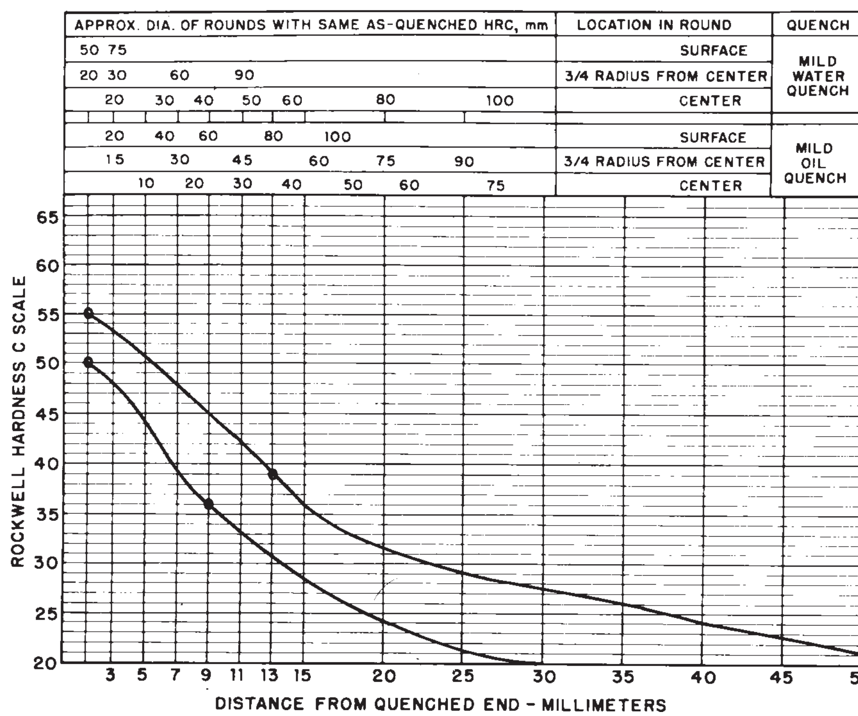


FIG. 16 Limits for Hardenability Band 5130 RH

HARDENABILITY BAND 5140 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.38/0.43	0.70/0.90	0.15/0.35	--	0.70/0.90	--	

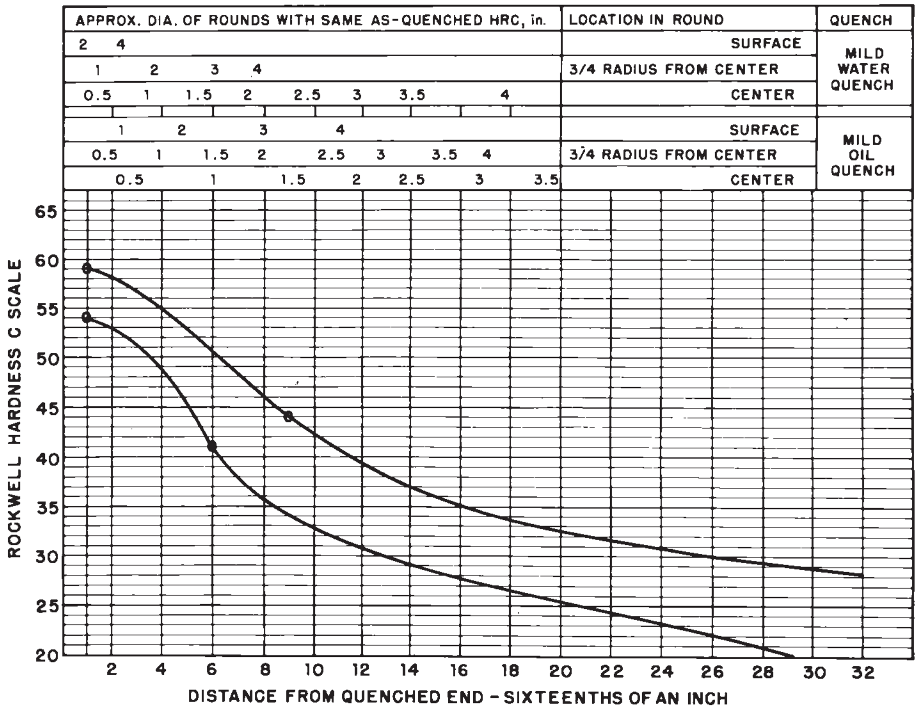
HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	59	54
2	58	53
3	57	51
4	55	49
5	53	45
6	51	41
7	48	38
8	46	36
9	44	34
10	43	33
11	41	32
12	40	31
13	39	30
14	37	29
15	36	28
16	35	27
18	34	26
20	33	25
22	32	24
24	31	23
26	30	22
28	30	21
30	29	20
32	29	--

HEAT TREATING TEMPERATURES

*NORMALIZE	1600	°F
AUSTENITIZE	1550	°F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN.
1.5	59	54
3	58	53
5	57	51
7	55	47
9	52	42
11	48	38
13	46	36
15	44	34
20	39	30
25	35	27
30	33	25
35	32	24
40	31	22
45	30	21
50	29	20

HEAT TREATING TEMPERATURES

*NORMALIZE	870	°C
AUSTENITIZE	845	°C

*For forged or rolled specimens only

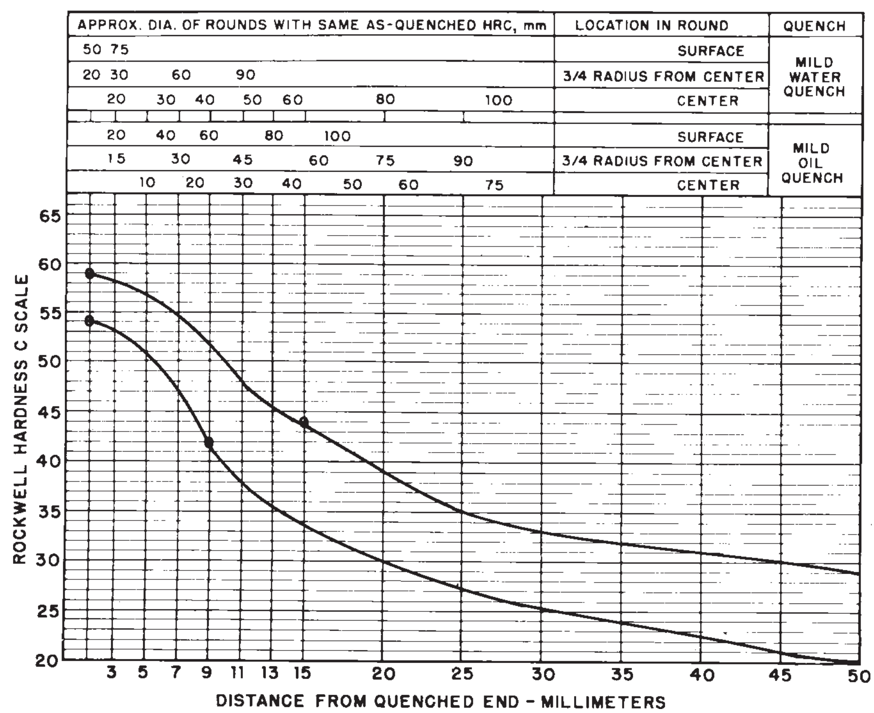


FIG. 17 Limits for Hardenability Band 5140 RH

HARDENABILITY BAND

5160 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.56/0.64	0.75/1.00	0.15/0.35	--	0.70/0.90	--	

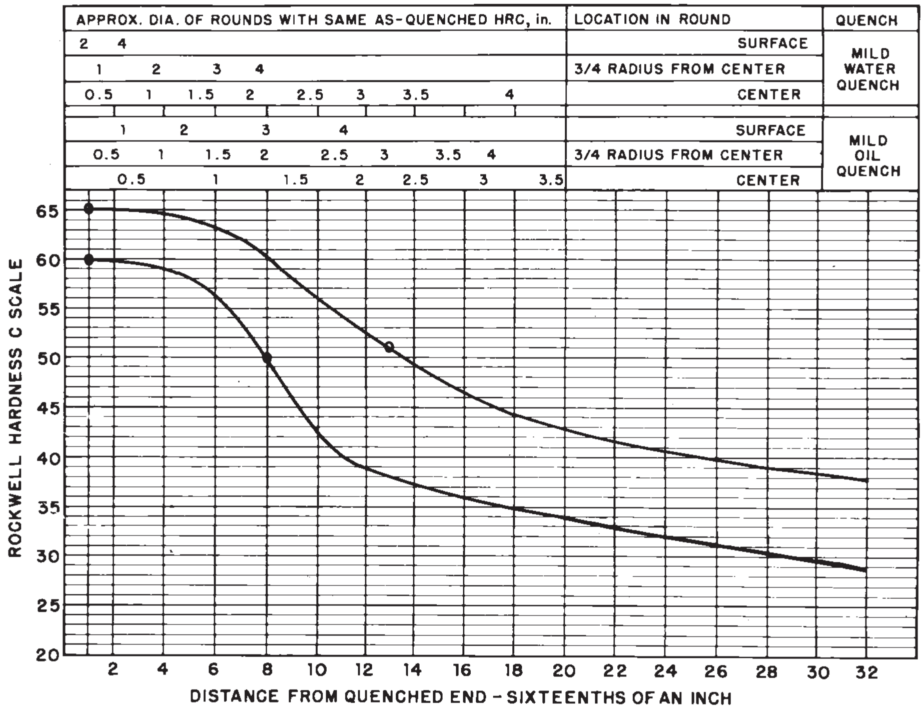
HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	65	60
2	65	60
3	65	60
4	65	59
5	64	58
6	63	57
7	62	54
8	60	50
9	58	45
10	56	42
11	55	40
12	53	39
13	51	38
14	50	37
15	48	36
16	47	36
18	44	35
20	43	34
22	42	33
24	41	32
26	40	31
28	39	30
30	39	29
32	38	29

HEAT TREATING TEMPERATURES

*NORMALIZE 1600 °F
AUSTENITIZE 1550 °F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN.
1.5	65	60
3	65	60
5	65	60
7	65	59
9	63	57
11	62	54
13	60	49
15	57	43
20	52	38
25	47	36
30	43	34
35	41	32
40	40	31
45	39	30
50	38	29

HEAT TREATING TEMPERATURES

*NORMALIZE 870 °C
AUSTENITIZE 845 °C

*For forged or rolled specimens only

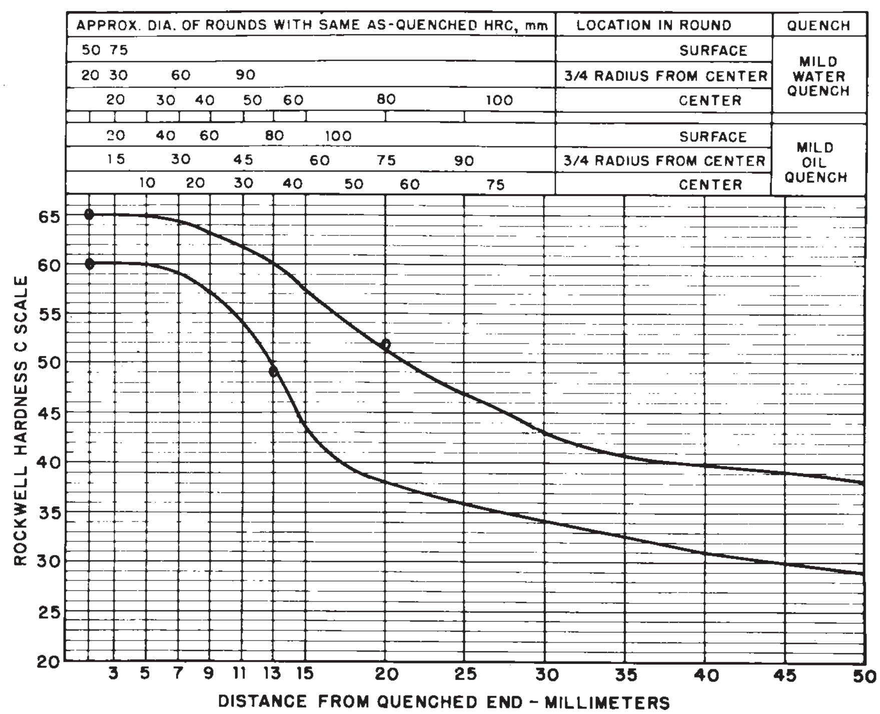


FIG. 18 Limits for Hardenability Band 5160 RH

HARDENABILITY BAND

8620 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.18/0.23	0.70/0.90	0.15/0.35	0.40/0.70	0.40/0.60	0.15/0.25	

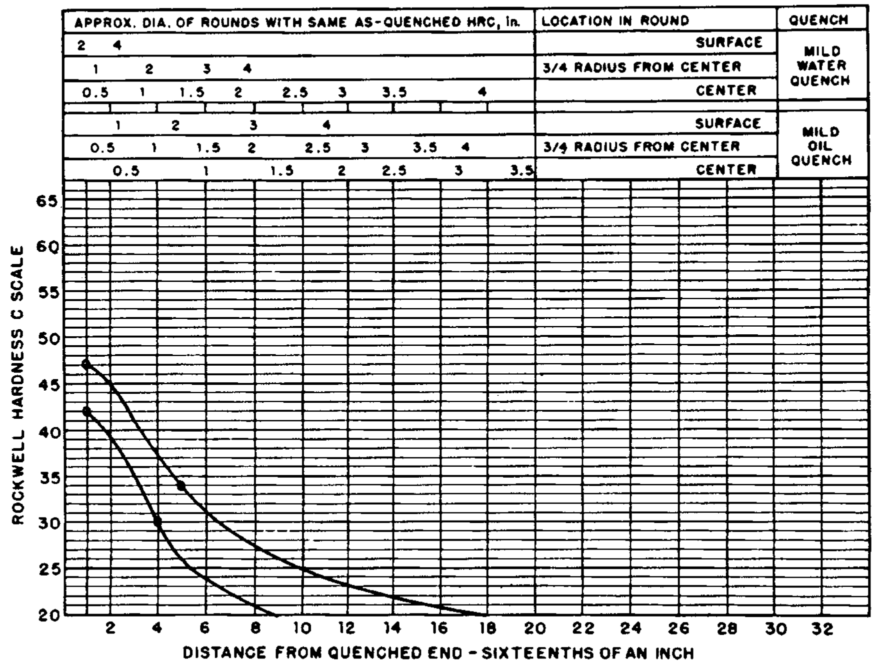
HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	47	42
2	45	39
3	41	35
4	38	30
5	34	26
6	31	24
7	29	22
8	28	21
9	26	20
10	25	--
11	24	--
12	23	--
13	23	--
14	22	--
15	22	--
16	21	--
18	20	--
20	--	--
22		
24		
26		
28		
30		
32		

HEAT TREATING TEMPERATURES

*NORMALIZE	1700	°F
AUSTENITIZE	1700	°F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN.
1.5	47	42
3	45	39
5	41	34
7	36	28
9	32	25
11	29	22
13	28	21
15	26	20
20	23	--
25	21	--
30	--	--
35		
40		
45		
50		

HEAT TREATING TEMPERATURES

*NORMALIZE	925	°C
AUSTENITIZE	925	°C

*For forged or rolled specimens only

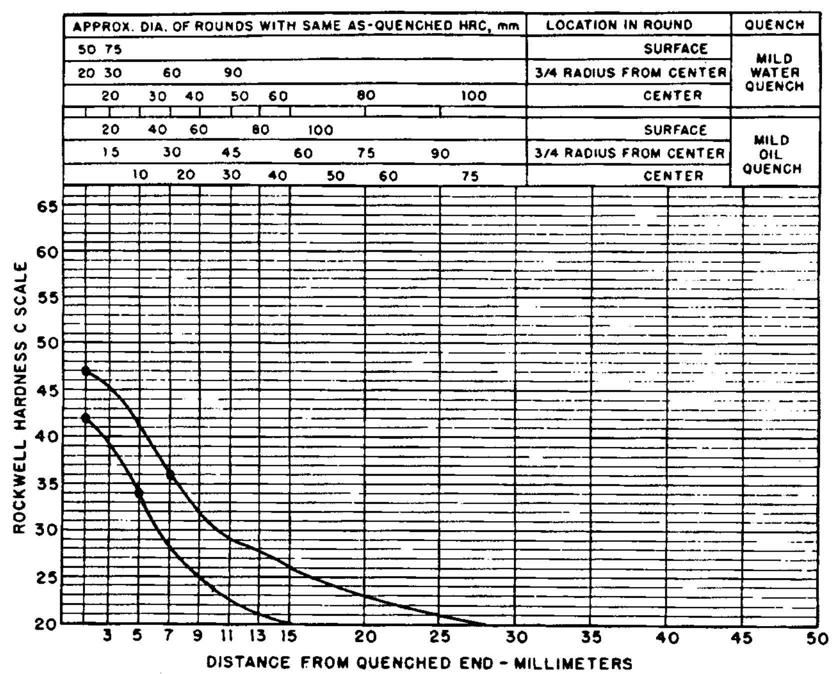


FIG. 19 Limits for Hardenability Band 8620 RH

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	HRC	
	MAX.	MIN.
1	49	44
2	47	41
3	45	37
4	41	32
5	38	29
6	35	27
7	32	24
8	30	22
9	29	21
10	28	20
11	27	--
12	26	--
13	25	--
14	24	--
15	24	--
16	23	--
18	23	--
20	22	--
22	22	--
24	22	--
26	22	--
28	22	--
30	22	--
32	22	--

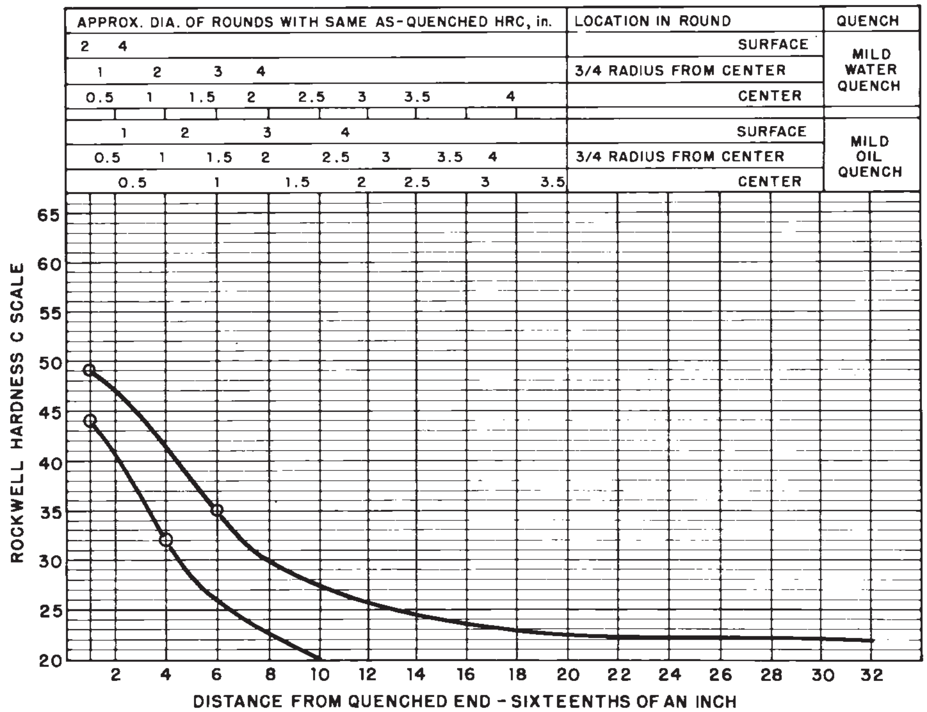
HEAT TREATING TEMPERATURES

*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F

*For forged or rolled specimens only

HARDENABILITY BAND 8622 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.20/0.25	0.70/0.90	0.15/0.35	0.40/0.70	0.40/0.60	0.15/0.25	



HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE MILLIMETERS	HRC	
	MAX.	MIN.
1.5	49	44
3	48	42
5	44	36
7	39	31
9	36	28
11	32	24
13	29	22
15	28	20
20	25	--
25	23	--
30	22	--
35	22	--
40	22	--
45	22	--
50	22	--

HEAT TREATING TEMPERATURES

*NORMALIZE 925 °C
AUSTENITIZE 925 °C

*For forged or rolled specimens only

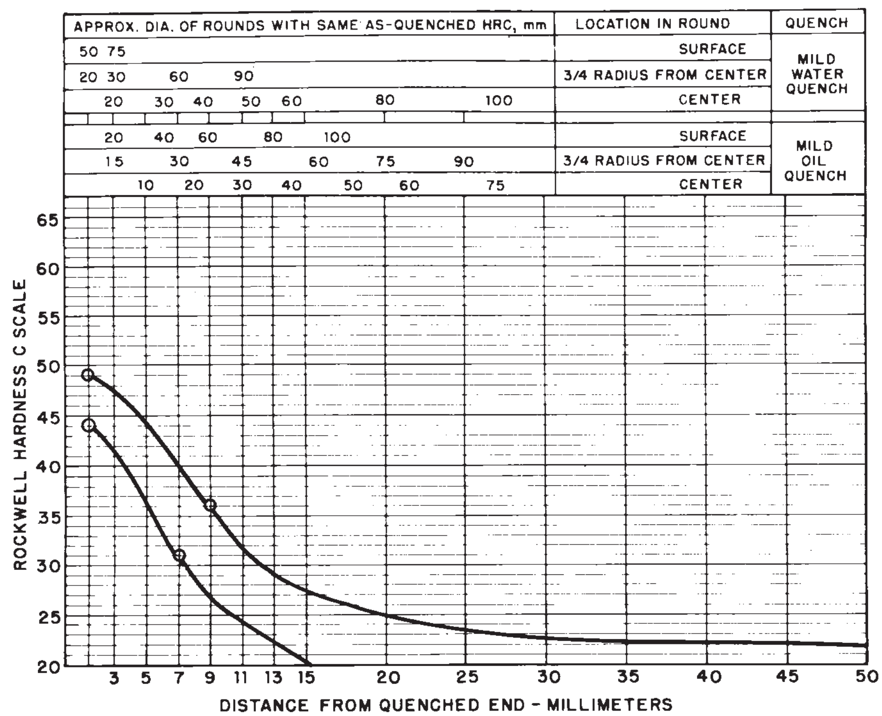


FIG. 20 Limits for Hardenability Band 8622 RH

HARDENABILITY BAND 8720 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.18/0.23	0.70/0.90	0.15/0.35	0.40/0.70	0.40/0.60	0.20/0.30	

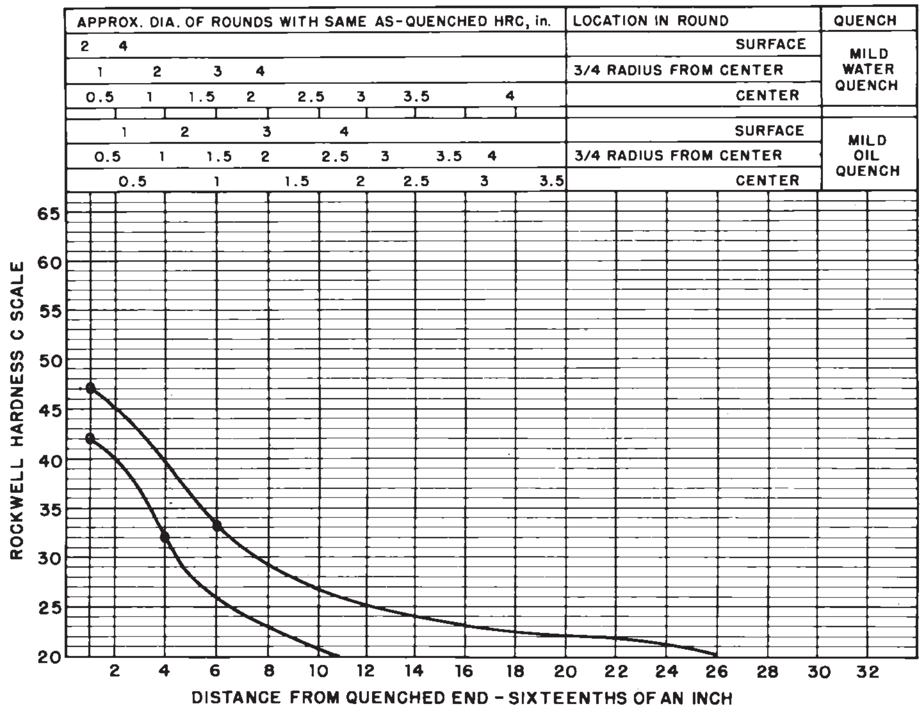
HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	47	42
2	45	39
3	43	37
4	40	32
5	36	28
6	33	26
7	31	24
8	29	23
9	28	22
10	27	21
11	26	20
12	25	--
13	25	--
14	24	--
15	24	--
16	23	--
18	23	--
20	22	--
22	22	--
24	21	--
26	20	--
28	--	--
30		
32		

HEAT TREATING TEMPERATURES

*NORMALIZE 1700 °F
AUSTENITIZE 1700 °F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN.
1.5	47	42
3	45	39
5	42	35
7	38	30
9	34	27
11	31	24
13	29	23
15	28	22
20	25	--
25	23	--
30	23	--
35	22	--
40	20	--
45	--	--
50		

HEAT TREATING TEMPERATURES

*NORMALIZE 925 °C
AUSTENITIZE 925 °C

*For forged or rolled specimens only

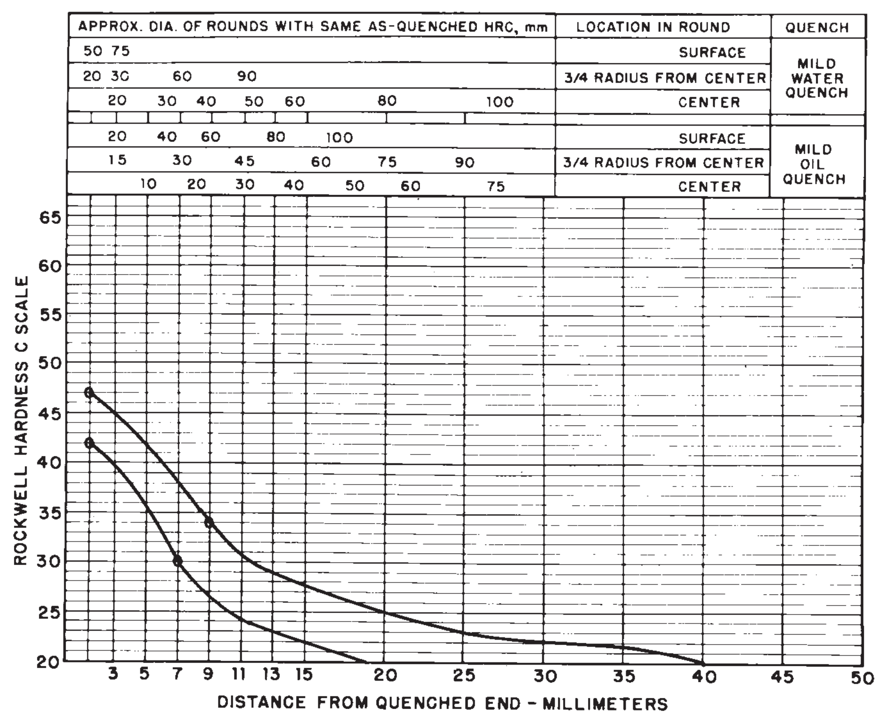


FIG. 21 Limits for Hardenability Band 8720 RH

HARDENABILITY BAND

8822 RH

%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.20/0.25	0.75/1.00	0.15/0.35	0.40/0.70	0.40/0.60	0.30/0.40	

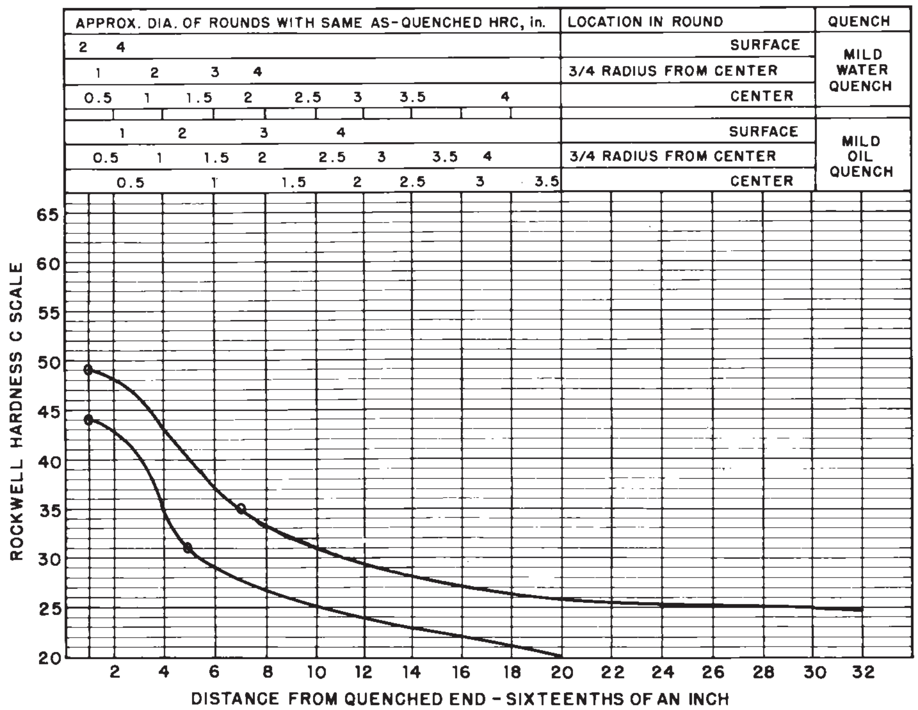
HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	49	44
2	48	43
3	47	40
4	43	35
5	40	31
6	37	29
7	35	27
8	33	26
9	32	25
10	31	25
11	30	24
12	30	23
13	29	23
14	28	23
15	28	22
16	27	22
18	27	21
20	26	20
22	26	--
24	26	--
26	26	--
28	25	--
30	25	--
32	25	--

HEAT TREATING TEMPERATURES

*NORMALIZE	1700	°F
AUSTENITIZE	1700	°F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES

"J" DISTANCE MILLIMETERS	HRC MAX.	HRC MIN.
1.5	49	44
3	48	43
5	46	39
7	42	33
9	38	30
11	35	27
13	33	26
15	32	25
20	29	23
25	27	22
30	27	21
35	26	20
40	26	--
45	25	--
50	25	--

HEAT TREATING TEMPERATURES

*NORMALIZE	925	°C
AUSTENITIZE	925	°C

*For forged or rolled specimens only

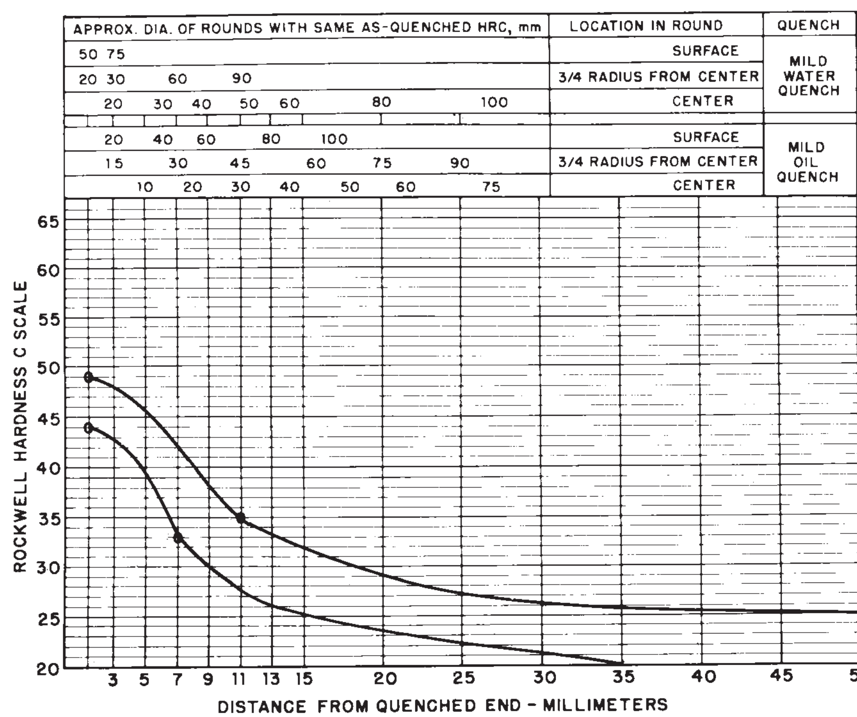


FIG. 22 Limits for Hardenability Band 8822 RH

HARDENABILITY BAND

9310 RH

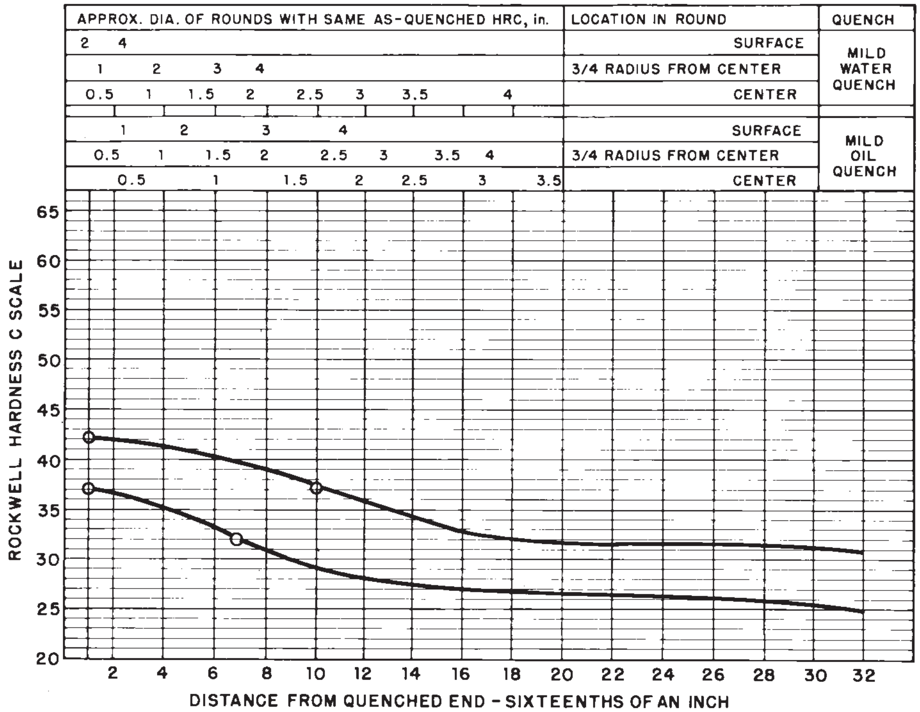
%C	%Mn	%Si	%Ni	%Cr	%Mo	
0.08/0.13	0.45/0.65	0.15/0.35	3.00/3.50	1.00/1.40	0.08/0.15	

HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE SIXTEENTHS OF AN INCH	HRC MAX.	HRC MIN.
1	42	37
2	42	36
3	42	36
4	41	35
5	41	34
6	40	33
7	40	32
8	39	31
9	38	30
10	37	29
11	37	29
12	36	28
13	35	28
14	34	28
15	34	28
16	33	27
18	33	27
20	32	26
22	32	26
24	32	26
26	32	26
28	32	26
30	31	25
32	31	25

HEAT TREATING TEMPERATURES

*NORMALIZE	1700 °F
AUSTENITIZE	1550 °F

*For forged or rolled specimens only



HARDNESS LIMITS FOR SPECIFICATION PURPOSES		
"J" DISTANCE MILLIMETERS	HRC MAX	HRC MIN.
1.5	42	37
3	42	36
5	42	36
7	41	35
9	40	34
11	40	32
13	39	31
15	37	29
20	35	28
25	34	27
30	32	26
35	32	26
40	32	26
45	31	25
50	31	25

HEAT TREATING TEMPERATURES

*NORMALIZE	925 °C
AUSTENITIZE	845 °C

*For forged or rolled specimens only

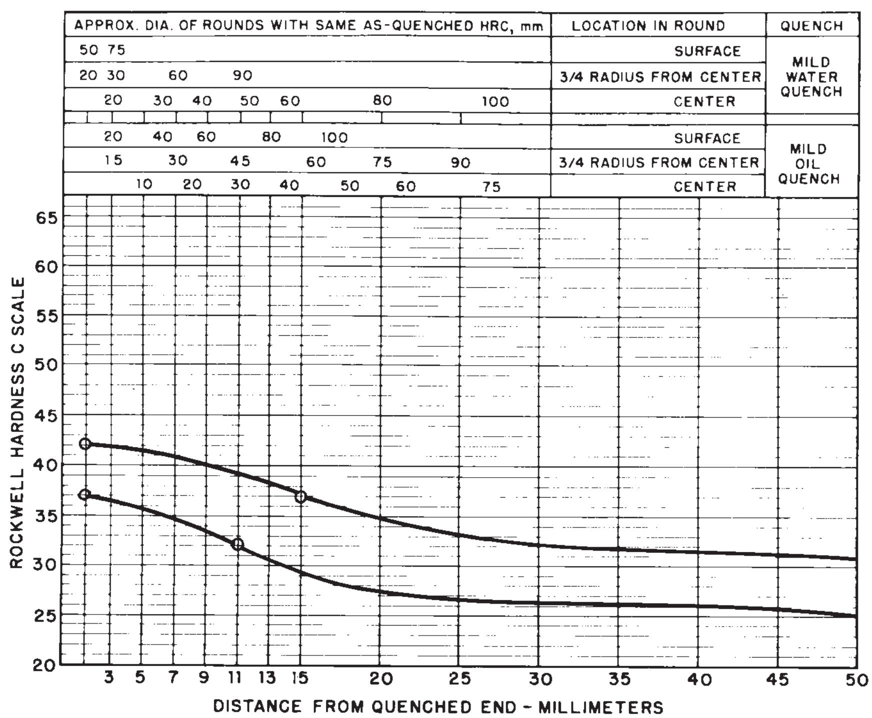


FIG. 23 Limits for Hardenability Band 9310 RH

INTERNATIONAL

Designation: A 920/A 920M – 02

Standard Specification for Steel Bars, Microalloy, Hot-Wrought, Special Quality, Mechanical Properties[1]

This standard is issued under the fixed designation A 920/A 920M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers hot-wrought, special quality microalloyed carbon steel bars intended for use in applications where as-rolled mechanical properties are desired. A typical end use is hydraulic cylinder shafts.

1.2 The bars shall be furnished to chemical composition and mechanical properties as provided herein. Chemical composition is based on standard carbon steel grades modified to include microalloying elements such as columbium (niobium), vanadium, or molybdenum. Four strength classes are available, designated 60, 75, 80, and 100, corresponding to the minimum yield strength in ksi.

1.3 Sections and sizes of bar steels available are covered in Specification A 29/A 29M.

1.4 Supplementary Requirements S1 to S5 are provided for use when additional controls or requirements are desired. These shall apply only when specified on the purchase order.

1.5 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text and tables, SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.6 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

A 576 Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality[2]

E 45 Practice for Determining the Inclusion Content of Steel[4]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *microalloyed steels*—microalloyed steels are carbon steels to which small quantities of certain elements are added in order to enhance mechanical properties. This enhancement of mechanical properties results from control of the temperature and cooling rate during the hot-rolling process.

4. Ordering Information

4.1 Orders for material supplied to this specification should include the following, as required, to describe adequately the desired material:

4.1.1 Quantity (weight or number of bars),

4.1.2 Name of material (hot-rolled microalloyed steel bars),

4.1.3 Dimensions,

4.1.4 ASTM specification number and date of issue,

4.1.5 Grade designation or chemical composition limits (see Section 8),

4.1.6 Class,

4.1.7 Type (see 7.1) to designate grain refiner,

4.1.8 Additions to the specification and Supplementary Requirements, if required, and,

4.1.9 End use.

5. General Requirements

5.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 29/A 29M, unless otherwise provided herein.

6. Materials and Manufacture

6.1 *Melting Practice*—The steel shall be produced in accordance with the applicable methods for primary and secondary melting outlined in Specification A 576.

6.2 The steel shall be killed. Supplementary Requirements S1 through S5 may be invoked upon agreement between producer and purchaser.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

Current edition approved March 10, 2002. Published May 2002. Originally published as A 920/A 920M-93. Last previous edition A 920/A 920M-97.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

6.3 The bars shall be special quality.

6.4 The bars shall be hot-wrought, as wrought, unless otherwise specified.

7. Metallurgical Requirements

7.1 *Grain Size*—The steel shall conform to the fine grain size requirement of Specification A 29/A 29M. The grain refining element may be specified according to one of the following types:

7.1.1 *Type A, Aluminum*—The total aluminum analysis shall be 0.020 % or greater, and shall be reported.

7.1.2 *Type B*—The grain refining element shall be specified in accordance with 5.1.2.3 of Specification A 29/A 29M.

7.2 *Microstructure*—The microstructure shall consist of a minimum of 90 % ferrite-pearlite or 90 % bainite as agreed upon between the purchaser and producer.

8. Chemical Composition

8.1 Typical examples of chemical compositions are shown in Table 1. Other compositions may be specified using one of the following methods:

8.1.1 Base compositions selected from Table 1 of Specification A 576, with the addition of microalloying elements as provided in 8.3 to 8.5, or

8.1.2 Base compositions using the ranges and limits shown in Table 2 of Specification A 576, with the addition of microalloying elements as provided in 8.3 to 8.5.

NOTE 1—For improved machinability, alternative sulfur ranges may be specified upon agreement between the purchaser and the producer. Additional machinability-enhancing elements such as lead, bismuth, selenium, or tellurium may also be specified by agreement.

8.2 Silicon analysis shall be 0.15/0.35 %. Silicon content up to 0.80 % maximum may be furnished upon agreement between purchaser and producer.

8.3 Vanadium, columbium (niobium), or molybdenum may be specified singly or in combination, subject to the limits shown in Table 2. The elements and ranges specified shall be upon agreement between the purchaser and the producer.

8.4 Titanium shall be added when specified for refinement of the ferritic-pearlitic (or bainitic) or austenitic grain size. When titanium is specified, the titanium limits shall be as agreed upon between producer and purchaser. The titanium content shall be reported.

8.5 Nitrogen may be specified as a supplement to vanadium, columbium, or titanium. If specified, the nitrogen content shall not exceed 0.03 % and shall be reported.

TABLE 2 Chemical Requirements—(Microalloy Elements)

Element	Chemical Ranges and Limits, %	
	Heat Analysis	Product Analysis
Vanadium	0.02–0.20	0.01–0.21
Columbium (Niobium)	0.005–0.07	0.004–0.08
Molybdenum	0.01–0.30	0.31 max

8.6 Sampling for heat and product analysis shall be in accordance with the requirements of Specification A 29/A 29M.

9. Mechanical Properties

9.1 The material as represented by the test specimens shall conform to the requirements of Table 3 for the class specified.

9.2 Test specimens shall be prepared from the material in the as-rolled condition, unless otherwise specified.

9.3 Test specimens shall be taken longitudinally and may be tested in full thickness or they may be machined to the dimensions shown in Figs. 4 or 5 of Test Methods and Definitions A 370. If the test specimens are selected conforming to the dimensions of Fig. 5, they shall be machined from a position midway between the center and surface of the bar.

9.4 Two tension tests shall be made from each heat, unless the finished material from a heat is less than 50 tons (45 mg), when one tension test will be sufficient.

10. Workmanship and Appearance

10.1 The bars shall be free of visible pipe and conditioned as necessary to remove any injurious surface imperfections.

11. Certification and Test Reports

11.1 When specified by the purchaser, a manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the heat analysis for the specified elements and for copper, chromium, nickel, molybdenum, vanadium, and columbium shall be furnished. When the amount of an element present is less than 0.02 %, the heat analysis may be reported as <0.02 %, except for aluminum, titanium, and nitrogen. When specified, these elements shall be reported to three decimal places.

11.2 The report shall include the results of any mechanical tests performed in accordance with this specification, including supplementary requirements, if any.

TABLE 1 Typical Chemical Compositions of Microalloyed Carbon Steels

NOTE—These compositions are identical to those in Specification A 576, with the exception of the addition of vanadium.

Base Grade Designation	Chemical Composition Limits, %				
	C	MN	P	S	V
10V40	0.37–0.44	0.60–0.90	0.040 max	0.050 max	0.02–0.20
10V45	0.43–0.50	0.60–0.90	0.040 max	0.050 max	0.02–0.20
11V37	0.32–0.39	1.35–1.65	0.040 max	0.08–0.13	0.02–0.20
11V41	0.37–0.45	1.35–1.65	0.040 max	0.08–0.13	0.02–0.20
15V24	0.19–0.25	1.35–1.65	0.040 max	0.050 max	0.02–0.20
15V41	0.36–0.44	1.35–1.65	0.040 max	0.050 max	0.02–0.20

TABLE 3 Mechanical Property Requirements

Class	Yield Strength, min		Tensile Strength, min		Elongation, %, min	
	ksi	MPa	ksi	MPa	in 8 in. (200 mm)	in 2 in. (50 mm)
60	60	415	75	515	12	16
75	75	520	90	620	10	14
80	80	550	95	655	9	13
100	100	690	125	860	7	9

12. Keywords

12.1 carbon steel bars; microalloyed steel; steel bars

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser.

S1. Restricted Chemical Composition

S1.1 Restricted heat analysis limits or ranges or restricted product analysis tolerances on one or more elements may be specified by the purchaser if the manufacturer agrees to meet the requested restriction.

S2. Restricted Incidental Elements

S2.1 The steel shall not exceed the limits for copper, nickel, chromium, molybdenum, or other elements as shown on the purchase order.

S3. Nonmetallic Inclusion Requirement

S3.1 A microscopical examination of longitudinal sections to determine the nature and frequency of nonmetallic inclusions shall be made as prescribed in Practice E 45. The acceptance limits shall be specified by the purchaser.

NOTE S1.1—In resulfurized steels, much of the sulfur is present as sulfide inclusions. For this reason, maximum sulfide inclusion level should not be specified.

S4. Calcium Treatment

S4.1 The steel shall be calcium treated.

S5. Cleaning

S5.1 The surface of the bars shall be descaled by pickling or shotblasting, or other suitable means.

Designation: A 921/A 921M – 93 (Reapproved 1999)

Standard Specification for Steel Bars, Microalloy, Hot-Wrought, Special Quality, for Subsequent Hot Forging[1]

This standard is issued under the fixed designation A 921/A 921M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers hot-wrought, special quality microalloyed carbon steel bars intended for use as hot forging stock. The bars shall be hot-wrought, as-wrought, unless thermal treatment is necessary to ensure cold shearability.

1.2 The bars shall be furnished to chemical composition only. Chemical composition is based on standard carbon steel grades modified to include microalloying elements such as columbium (niobium), vanadium, or molybdenum. Desired mechanical properties are developed in the subsequent hot forging and controlled cooling operations.

1.3 Sections and sizes of bar steel available are covered in Specification A 29/A 29M.

1.4 Supplementary requirements S1 to S6 are provided for use when additional controls or requirements are desired. These shall apply only when specified on the purchase order.

1.5 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text and tables, SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.6 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 576 Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality[2]

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products[3]

A 788 Specification for Steel Forgings, General Requirements[2]

E 45 Practice for Determining the Inclusion Content of Steel[4]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *microalloyed steels*—microalloyed steels are carbon steels to which small quantities of certain elements are added in order to enhance mechanical properties. This enhancement of mechanical properties results from control of the temperature and cooling rate during the final hot-working process.

4. Ordering Information

4.1 Orders for material supplied to this specification should include the following, as required, to describe adequately the desired material:

4.1.1 Quantity (weight or number of bars),

4.1.2 Name of material (hot-rolled microalloyed steel bars),

4.1.3 Dimensions,

4.1.4 ASTM specification number and date of issue,

4.1.5 Grade designation or chemical composition limits (see 8.1 to 8.5),

4.1.6 Type (see 7.1) to designate grain refiner,

4.1.7 Additions to the specification and Supplementary Requirements, if required, and,

4.1.8 End use.

5. General Requirements

5.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 29/A 29M, unless otherwise provided herein.

6. Materials and Manufacture

6.1 *Melting Practice*—The steel shall be produced in accordance with the applicable methods for primary and secondary melting outlined in Specification A 788.

6.2 The steel shall be killed. Supplementary Requirements S1 through S6 may be invoked upon agreement between producer and purchaser.

6.3 The bars shall be special quality.

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bars.

Current edition approved Dec. 15, 1993. Published February 1994.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

6.4 The bars shall be hot-wrought, as wrought.

7. Metallurgical Requirements

7.1 *Grain Size*—The steel shall conform to the fine grain size requirement of Specification A 29/A 29M. The grain refining element may be specified according to one of the following types:

7.1.1 *Type A—Aluminum*—The total aluminum analysis shall be 0.020 % or greater, and shall be reported.

7.1.2 *Type B*—The grain refining element shall be specified in accordance with 5.1.2.3 of Specification A 29/A 29M.

8. Chemical Composition

8.1 Typical examples of chemical compositions are shown in Table 1. Other compositions may be specified using one of the following methods:

8.1.1 Base compositions selected from Table 1 of Specification A 576, with the addition of microalloying elements as provided in 8.3 to 8.5, or

8.1.2 Base compositions using the ranges and limits shown in of Specification A 576, with the addition of microalloying elements as provided in 8.3 to 8.5

NOTE 1—For improved machinability, alternative sulfur ranges may be specified by agreement between the purchaser and the producer. Additional machinability-enhancing elements such as lead, bismuth, selenium, or tellurium may also be specified by agreement.

8.2 Silicon analysis shall be 0.15/0.35 %. Silicon content up to 0.80 % maximum may be furnished by agreement between purchaser and producer.

8.3 Vanadium, columbium (niobium), or molybdenum may be specified singly or in combination, subject to the limits shown in Table 2. The elements and ranges specified shall be by agreement between the purchaser and the producer.

8.4 Titanium may be added for refinement of the austenitic and the as-forged ferritic grain size, or as a precipitation strengthener. When titanium is specified, the titanium limits shall be as agreed upon between producer and purchaser. The titanium analysis shall be reported.

8.5 Nitrogen may be specified as a supplement to vanadium, columbium, or titanium. When nitrogen is specified to supplement vanadium, the minimum ratio of vanadium to nitrogen shall be 4 to 1. The nitrogen content shall not exceed 0.03 % and shall be reported.

8.6 Sampling for heat and product analysis shall be in accordance with the requirements of Specification A 29/A 29M.

9. Workmanship and Appearance

9.1 The bars shall be free of visible pipe and conditioned as necessary to remove any injurious surface imperfections.

10. Certification and Test Reports

10.1 When specified by the purchaser, a manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the heat analysis for the specified elements and for copper, chromium, nickel, molybdenum, vanadium, and columbium shall be furnished. When the amount of an element present is less than 0.02 %, the heat analysis may be reported as <0.02 %, except for titanium, aluminum, and nitrogen. When specified, these elements shall be reported to three decimal places.

11. Keywords

11.1 carbon steel bars; microalloyed steel; steel bars

TABLE 2 Chemical Requirements—(Microalloy Elements)

Element	Chemical Ranges and Limits, %	
	Heat Analysis	Product Analysis
Vanadium	0.02–0.20	0.01–0.21
Columbium (Niobium)	0.005–0.07	0.004–0.08
Molybdenum	0.01–0.30	0.31 max

TABLE 1 Typical Chemical Compositions of Microalloyed Carbon Steels

NOTE 1—These compositions are identical to those in Specification A 576, with the exception of the addition of vanadium.

Grade Designation	Chemical Composition Limits, %				
	C	MN	P	S	V
10V40	0.37–0.44	0.60–0.90	0.040 max	0.050 max	0.02–0.20
10V45	0.43–0.50	0.60–0.90	0.040 max	0.050 max	0.02–0.20
11V37	0.32–0.39	1.35–1.65	0.040 max	0.08–0.13	0.02–0.20
11V41	0.37–0.45	1.35–1.65	0.040 max	0.08–0.13	0.02–0.20
15V24	0.19–0.25	1.35–1.65	0.040 max	0.050 max	0.02–0.20
15V41	0.36–0.44	1.35–1.65	0.040 max	0.050 max	0.02–0.20

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser.

S1. Restricted Chemical Composition

S1.1 Restricted heat analysis limits or ranges or restricted product analysis tolerances on one or more elements may be specified by the purchaser if the manufacturer agrees to meet the requested restriction.

S2. Restricted Incidental Elements

S2.1 The steel shall not exceed the limits for copper, nickel, chromium, molybdenum, or other elements as shown on the purchase order.

S3. Nonmetallic Inclusion Requirement

S3.1 A microscopical examination of longitudinal sections to determine the nature and frequency of nonmetallic inclusions shall be made as prescribed in Practice E 45. The acceptance limits shall be specified by the purchaser.

NOTE S1—In resulfurized steels, much of the sulfur is present as sulfide inclusions. For this reason, maximum sulfide inclusion level should not be specified.

S4. Calcium Treatment

S4.1 The steel shall be calcium treated.

S5. Thermal Treatment to Insure Cold Shearability

S5.1 The bars shall be thermal treated to insure cold shearability. The type of treatment shall be as agreed upon between the purchaser and producer.

S6. Cleaning

S6.1 The surface of the bars shall be descaled by pickling or shotblasting, or other suitable means.

Designation: A 939 – 96 (Reapproved 2001)

Standard Test Method for Ultrasonic Examination from Bored Surfaces of Cylindrical Forgings[1]

This standard is issued under the fixed designation A 939; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers a basic procedure of ultrasonically inspecting cylindrical forgings with bores from the bore surface.

1.2 This test method applies to the manual testing mode. It does not restrict the use of other testing modes, such as mechanized or automated.

1.3 This test method applies to cylindrical forgings having bore sizes equal to or greater than 2.5 in. (63.5 mm).

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are provided for information purposes only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Significance and Use

2.1 This test method shall be used when ultrasonic inspection from the bore surface is required by the order or specification for inspection purposes in which the acceptance of the forging is based on limitations of the number, amplitude, or location of discontinuities or a combination thereof, which leads to ultrasonic indications.

2.2 The acceptance criteria shall be stated clearly as order requirements.

2.3 This test method specifies dual search units, which depending on the angle, are sensitive only to 2 to 3 in. into the metal from the bore surface.

3. General Requirements

3.1 As far as possible, the entire bore surface shall be subjected to ultrasonic inspection. It may be impossible to inspect some small portions of the bore surface because of chamfers at stepdowns and other local configurations.

3.2 The bore ultrasonic inspection shall be performed after the final austenitizing and tempering heat treatment for mechanical properties of the forging, and may be performed either prior to or after any subsequent stress relieving heat treatment.

3.3 The ultrasonic beam shall be introduced radially for overall scanning.

3.4 Forgings may be tested either when stationary or while rotated by means of a lathe or rollers.

3.5 To ensure complete coverage of the bore surface, the search unit shall be indexed approximately 75 % of the transducer width with each pass of the search unit.

3.6 A frequency of 2¼ MHz shall be used unless additional transducer frequencies are specified by the purchaser.

3.7 The bore hole diameter and calibration hole(s) shall be as specified on the purchaser's drawing or order.

4. Pulsed Ultrasonic Reflection Equipment and Accessories

4.1 *Electronic Apparatus*—A pulse echo instrument permitting inspection frequencies of 1, 2.25, and 5 MHz is required. The accuracy of discontinuity amplitude analysis using this test method involves a knowledge of the true operating frequency of the complete inspection system. One of the best ways to obtain the desired accuracy is by use of a tuned pulser and narrow bans amplifier of known frequency response, with either a broad band transducer or a narrow band tuned transducer of known and matching frequency. An equipment calibration plan that is acceptable to both the purchaser and the supplier shall be available.

4.2 *Amplifier*—The amplifier and the cathode ray tube shall provide linear response (within ± 5 %) up to 1½ in. (38.1 mm) sweep to peak. An equipment calibration plan that is acceptable to both the purchaser and the supplier shall be available.

4.3 *Signal Attenuator*—The instrument shall contain a calibrated gain control or signal attenuator (accurate within ± 5 % in each case) that will allow indications beyond the linear range of the instrument to be measured. It is recommended that these controls permit signal adjustment up to 25 to 1 (28 dB).

4.4 *Search Units*—Dual longitudinal wave search units of known effective frequency should be used for scanning. Each ¼ - by 1-in. (6.35 by 25.4-mm) 2.25 MHz transducer, used with the 1-in. dimension parallel to the longitudinal axis of the

[1] This test method is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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forging, will provide a desirable combination of resolution and beam width. Search units shall have interchangeable plexiglass shoes that are machined to various diameters for matching different bore diameters.

5. Preparation of Forging for Ultrasonic Inspection

5.1 The surface of the bore shall be free of tool tears, loose scale, grinding particles, or other foreign material at the time of ultrasonic testing.

5.2 Bore surfaces should be honed for bore diameter uniformity to maintain a near constant energy transmission from the transducer into the forging.

6. Procedure

6.1 Establish the inspection sensitivity such that the reflection amplitude equals 100 % of the screen height throughout the entire inspection, using the calibration hole, specified by the purchaser, drilled parallel to the bore surface.

6.2 Check the distance calibration for linearity.

6.3 Using only one transducer connected with pulse delay, mark the location of the reflected signal from the curved surface of the plexiglass shoe as the bore surface.

6.4 Record the distance from the bore surface to the side of the calibrations hole.

6.5 Adjust the sweep length control to position the back reflection approximately three fourths of the distance across the cathode ray tube.

6.6 Record all indications axially and circumferentially as a percentage of the calibration hole sensitivity.

6.7 Support the search unit with structural means at regular intervals.

6.8 Record all indications for radial distance and axial distance.

7. Report

7.1 Report the following information:

7.1.1 Amplitudes of all indications as a percentage of the calibration hole sensitivity,

7.1.2 Axial locations of all indications,

7.1.3 Radial and circumferential locations of all indications,

7.1.4 Areas with high densities of indications as levels of 5 % increments, and

7.1.5 All reflection losses of 20 % or more.

8. Keywords

8.1 bore inspection; bored turbine rotor; forgings; ultrasonic examination

Standard Specification for Vacuum Treated Steel Forgings, Alloy, Differentially Heat Treated, for Turbine Rotors[1]

This standard is issued under the fixed designation A 940; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers vacuum treated, alloy steel forgings, differentially heat treated for turbine rotors.

1.2 Differential heat treatment of a rotor forging involves subjecting two portions of the forging concurrently to two different austenitizing temperatures followed by two different cooling rates for normalizing and quenching, and then tempering, to achieve creep resistance in the high pressure (HP) portion and high toughness in the low pressure (LP) portion.[2]

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A 275M Test Methods for Magnetic Particle Examination of Steel Forgings[3]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

A 418 Test Method of Ultrasonic Examination Inspection of Turbine and Generator Steel Rotor Forgings[3]

A 470 Specification for Vacuum-Treated Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts[3]

A 472 Test Method for Heat Stability of Steam Turbine Shafts and Rotor Forgings[3]

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products[4]

A 788 Specification for Steel Forgings, General Requirements[3]

E 139 Practice for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials[5]

3. Ordering Information

3.1 In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order a detailed drawing, sketch, or written description of the forging, including the mechanical test locations, the portion of the forging to be included in the heating chamber during the stability test, and the minimum stability test temperature.

3.2 The purchaser shall specify if check tests for mechanical properties are required after stress relief or heat stability tests.

3.3 *Supplementary Requirements*—Supplementary requirements are provided. These requirements shall apply only when specified in the purchase order.

4. General Requirements

4.1 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

4.2 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

5. Manufacture

5.1 Melting processes of Specification A 788 shall be applicable, except that the open hearth or basic oxygen methods of primary melting shall not be used and the molten steel shall be vacuum treated during processing. When the ladle degassing process is used, the evacuation system shall be capable of reducing the system vacuum pressure to a low level (usually less than 1000 µm). The molten metal shall be stirred adequately for a sufficient length of time to maximize exposure to the evacuated atmosphere. When this process is used, hydrogen testing per Supplementary Requirement S4 is mandatory.

5.1.1 If the ESR process is used, the electrodes shall have been produced from vacuum treated primary heat(s), and Supplementary Requirement S4 is mandatory.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved Sept. 10, 1996. Published July 1997. Originally published as A 940–95. Last previous edition A 940–95.

[2] *Symposium on Steel Forgings, ASTM STP 903*, ASTM, Philadelphia, PA, 1984, pp. 59-86.

[3] *Annual Book of ASTM Standards*, Vol 01.05.

[4] *Annual Book of ASTM Standards*, Vol 01.03.

[5] *Annual Book of ASTM Standards*, Vol 03.01.

5.2 In addition to the requirements of Specification A 788, it is important to maintain the axial center of the forging in common with the axial center of the original ingot.

5.3 *Differential Heat Treatment*—The heat treatment for mechanical properties shall consist of normalizing and tempering of the creep resistant portion, HP portion, and quenching and tempering of the high toughness portion, LP portion.

5.3.1 The preliminary heat treatment shall consist of normalizing well above the transformation temperature range.

5.3.2 The normalizing and quenching treatments shall be from above the transformation range but below the normalizing temperature described in 5.3.1. This treatment shall be performed after preliminary machining.

5.3.2.1 The heat treatment for the HP portion shall consist of normalizing, accelerated air cooling, and tempering.

5.3.2.2 For the high toughness LP portion, the heat treatment shall consist of water quenching (or water-spray quenching) and tempering.

5.3.3 The final tempering temperature for all zones shall not be below 1200°F (649°C).

5.3.4 After heat treatment and subsequent rough machining and boring, the forging shall be stress relieved at a temperature not more than 100°F (55°C) below the final tempering temperature, but not below 1100°F (593°C).

5.3.5 With the prior approval of the purchaser, the stress relieving temperature may approach, equal, or slightly exceed the final tempering temperature as a means of adjusting final strength or toughness. If the stress relieving temperature is within 25°F (14°C) of the final tempering temperature, or higher, acceptance tests shall be obtained after the stress relieving operation.

5.3.6 The method of cooling the HP and LP portions during the normalizing, quenching, tempering, and stress relieving heat treating cycles shall be reported.

5.4 *Machining*:

5.4.1 *Preliminary Rough Machining*—All exterior surfaces of the forging shall be machined prior to heat treatment for mechanical properties.

5.4.2 *Second Rough Machining*—After heat treatment for mechanical properties, all surfaces of the forging shall be rough machined prior to stress relief and the stability test.

5.4.3 *Boring*:

5.4.3.1 Forgings shall be bored to permissible bore size and tolerances when required by the purchaser's drawing.

5.4.3.2 Forgings may be bored to limits agreed to by the purchaser or indicated on the purchaser's drawing, to remove objectionable center conditions revealed by ultrasonic inspection.

5.4.3.3 Unless otherwise specified by the purchaser, the manufacturer may bore the forging at any time after quenching and prior to stress relief.

5.4.4 *Machining to Purchaser's Requirements for Shipment*—The forging, as shipped, shall conform to the finish and dimensions specified on the purchaser's drawing or order.

6. Chemical Composition

6.1 *Heat Analysis*—An analysis of each heat of steel shall be made by the manufacturer. This analysis shall be made from a test sample taken preferably during the pouring of the heat. The steel shall conform to the requirements for chemical composition prescribed in Table 1.

6.2 *Product Analysis*—The manufacturer shall make a product analysis from each forging. The chemical composition thus determined shall not vary from the requirements specified in Table 1 by more than the amounts prescribed in Specification A 788.

6.3 *Referee Analysis*—Test Methods, Practices, and Terminology A 751 shall be used.

7. Mechanical Properties

7.1 *Tension Test*:

7.1.1 The steel shall conform to the tensile requirements of Table 2.

7.1.2 The number and location of tension test specimens shall be as specified on the forging drawings furnished by the purchaser.

7.1.3 Final acceptance tests shall be performed after heat treatment of the forging for mechanical properties prior to stress relief. If the stress relief temperature is within 25°F (14°C) of the tempering temperature, or higher, check tests shall be made after the stress relief treatment and reported to the purchaser. The purchaser may require check tests after the completion of all heating cycles, including stress relief and the heat stability tests.

7.1.4 The yield strength prescribed in Table 2 shall be determined by the offset method of Test Methods and Definitions A 370.

7.2 *Impact Test*:

7.2.1 The steel shall conform to the requirements for notch toughness (both transition temperature and room temperature impact values) prescribed in Table 3.

7.2.2 The notch toughness specimens shall be machined from radial bars taken from the main body of the forging, as shown in the forging drawing. The specimens shall be Charpy V-notch, Type A, as shown in Test Methods and Definitions A 370. The notch direction of the Charpy bars shall be as prescribed in Specification A 470.

8. Nondestructive Tests

8.1 *General Requirements*:

8.1.1 The forgings shall be free of cracks, seams, laps, shrinkage, and other injurious imperfections.

8.1.2 The purchaser may request ultrasonic, magnetic particle, dye penetrant, etch, or other nondestructive inspections

TABLE 1 Chemical Composition

	Composition, % Grade 1
Carbon	0.23–0.31
Manganese	0.50–1.00
Phosphorus, max	0.012
Sulfur, max	0.015
Silicon, max	0.10
Nickel	0.80–1.10
Chromium	0.90–1.50
Molybdenum	1.10–1.50
Vanadium	0.20–0.30
Columbium (Niobium)	0.01–0.05
Aluminum	0.010 max

TABLE 2 Tensile Requirements

	Grade 1
Tensile strength, ksi (MPa)	105–125 (725–860)
Yield strength, min, ksi (MPa), 0.2 % offset	85 (585)
Elongation in 2 in. or 50 mm, min, %	17 longitudinal 14 radial
Reduction of area, min, %	43 longitudinal 38 radial

TABLE 3 Notch Toughness Requirements

Test Location	Grade 1	
	ft·lb (J), min	Transition Temperature, $FATT_{50}$°F (°C), max
HP	6 (8.2)	250 (121)
LP	25 (34)	36 (2)

necessary to evaluate imperfections and to ensure compliance with this requirement.

8.2 *Ultrasonic Inspection*:

8.2.1 An ultrasonic inspection shall be performed on the machined forging at the manufacturer's plant. This inspection shall be made in accordance with Test Method A 418 to demonstrate freedom from detrimental internal defects.

8.2.2 The ultrasonic inspection shall be conducted from all available surfaces prior to removal of the test specimens that would interfere with complete testing of the forging.

8.2.3 Forgings with reportable ultrasonic indications shall be referred to the purchaser for evaluation based on the nature, frequency, and location of the indications, both stationary and traveling. It shall be determined by conventional or mutually acceptable inspection procedures whether the forging will be rejected if the ultrasonic indications are considered objectionable.

8.3 *Internal Inspection*:

8.3.1 When specified for internal periscope inspection, boring shall be in accordance with the drawings furnished by the purchaser. The drawings shall specify the nominal dimensions of the bore hole.

8.3.2 If objectionable conditions are encountered during internal inspection of the bore hole, the manufacturer shall notify the purchaser of the location and nature of the condition. Further action shall be taken only after mutual agreement between the manufacturer and the purchaser.

9. Stability Test

9.1 Each forging shall be subjected to a heat stability test at the manufacturer's plant in accordance with the latest issue of Test Method A 472 to determine the stability or freedom from a tendency to distort during high-temperature operating conditions.

9.2 The stability test shall be conducted after the forging has been stress relieved.

9.2.1 The stress relief may be performed as part of the stability test if agreed to by the purchaser.

9.3 *Stability Test Requirements*:

9.3.1 The purchaser's drawings shall indicate the portion of the forging to be included within the heating chamber during the stability test.

9.3.2 The purchaser's drawings or order shall indicate the minimum stability test temperature.

10. Retreatment

10.1 If the results of the mechanical tests of any forging do not conform to the requirements specified, the manufacturer may retreat the entire forging one or more times, but not more than three additional times, without the approval of the purchaser.

10.2 If the bore core properties are specified under Supplementary Requirement S1 and retemper is necessary after boring, the remaining portions of the core shall be replaced in the bore during retemper. If the stress relief temperature is within 25°F (14°C) of the tempering temperature, the core bar shall be reinserted for the stress relief.

10.3 If complete retreatment, including differential heat treatment by normalizing and quenching, is necessary after boring, the feasibility of retreating portions of the bore core in the bore of the forging shall be discussed between the manufacturer and the purchaser and a procedure agreed upon before treatment.

11. Dimensions, Tolerances, and Finish

11.1 Each forging shall conform to the dimensions and tolerances specified on the purchaser's drawing or order.

11.2 The finish on each forging shall conform to the finish specified on the purchaser's drawing or order.

12. Certification and Reports

12.1 In addition to the certification requirements of Specification A 788, the following shall be reported:

12.1.1 Product analysis results, and

12.1.2 Location of the heat treatment transition point on the forging.

13. Package Marking, Packing, and Loading

13.1 Each forging shall be stamped legibly by the manufacturer with the manufacturer's name or symbol, the manufacturer's identification number, the ASTM designation, the appropriate grade number, and identification numbers specified by the purchaser on his drawing of the order.

13.2 The location of such identification marks may be specified by the purchaser on his drawing or order.

13.3 Test specimens shall be identified with numbers corresponding to the test location and type, if specified on the purchaser's drawings or order.

13.4 The axial bores of bored forgings shall be protected and plugged suitably to prevent damage or corrosion during shipment or storage.

14. Keywords

14.1 differential heat treatment; steel forgings; turbine rotor; vacuum treated steel

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order. Details of these supplementary requirements shall be agreed upon by the manufacturer and the purchaser.

S1. Bore Core Properties

S1.1 The purchaser may require the removal of a longitudinal bore core from the forging after heat treatment for mechanical properties and subsequent approval of the usual surface mechanical property tests.

S1.1.1 The diameter of the longitudinal bore core shall be subject to agreement between the manufacturer and the purchaser.

S1.1.2 The purchaser may require mechanical tests on tension or impact specimens from locations in the longitudinal bore core as specified on the forging drawings furnished by the purchaser.

S1.1.3 The acceptance level of the mechanical properties obtained from specimens from the longitudinal bore core shall be as agreed upon between the manufacturer and the purchaser.

S2. Stress Rupture Properties

S2.1 The purchaser may require that stress-rupture tests be made, by the manufacturer or by himself, on radial specimens taken from locations shown on the forging drawing.

S2.1.1 Stress-rupture tests shall be performed in accordance with Practice E 139.

S2.1.2 The size and shape of the test specimen and stress-rupture test requirements shall be mutually agreed upon between by the manufacturer and the purchaser.

S3. Vertical Heat Treatment

S3.1 Heat treatment for mechanical properties shall be performed with the forging in the vertical position.

S4. Hydrogen Determination

S4.1 A hydrogen determination shall be made. The acceptable hydrogen limit as well as the stage in processing when sampling, the sample preparation procedure, and the method of analysis shall be agreed upon between the manufacturer and the purchaser.

S5. Magnetic Particle Examination

S5.1 A magnetic particle examination of the complete exterior and bore surfaces of the machined forging shall be made at the forging manufacturer's plant. The examination shall be performed in accordance with the latest issue of Test Method A 275/A 275M.

S5.2 Forgings with either cracks or linear indications of any length are subject to rejection unless they can be removed to the purchaser's satisfaction.

S6. Heat Treatment After Machining of Disks or Wheels, or Both

S6.1 When agreed upon between the manufacturer and the purchaser, the heat treatment for mechanical properties shall be performed after additional machining of the material between the rotor discs or wheels, or both. This agreement should also address the following:

S6.1.1 Machining finish allowances, radii, and surface finish before and after the heat treatment for mechanical properties.

S6.1.2 Locations of the tension test specimens and the test direction.

S6.1.3 Locations of the impact test specimens and the notch direction.

S6.1.4 Impact energy and FATT requirements.

S6.1.5 Ultrasonic inspection of the cylindrical forging shapes following the preliminary heat treatment.

S6.1.6 Ultrasonic inspection of the discs or wheels, or both, and remaining shaft diameters after the heat treatment for mechanical properties.

S6.1.7 Magnetic particle inspection after the heat treatment for mechanical properties.

Designation: A 952/A 952M – 02

Standard Specification for Forged Grade 80 and Grade 100 Steel Lifting Components and Welded Attachment Links[1]

This standard is issued under the fixed designation A 952/A 952M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers the requirements for forged alloy steel lifting components and welded coupling and master links for Grade 80 and Grade 100 alloy chain slings as described in Specification A 906/A 906M.

1.2 Two grades of components and welded links are covered:

1.2.1 Grade 80.

1.2.2 Grade 100.

1.3 This specification is a performance standard. Other standards apply to use of these products. Some of these standards are: OSHA 1910.184, ASME B30.10, and ASME B30.9.

1.4 The values stated in either inch-pound or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 391/A 391M Specification for Grade 80 Alloy Steel Chain[2]

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products[3]

A 906 Specification for Alloy Steel Chain Slings for Overhead Lifting[2]

A 973/A 973M Specification for Grade 100 Alloy Steel Chain[2]

E 4 Practices for Force Verification of Testing Machines[4]

E 44 Definitions of Terms Relating to Heat Treatment of Metals[5]

E 165 Test Method for Liquid Penetrant Examination[6]

E 709 Guide for Magnetic Particle Examination[6]

2.2 *Other Standards:*

OSHA 1910.184 Slings[7]

ASME B30.9 Slings[8]

ASME B30.10 Hooks[8]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *breaking force, minimum*—the minimum force in pounds or newtons at which the component has been found by verification testing to break when a constantly increasing force was applied in direct tension. This test is a manufacturer's design verification test and shall not be used as criteria for service.

3.1.2 *chain sling*—an assembly consisting of alloy steel chain joined to upper and lower end components for attaching loads to be lifted by a crane or lifting machine.

3.1.3 *coupling link*—a link fitted to the end of the chain to connect to another component of the sling. See Fig. 1.

3.1.4 *master link*—a link used as an upper end component of a chain sling and by means of which the sling may be attached to a crane or other device. See Fig. 1.

3.1.5 *master coupling link (secondary or intermediate link)*—a link used on three and four leg slings to connect the legs to a master link. See Fig. 1.

3.1.6 *proof test*—a quality control tensile test applied to components for the purpose of verifying manufacturing and material quality. It is the minimum force in pounds or newtons which the component has withstood at the time it left the producer, under a test in which a constantly increasing force

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.27 on Steel Chain.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] *Annual Book of ASTM Standards*, Vol 01.02.

[6] *Annual Book of ASTM Standards*, Vol 03.03.

[7] Available from OSHA.

[8] Available from ASME, 345 E. 47th Street, New York, NY 10017.

***A Summary of Changes section appears at the end of this standard.**

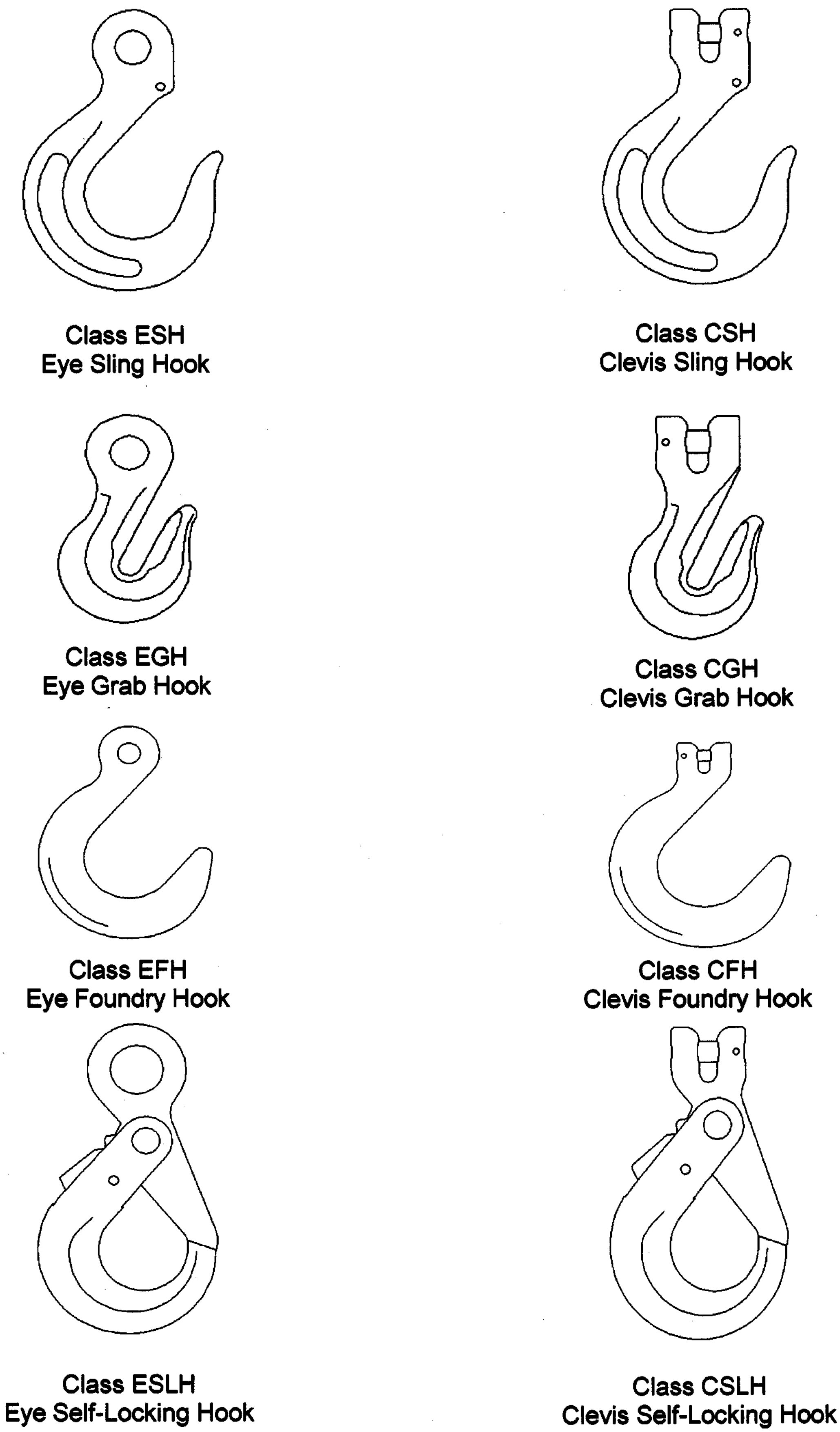
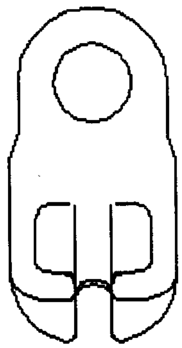
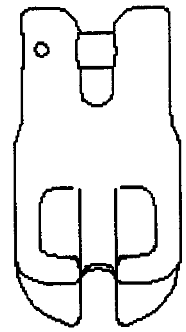


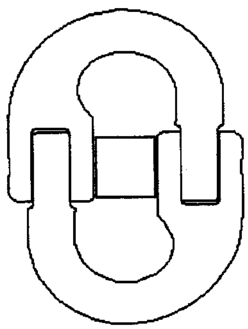
FIG. 1 General Component Configuration



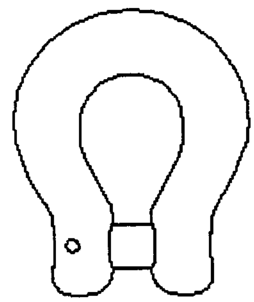
Class ECGH
Eye Claw Grab Hook



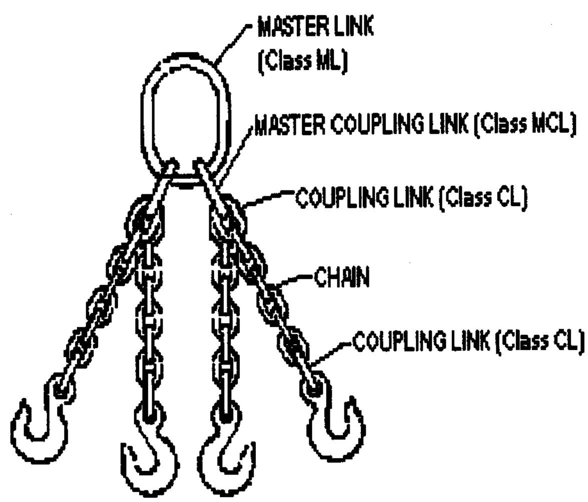
Class CCGH
Clevis Claw Grab Hook



Class CLM
Coupling Link, Mechanical



Class CCL
Clevis Coupling Link



Class ML, MCL, CL
Master Link, Master Coupling Link, Coupling Link

FIG. 1 General Component Configuration *(continued)* has been applied in direct tension. Proof test loads are a manufacturing integrity test and shall not be used as criteria for service.

3.1.7 *traceability code*—a series of letters, or numbers, or both, marked on a component which enables its manufacturing history, including identity of the steel heat, to be traced.

3.1.8 *working load limit (WLL)*—the maximum combined static and dynamic load in pounds or kilograms that shall be applied in direct tension to the component.

4. Classification

4.1 Only Grade 80 and Grade 100 components are covered under this specification.

4.2 Sixteen classes of components are covered under this specification. The general configuration on these components are shown in Fig. 1.

4.2.1 *Class EGH*—Eye Grab Hook.
4.2.2 *Class CGH*—Clevis Grab Hook.
4.2.3 *Class ESH*—Eye Sling Hook.
4.2.4 *Class CSH*—Clevis Sling Hook.
4.2.5 *Class EFH*—Eye Foundry Hook.
4.2.6 *Class CFH*—Clevis Foundry Hook.
4.2.7 *Class CLM*—Coupling Link, Mechanical.
4.2.8 *Class ESLH*—Eye Self-Locking Hook.
4.2.9 *Class CSLH*—Clevis Self-Locking Hook.
4.2.10 *Class ECGH*—Eye Claw Grab Hook.
4.2.11 *Class CCGH*—Clevis Claw Grab Hook.
4.2.12 *Class ML*—Master Link.
4.2.13 *Class MCL*—Master Coupling Link.
4.2.14 *Class CL*—Coupling Link.
4.2.15 *Class CCL*—Clevis Coupling Link.
4.2.16 *Class OTH*—Specialty components may be required for certain applications.

4.3 For the classes listed in 4.2, an "S" prefix denotes a component with a swivel joint.

5. Ordering Information

5.1 It shall be the responsibility of the purchaser to specify all requirements that are necessary for material ordered under this specification. Such requirements to be considered include, but are not limited to, the following:

5.1.1 Product to conform to Specification A 952 or Specification A 952M and year of issue.
5.1.2 Nominal size of component, in. [mm] (see Note 1).
5.1.3 Grade of component.
5.1.4 Class of component.
5.1.5 Quantity of components.
5.1.6 Finish, if required.
5.1.7 Certification, if required.
5.1.8 Acceptance of inspection by purchaser, if required.
5.1.9 Supplementary requirements, if required.

NOTE 1—Component size and working load limits are based on Grade 80 and Grade 100 alloy steel chain nominal sizes. See Specification A 391/A 391M and A 973/A 973M.

6. Materials

6.1 *Quality*—The selection of the type of steel is left to the judgment of the manufacturer provided the material meets the requirements set forth in 6.2 and 6.3.

6.2 *Melting Process*—The steel used shall be produced by an electric process or by an oxygen blown process. The steel shall be fully killed and have an austenitic grain size of 5 or finer.

6.3 *Chemical Requirements*:

6.3.1 The alloy steel used shall contain at least two of the three alloying agents in the minimum percentages as listed below:

Nickel	0.40 % minimum
Chromium	0.40 % minimum
Molybdenum	0.15 % minimum

6.3.2 The phosphorous and sulfur content of the steel shall not exceed 0.025 % for each element.

6.3.3 *Product Analysis*—The steel used may be analyzed by the purchaser and shall conform to the requirements of 6.3.1 and 6.3.2 subject to the product analysis tolerances specified in Specification A 29/A 29M. Test samples may be taken from rods, bars, or finished product.

6.3.4 Chemical analysis of material covered by this specification for referee purposes shall be in accordance with Test Methods, Practices, and Terminology A 751.

7. Manufacture

7.1 The body of all components shall be forged hot in one piece, with the exception of Class ML, MCL and CL link components.

7.2 Excess metal flash shall be cleanly removed, leaving the surface free from sharp edges.

7.3 Class ML, MCL, and CL link components may be manufactured using the electric welding, gas welding, or forging process.

7.4 Ancillary components such as load pins, latches, bearings, and springs need not be forged components.

7.5 Welding shall not be used to repair forged components. Grinding of surface discontinuities may be carefully performed as long as no dimension is altered outside of the manufacturer's dimensions and tolerances for that component. All ground areas must blend in smoothly with the surface.

7.6 *Heat Treatment*—After forging or welding is completed, each load bearing component shall be heat treated before applying the proof test. Heat treatment shall include quenching and tempering as defined in Definitions E 44.

7.7 After heat treatment, furnace scale shall be removed from the component.

8. Performance Requirements

8.1 *Proof Test*—All components shall be proof tested as required per 8.1.1 through 8.1.5. All tests shall be performed on equipment certifiable to Practices E 4.

8.1.1 All components used on single legs of slings shall be tested to at least the proof test load prescribed in Table 1 for Grade 80 components and Table 2 for Grade 100 components.

8.1.2 All components to which two legs of a sling are attached shall be proof tested to at least a load equal to four times the working load limit of the relevant size single leg component shown in Table 1 for Grade 80 components and Table 2 for Grade 100 components.

8.1.3 All components to which three or four legs of a sling are attached shall be proof tested to at least a load equal to six

TABLE 1 Mechanical Requirements for Grade 80 Single Leg Components

Nominal Size		Working Load Limit, max		Proof Test[A], min		Minimum Breaking Force[A]	
in.	mm	lb	kg	lb	kN	lb	kN
7⁄32	5.5	2100	970	4200	19.0	8400	38.0
9⁄32	7.0	3500	1570	7000	30.8	14 000	61.6
5⁄16	8.0	4500	2000	9000	40.3	18 000	80.6
3⁄8	10.0	7100	3200	14 200	63.0	28 400	126.0
1⁄2	13.0	12 000	5400	24 000	107.0	48 000	214.0
5⁄8	16.0	18 000	8200	36 200	161.0	72 400	322.0
3⁄4	20.0	28 300	12 800	56 600	252.0	113 200	504.0
7⁄8	22.0	34 200	15 500	68 400	305.0	136 800	610.0
1	26.0	47 700	21 600	95 400	425.0	190 800	850.0
1¼	32.0	72 300	32 800	144 600	644.0	289 200	1288.0

[A]The proof test and minimum breaking force loads shall not be used as criteria for service (See Section 3).

TABLE 2 Mechanical Requirements for Grade 100 Single Leg Components

Nominal Size		Working Load Limit, max		Proof Test, min		Breaking Force, min	
in.	mm	lb	kg	lb	kN	lb	kN
7⁄32	5.5	2700	1220	5400	23.8	10 800	47.6
9⁄32	7.0	4300	1950	8600	38.5	17 200	77
5⁄16	8.0	5700	2600	11 400	51	22 800	102
3⁄8	10.0	8800	4000	17 600	79	35 200	158
1⁄2	13.0	15 000	6800	30 000	134	60 000	268
5⁄8	16.0	22 600	10 300	45 200	201	90 400	402
3⁄4	20.0	35 300	16 000	70 600	315	141 200	630
7⁄8	22.0	42 700	19 400	85 400	381	170 800	762

times the working load limit of the relevant size single leg component shown in Table 1 for Grade 80 components and Table 2 for Grade 100 components.

8.1.4 The fixture over which Class ML, MCL, and CL components are proof tested shall be a maximum of 60% of the inside width and suitably large to prevent localized point loading and deformation of the links.

8.1.5 All components shall withstand the proof test load without loss of integrity or detrimental dimensional changes as defined in 8.3.1. Components that do not withstand the proof test shall be discarded.

8.2 *Design Verification Requirements*:

8.2.1 The purpose of the verification tests is to prove the design, material, heat treatment, and method of manufacture of each size of component. Any change of design, material, heat treatment, method of manufacture or in any dimension outside normal manufacturing tolerances shall require that verification be performed on the modified components.

8.2.2 The tests specified in 8.3 shall be performed on at least three samples of each size of component of each design, material, heat treatment, and method of manufacture. During testing, the force shall be applied to the component axially without shock.

8.3 *Design Verification Tests*:

8.3.1 *Deformation Test*—Three samples shall be tested and each shall withstand the proof test load as prescribed in 8.1. No dimension shall be altered after the proof test by more than 1 % of the initial dimension. Class ML, MCL, and CL components are exempt from the deformation requirement test.

8.3.2 *Breaking Force Test*:

8.3.2.1 For single leg components, three samples shall be tested and be capable of withstanding the relevant minimum breaking force as prescribed in Table 1 for Grade 80 components and Table 2 for Grade 100 components.

8.3.2.2 For components to which two sling legs will be attached, the minimum breaking force is twice the minimum breaking force shown in Table 1 for Grade 80 components and Table 2 for Grade 100 components.

8.3.2.3 For components to which three or four sling legs will be attached, the minimum breaking force is three times the minimum breaking force shown in Table 1 for Grade 80 components and Table 2 for Grade 100 components.

8.3.2.4 The component shall show evidence of ductility prior to failure. Ductility is defined as the altering of a dimension by more than 15 % from its original condition. Class CLM components are exempted from this minimum ductility requirement.

NOTE 2—It is not necessary to test the component to its actual breaking force as long as the minimum breaking force loads and deformation requirements are obtained.

NOTE 3—The breaking force tests may be conducted on the samples used for the deformation tests.

8.3.3 *Fatigue Test*:

8.3.3.1 Three samples shall be tested and each shall be capable of withstanding at least 20 000 cycles of the force range without failure.

8.3.3.2 The force range applied during each cycle shall be at least equivalent to 1.5 times the working load limit specified in Table 1 for Grade 80 and Table 2 for Grade 100 for that size component. The minimum force in each cycle shall be positive.

8.3.3.3 The frequency of force applications shall not be greater than 25 Hz.

8.3.3.4 The fixtures used in fatigue testing shall be suitably large to prevent localized point loading or deformation of the component. The fixture shall be a maximum of 60% of the inside width for Class ML, MCL, and CL components.

9. Dimensional Requirements

9.1 The dimensions of the components are left to the judgment of the component manufacturer provided that the dimensions are sufficient to meet the requirements set forth in this specification.

10. Workmanship, Finish, and Appearance

10.1 The components, at the time of shipment, shall be free of discontinuities that would prevent the components from enduring the working load limit forces.

10.2 The manufacturer may apply a surface treatment or coating of their own choice for identification or corrosion resistance unless the customer specifies otherwise.

11. Retests

11.1 If one of the verification test samples fails to meet the requirements of 8.3.1, 8.3.2, or 8.3.3, two additional samples shall be tested. If both additional tests meet or exceed the requirements, the component is considered in compliance with this specification. If two or more of the original samples or one of the retests fail to meet the requirements of 8.3.1, 8.3.2, or 8.3.3, the component does not comply with this specification.

12. Inspection

12.1 When requested on the purchase order or contract, the component shall be free of paint or other coatings which could mask surface discontinuities at the time of inspection.

12.2 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to verify that the component produced is being furnished in accordance with this specification. Inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspection shall be made at the place of manufacture, unless otherwise agreed upon.

12.3 The purchaser may perform the tests to govern acceptance or rejection of the component at their own laboratory or elsewhere. Tests and acceptance criteria shall conform to the requirements contained in this specification unless otherwise stated in the purchase order. Tests at the purchaser's laboratory or elsewhere shall be made at the expense of the purchaser.

13. Rejection and Rehearing

13.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection shall be reported to the producer or supplier promptly and in writing.

13.2 In the case of dissatisfaction with the results of the test in 12.3, the manufacturer may make claim for a rehearing.

14. Certification

14.1 When specified on the purchase order or contract, a certification shall be issued by the manufacturer. The certificate shall include at least the following:

14.1.1 Name of the manufacturer.

14.1.2 Conformance to Specification A 952 or Specification A 952M and year of issue.

14.1.3 Size of component, in. [mm].

14.1.4 Grade of component.

14.1.5 Class of component.

14.1.6 Quantity and description of the component.

14.1.7 Proof test force applied, lb [kN].

14.1.8 Working load limit of the component, lb [kg].

15. Product Marking

15.1 *Forged Components*—Each component shall be legibly and indelibly marked in a manner which will not impair the mechanical properties of the component. This marking shall include at least the following:

15.1.1 Component size, in. [mm]. Class ML, MCL, and CL components are exempt from this marking requirement.

15.1.2 *Grade*—The marking for Grade 80 shall be at least 8, 80 or 800, or any combination. The marking for Grade 100 shall be at least 10, 100, or 1000, or any combination. Class ML, MCL, and CL components are exempt from this marking requirement.

15.1.3 The manufacturer's symbol, mark, or code.

15.1.4 The traceability code.

15.2 *Welded Components*—Each Class ML component shall be legibly and indelibly marked in a manner which will not impair the mechanical properties of the component. This marking shall include at least the following:

15.2.1 The manufacturer's symbol, mark, or code.

15.2.2 The traceability code.

16. Keywords

16.1 alloy steel—chain; chain slings; steel chain; steel chain—components

SUPPLEMENTARY REQUIREMENTS

The following Supplementary Requirements shall apply only when specified in the purchasing contract or order.

S1. Non-Destructive Inspection

S1.1 When specified by the purchaser in the contract or order, components shall be inspected by magnetic particle inspection per Practice E 709, by die penetrant inspection per Practice E 165, or by other means stated in the contract or order.

S1.2 The acceptance/rejection criteria shall be specified in the purchase order or contract. If no criteria is specified, indications greater than 0.08 in. [2 mm] occurring in areas of the components which are subject to tensile stresses are cause for rejection.

S1.3 The percentage of components to be inspected shall be specified in the purchase order or contract. If no criteria is specified, inspection shall be performed on 100 % of the components.

S1.4 Rework by grinding to remove indications is permitted provided the requirements of 7.5 are maintained.

SUMMARY OF CHANGES

(1) Changed "branch" and "branches" to "leg" and "legs," respectively; changed "fitting" and "fittings" to "component" and "components," respectively throughout.
(2) Deleted defintions for "end fitting" and "overhead lifting" and previous section 9.2.
(3) Revised 1.1, 3.1.1–3.1.5, 7.6, 8.1, 8.3.1, 8.3.2.1–8.3.2.3, 13.1, 15.1.1, 15.1.2, Fig. 1,Table 1, and Table 2.
(4) Added 8.1.4, 8.3.3.4, and 15.2.

Designation: A 956 – 02

Standard Test Method for Leeb Hardness Testing of Steel Products[1]

1. Scope

1.1 This test method covers the determination of the Leeb hardness of steel, cast steel, and cast iron (Part A), including the methods for the verification of Leeb hardness testing instruments (Part B), and the calibration of standardized test blocks (Part C).

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

NOTE 1—The original title of this standard was "Standard Test Method for Equotip Hardness Testing of Steel Products".[1]

2. Referenced Documents

2.1 *ASTM Standards:*

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *calibration*—determination of the values of the significant operating parameters of the instrument by comparison with values indicated by a reference instrument or by a set of reference standards.

3.1.2 *Leeb hardness number*—a number equal to the ratio of the rebound velocity to the impact velocity of a 3-mm or 5-mm (based on the type of impact device) diameter tungsten carbide ball or diamond tipped impact body, multiplied by 1000.

$$L = \frac{\text{Rebound Velocity}}{\text{Impact Velocity}} \times 1000$$

The Leeb hardness number is followed by the symbol *HL* with one or more suffix characters representing the type of impact device.

3.1.3 *Leeb hardness test*—a dynamic hardness test method using a calibrated instrument that impacts a spherically shaped carbide ball or diamond tipped body with a fixed velocity (generated by a spring force) onto a surface of the material under test. The ratio of the rebound velocity to the impact velocity of the impact body is a measure of the hardness of the material under test.

3.1.4 *surface finish*—all references to surface finish in this test method are defined as surface roughness (that is, *Ra* = average roughness value, *AA* = arithmetic average).

3.1.5 *verification*—checking or testing the instrument to ensure conformance with this test method.

4. Significance and Use

4.1 Hardness of a material is a poorly defined term that may have many meanings depending on the type of test performed and the expectations of the person involved. The Leeb hardness test is of the dynamic or rebound type, which primarily depends both on the plastic and on the elastic properties of the material being tested. The results obtained are indicative of the strength and dependent on the heat treatment of the material tested.

4.2 The Leeb hardness test is a superficial determination only measuring the condition of the surface contacted. The results generated at that location do not represent the part at any other surface location and yield no information about the material at subsurface locations.

A. GENERAL DESCRIPTION OF INSTRUMENTS AND TEST PROCEDURE FOR LEEB HARDNESS TEST

5. Apparatus

5.1 The instrument used for Leeb hardness testing consists of (*1*) an impact device that is equipped with a tungsten carbide ball or synthetic diamond tipped impact body, an induction coil velocity measuring assembly, and a support ring, and (*2*) an electronic digital display hardness indicating device.

5.2 *Impact Devices*—There are six types of impact devices used in Leeb hardness testing. These are the *D*, *DC*, *D*+15, *G*, *C*, and the *E* impact units. Brief descriptions of the types of devices and their common applications are given in Appendix X1.

5.3 *Summary of Test Method*—During a hardness test, an impact body with a spherically shaped tungsten carbide or diamond tip impacts under spring force, the test surface from which it rebounds. The impact and rebound velocities are

[1] This test method is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] *Annual Book of ASTM Standards*, Vol 14.02.

measured when the impact body is approximately 1 mm from the test surface. This is accomplished by means of a permanent magnet mounted in the impact body which, during the test, moves through a coil in the impact device and induces an electric voltage on both the impact and rebound movements. These induced voltages are proportional to the respective impact and rebound velocities. The quotient of these measured voltage values derived from the impact and rebound velocities, multiplied by the factor 1000 produces a number which constitutes the Leeb hardness value.

6. Test Piece

6.1 *Form*—The Leeb hardness test is acceptable for steel, cast steel, and cast iron with varying shapes and sizes.

6.2 *Thickness and Weight*—The thickness and weight of the test piece shall be considered when selecting the impact device to be employed. The following guidelines are offered as minimum weights and sizes of test pieces for selecting the proper test equipment. Test pieces of weights less than the minimum or pieces of any weight with sections less than the minimum thickness require rigid support and coupling to a thick, heavier non-yielding surface to resist the impact of the device. Failure to provide adequate support and coupling will produce test results lower than the true hardness value.

Impact Device	Weight (min) or	Thickness (min)
D, *DC*, *D*+15, *E*	15 lb (5 kg)	⅛ in. (3 mm)
G	40 lb (15 kg)	⅜ in. (10 mm)
C	4 lb (1.5 kg)	1⁄32 in. (1 mm)

6.3 *Curvature*—Test pieces with curved surfaces may be tested on either the convex or concave surfaces providing that this radius of curvature of the specimens is matched to the size of the support ring and is not less than 2 in. (50 mm) for the *G* impact device or 1 3⁄16 in. (30 mm) for other impact devices.

6.4 *Surface Finish/Preparation*—The test surface shall be carefully prepared to avoid any alterations in hardness caused by heating during grinding or by work hardening during machining. Any paint, scale, pits, or other surface coatings shall be completely removed. The surfaces to be tested shall be smooth. Failure to provide adequate surface finish will produce questionable test results. Coarse finishes will tend to lower the measured value. It is recommended that the test surface be machined or ground and polished to the following finishes. (The grinding wheel grit size shown for each finish is offered for guidance in achieving the finish noted.)

Impact Device	Surface Finish—Ra (max)	Grit Size (Approx.)
D, *DC*, *D*+15, *E*	63 µin. (2 µm)	200
G	250 µin. (7 µm)	65
C	16 µin. (0.4 µm)	500

6.5 *Magnetic Fields*—Performance of the Leeb hardness test on parts with a residual magnetic field may affect the results. It is recommended that any residual magnetic field be less than 4 G.

6.6 *Vibration*—Vibration of the test specimen may affect the results of the Leeb hardness test. It is recommended that this test be performed with the test piece at rest.

6.7 *Temperature*—The temperature of the test piece may affect the results of the test. In addition, this effect may be different for different materials. Testing to this procedure shall be performed with the temperature of the test piece between 40°F (4°C) and 100°F (38°C). At temperatures outside this range, the user shall develop a temperature correction for the specific material being tested.

7. Verification of Apparatus

7.1 *Verification Method*—Prior to each shift, work period, or use and following a period of extended continuous use (1000 impacts), the instrument shall be verified as specified in Part B. Any instrument not meeting the requirements of Part B shall not be employed for the acceptance testing of product.

8. Procedure

8.1 *Test Method*—To perform a hardness test, the impact device is connected to the indicator device and the instrument is turned on. The impact device, while not in contact with the test piece, is held firmly with one hand and the charging tube is depressed with the other hand until contact is felt. The charging tube is allowed to slowly return to the starting position. The impact body is now in its loaded or locked position. After placing the impact device on the test surface, trigger the impact body by exerting a light pressure on the release button. The Leeb hardness value is read on the indicator device.

8.2 *Alignment*—To prevent errors resulting from misalignment, the base support ring of the impact device shall be held snugly and perpendicular to the surface of the test piece.

8.3 *Impact Direction*—The impact device is calibrated for the down vertical impact direction (perpendicular to a horizontal surface). For other impact directions such as 45° from the horizontal plane or from underneath, the measured hardness values will require adjustment (see 9.2). Some newer models automatically compensate for test direction.

8.4 *Spacing Indentations*—The distance between any two impact points shall not be less than two diameters edge-to-edge. The distance between the impact point and a specimen edge shall not be less than three diameters edge-to-edge. No point shall be impacted more than once.

8.5 *Reading the Leeb Instrument*— Hardness values in Leeb units are read directly on the electronic display of the indicator device. The indicated value is automatically replaced with the next test impact result.

8.6 *Number of Impacts*—Five impacts in an area of approximately 1 in.^{2} (645 mm^2) shall constitute a test. If the material being tested is considered to be nonhomogeneous (for example, cast iron) ten impacts in an area shall be made to constitute a test.

9. Calculation of Hardness Result

9.1 The hardness test result shall be the arithmetic average of the five individual impact readings in the measuring area.

9.2 *Correction for Test Direction*— When using an Leeb instrument without automatic compensation for test direction, the correction value for direction of test impact is to be subtracted from the average value determined for the measuring area. This correction value can be determined in accordance with Tables 1-6.

TABLE 1 Correction Values for Other Impact Directions: Device D

L_D				
300				
	-6	-12	-20	-29
350				
	-6	-12	-19	-27
400				
	-5	-11	-18	-25
450				
	-5	-10	-17	-24
500				
	-5	-10	-16	-22
550				
	-4	-9	-15	-20
600				
	-4	-8	-14	-19
650				
	-4	-8	-13	-18
700				
	-3	-7	-12	-17
750				
	-3	-6	-11	-16
800				
	-3	-6	-10	-15
850				
	-2	-5	-9	-14
900				

TABLE 2 Correction Values for Other Impact Directions: Device D + 15

L_{D+15}				
300				
	-7	-14	-26	-38
350				
	-7	-13	-25	-36
400				
	-6	-12	-23	-34
450				
	-6	-12	-22	-32
500				
	-6	-11	-21	-30
550				
	-6	-11	-20	-28
600				
	-5	-10	-19	-27
650				
	-5	-10	-18	-25
700				
	-5	-9	-17	-24
750				
	-4	-9	-16	-22
800				
	-4	-8	-15	-21
850				
	-4	-8	-14	-20
900				

TABLE 3 Correction Values for Other Impact Directions: Device E

L_E				
300				
	-5	-9	-18	-26
350				
	-4	-9	-17	-24
400				
	-4	-9	-16	-22
450				
	-4	-8	-15	-21
500				
	-4	-8	-14	-20
550				
	-4	-8	-13	-18
600				
	-3	-7	-12	-17
650				
	-3	-7	-12	-16
700				
	-3	-6	-11	-15
750				
	-3	-6	-10	-14
800				
	-3	-5	-9	-13
850				
	-2	-5	-8	-12
900				

TABLE 4 Correction Values for Other Impact Directions: Device C

L_C				
350				
	-7	-15	[A]	[A]
400				
	-7	-14		
450				
	-7	-13		
500				
	-6	-13		
550				
	-6	-12		
600				
	-6	-11		
650				
	-5	-10		
700				
	-5	-10		
750				
	-4	-9		
800				
	-4	-8		
850				
	-4	-7		
900				
	-3	-6		
950				

[A] Not permitted.

10. Conversion to Other Hardness Scales or Tensile Strength Values

10.1 There is no direct correlation between the Leeb hardness test principle and other hardness methods or a tensile strength test. All such conversions are, at best, approximations and therefore conversions should be avoided except for special cases where a reliable basis for the approximate conversion and the accuracy of the conversion has been obtained by comparison testing. No conversions shall be employed without specific agreement between the party specifying this test method and the party performing the hardness test.

11. Report

11.1 Report the following information:

TABLE 5 Correction Values for Other Impact Directions: Device G (Steel)

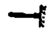
L_G				
300				
	. . .	. . .	-12	-18
350				
	. . .	. . .	-11	-17
400				
	. . .	. . .	-11	-16
450				
	-2	-5	-10	-15
500				
	. . .	. . .	-9	-14
550				
	. . .	. . .	-9	-13
600				
	. . .	. . .	-8	-12
650				
	. . .	. . .	-8	-11
700				
	. . .	. . .	-7	-10
750				

TABLE 6 Correction Values for Other Impact Directions: Device G (Grey Cast Iron)

L_G				
350				
	. . .	. . .	-11	-17
400				
	. . .	. . .	-11	-16
450				
	-2	-5	-10	-15
500				
	. . .	. . .	-9	-14
550				
	. . .	. . .	-9	-13
600				

11.1.1 The average Leeb hardness number for each test area with the impact device indicated (for example, xxx *HLD* or xxx *HLD*+15).

11.1.2 When hardness values converted from the Leeb number are reported, the instrument used shall be reported in parentheses, for example, *HB* (*HLG*).

12. Precision and Bias

12.1 *Precision*:

12.1.1 *Interlaboratory Test Program*—An interlaboratory test program was conducted in accordance with to develop information regarding the precision of the Leeb hardness measurements. Eight laboratories tested five certified test blocks. Each laboratory measured the hardness of each block 25 times.

12.1.2 *Test Result*—The precision information given below is the average of the five certified test blocks, each of a different hardness.

12.1.3 *Repeatability and Reproducibility:*

95 % Repeatability Limit (within laboratory) = 4.4 %
95 % Reproducibility Limit (between laboratories) = 8.8 %

12.1.3.1 The terms in 12.1.3 (repeatability limit and reproducibility limit) are used as specified in Practice E 691. The respective standard deviations among test results, related to the above numbers by the factor 2.8, are:

Repeatability Standard Deviation = 1.6 %
Reproducibility Standard Deviation = 3.2 %

12.2 *Bias*—Since hardness is not an intrinsic property of a material, there is no basis on which to determine or assign an accepted reference value. Consequently, there is no basis for defining the bias of this test method.

B. VERIFICATION OF LEEB HARDNESS INSTRUMENTS

13. Scope

13.1 Part B covers the procedure for verification of Leeb hardness instruments by a standardized block method.

14. General Requirements

14.1 Before a Leeb hardness instrument is verified, the instrument shall be examined to ensure that:

14.1.1 The batteries in the indicating device are not discharged, and faulty batteries are replaced as required.

14.1.2 The impact device is clean, and the spherical tip of the impact body is free from all foreign matter (for example, dust, dirt, grease, scale, etc.).

14.1.3 The tip of the impact body is free from cracks or deformed areas.

14.1.4 The test block is placed on a clean, level, firmly supported base.

15. Verification by Standardized Test Blocks

15.1 Check the Leeb hardness instrument by making two impacts on a standardized test block.

15.2 The Leeb hardness instrument shall be considered verified if the individual readings fall within ±6 HL units of the reference value. Any instrument not verified shall not be used for testing without repair and re-verification.

C. CALIBRATION OF STANDARDIZED HARDNESS TEST BLOCKS FOR LEEB HARDNESS INSTRUMENTS

16. Scope

16.1 Part C covers the calibration of standardized hardness test blocks used for the verification of Leeb hardness instruments.

17. Manufacture

17.1 Each test block shall be made of steel with dimensions not less than 3½ in. (90 mm) in diameter by 2⅛ in. (54 mm) thick for impact devices *D*, *DC*, *D*+15, *C*, and *E* and 4¾ in. (120 mm) in diameter by 2¾ in. (70 mm) thick for impact device *G*. The two opposite end plane surfaces shall be parallel.

17.2 Each block shall be specifically prepared and heat treated to give a specific hardness and the necessary homogeneity and stability of structure.

17.3 Each steel block shall be demagnetized by the manufacturer and maintained demagnetized by the user.

17.4 A non-test surface of the test block shall have a fine ground finish of 250 µin. (7 µm) maximum.

17.5 The test surface shall be polished or fine ground and free of scratches and other discontinuities which would influence the rebound characteristics of the test block.

17.6 The surface finish of the test surface shall not exceed 16 µin. (0.4 µm) maximum.

17.7 To ensure that no material is subsequently removed from the test surface of the standardized test block, an official mark or the thickness to an accuracy of ±0.001 in. (±0.025 mm) at the time of calibration shall be marked on the test surface.

18. Standardizing Procedure

18.1 The standardizing hardness test blocks shall be calibrated with an Leeb instrument for which the operational characteristics have been certified by the manufacturer and which has been verified in accordance with the requirements of Part B.

18.2 Make ten randomly distributed hardness impacts on the test surface of the test block.

18.3 Take the arithmetic mean of all of the readings as the mean hardness of the test block.

19. Uniformity of Hardness

19.1 Unless the difference between the largest and the smallest of the ten readings is less than 13 Leeb units, the block cannot be regarded as sufficiently uniform for standardization purposes.

20. Marking

20.1 Each block shall be marked with:

20.1.1 Arithmetic mean of the hardness values found in the standardization test suffixed by the scale designation letter (for example, *HLD*).

20.1.2 The name or mark of the supplier.

20.1.3 The thickness of the test block.

21. Keywords

21.1 Dynamic Hardness Test; Equotip; Equotip Hardness Test; Leeb; Rebound Hardness Test

APPENDIXES

(Nonmandatory Information)

X1. STANDARD SINGLE COIL REBOUND HARDNESS TESTERS ACCORDING TO THE LEEB PRINCIPLE

X1.1 General Description

X1.1.1 There are seven established types of impact devices for rebound hardness testers according to the Leeb principle, *D*, *DC*, *E*, *D*+15, *DL*, *C*, and *G*. The impact devices *D* and *E* have become industry standards for general purpose applications since the first introduction of the *D*-device in 1975. The other types have been added with the time for applications with special requirements. For more details, see X1.4.

X1.1.2 It is well known that the *L*-readings for a given specimen differ significantly, depending on the impact device type used. The main reasons for this are:

X1.1.2.1 Different impact energies;

X1.1.2.2 Different sizes and materials of the indenter; and

X1.1.2.3 Different stiffnesses of the impact bodies.

X1.1.3 One important advantage of the Leeb testing method is, that it can be used for any direction. The results are, however, not completely independent on the impact angle. Each of the standard probes has its own characteristic direction dependency, which is determined by:

X1.1.3.1 The combination of the impact velocity and the free flight length of the impact body; and

X1.1.3.2 The shape of the induction voltage signal, which is determined by the velocity vs. time curve on the one hand and by the characteristics of the sensor coil and the permanent magnet on the other hand.

X1.1.4 For the standard single coil rebound hardness testing devices, a typical induction voltage curve is sketched in Fig. X1.2 where the shape of this curve is unique for all impact devices of this type. The impact and rebound velocities are assumed to be proportional to the extremal values *A* and *B* of the signal curve, which is a good approximation, if the device is constructed so, that the extremals are near the signal step caused by the impact. If they are too near, however, the reproducibility of the measurement suffers, because the signal

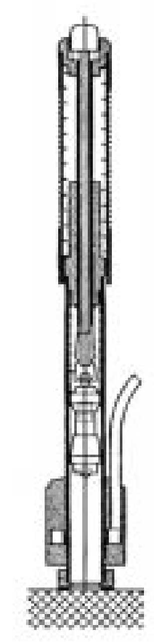


FIG. X1.1 Impact Device D

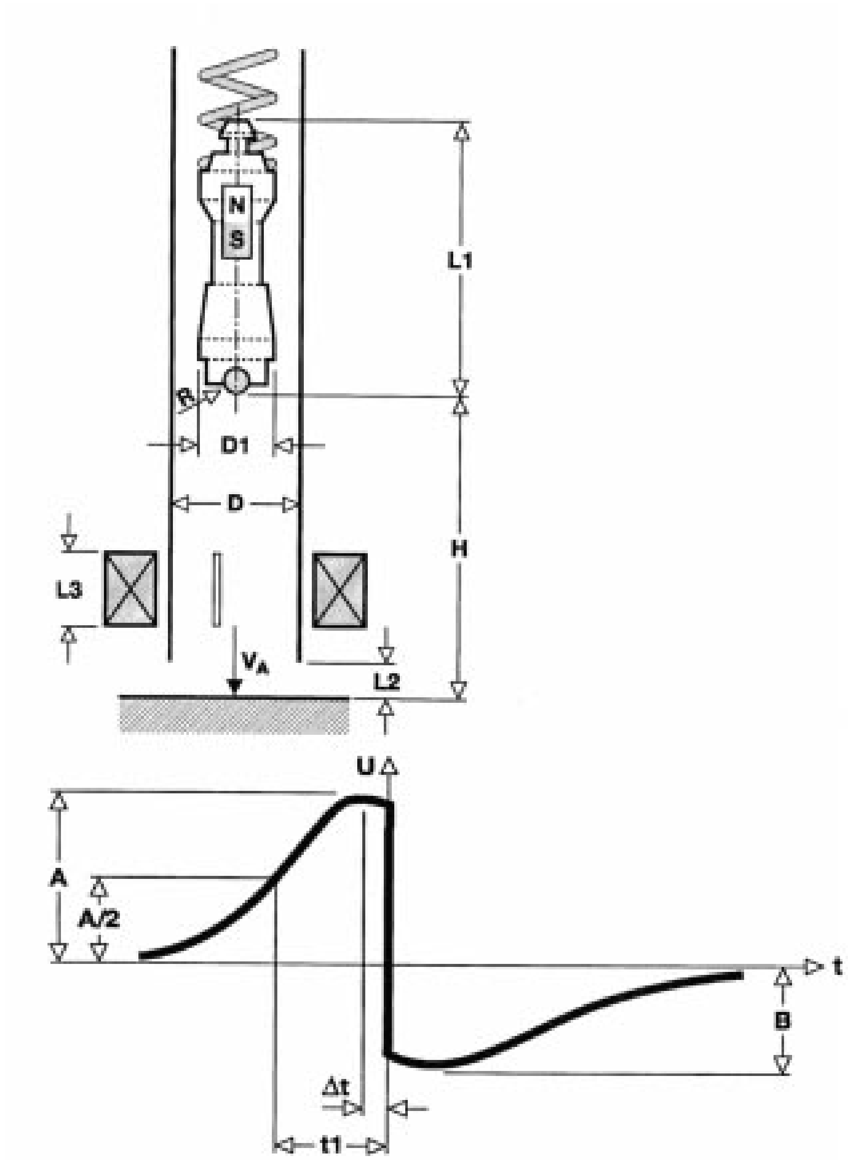


FIG. X1.2 Principle of Standard Single Coil Leeb Hardness Testers

is often disturbed short after the impact. The width of the signal curve has some influence on the result, because it determines, how good the proportionality between mimimum value *B* and rebound velocity is.

X1.1.5 Another parameter of paramount importance determining the actual *L* value for a material of a given hardness is the impact energy, which follows from the impact velocity, the mass of the impact body, and its stiffness (which determines, how much energy the impact body absorbs). In order to reproduce the standard direction dependency, it is necessary to specify velocity and mass separately and to have a specific free flight length. This means that the impact energy in general is the most important parameter for significance of *L*-values for all rebound hardness testers working in units of the seven different standard impact devices listed in 5.1 and given in Table X1.1. Furthermore, the *L* value depends on the geometry of the indenter and its material properties, predominantly hardness and elasticity.

X1.1.6 Finally, the effect of deceleration by eddy currents may affect the result. So the tube material must be specified, too, as well as special precautions have to bee taken to reduce eddy currents.

X1.2 Specifications of Standard Single Coil Hardness Testers

X1.2.1 Table X1.1 compiles the relevant specification for impact devices *D/DC*, *E*, *D*+15, *DL*, *C*, and *G*. Coil and permanent magnet are not explicitly specified. They have to be chosen in such a way, that the specified parameters of the

TABLE X1.1 Specifications of Standard Single Coil Leeb Hardness Testing Devices

Property	Symbol	Unit	*D/DC*	*E*	*D*+15	*DL*	*C*	*G*
Impact velocity[A]	v_A	m/s	2.05 ± 1%	2.05 ± 1%	2.05 ± 1%	2.05 ± 1%	1.39 ± 2%	2.98 ± 1%
Impact body, mass	M	G	5.45 ± 0,05	5.45 ± 0,05	7.80 ± 0,05	7.23 ± 0,05	3.00 ± 0,05	20.00 ± 0,05
material: St 18/8, nonmagnetic								
Free flight length	H	mm	8 ± 1	8 ± 1	8 ± 1	8 ± 1	8 ± 1	15 ± 1
Tube material: aluminium, nonmagnetic								
Eddy current slit			yes	no	yes	yes	yes	no
Indenter, radius	R	mm	1.5	1.5	1.5	1.5	1.5	2.5
material			TC[B]	PKD[C]	TC	TC	TC	TC
hardness	h	HV	1600 (typ)	5000 (typ)	1600 (typ)	1600 (typ)	1600 (typ)	1600 (typ)
Induction signal, peak position	t1	ms	0.55 ± 0,15	0.55 ± 0,15	0.55 ± 0,15	0.55 ± 0,15	0.62 ± 0,20	0.55 ± 0,15
half width	Δt	ms	2.5 ± 30%	2.5 ± 30%	2.5 ± 30%	2.5 ± 30%	4.0 ± 30%	2.0 ± 30%

[A] Impact direction: vertical down.
[B] TC = tungsten carbite.
[C] PCD = polycrystaline diamond.

induction voltage signal are fulfilled. For the definition of some of the parameters refer to Fig. X1.2.

X1.3 Impact Direction Compensation

X1.3.1 Rebound hardness testing devices designed according to the above specifications will not only give correct readings for vertical downward impacts, but will also have a characteristic dependency on the impact angle as shown in Tables X1.2-X1.8.

X1.3.2 Tables X1.2-X1.8 can be used for instruments determining only the velocity ratio in order to correct the readings manually for other directions than vertically down. With microprocessor controlled instruments, the user may set the impact direction and the instrument can determine and display the appropriately corrected values automatically. Instruments containing some means for determining the impact angle can make a fully automatic direction correction, eliminating the possibility of incorrect instrument settings by the user.

TABLE X1.2 Impact Direction Corrections, Probe D/DC

L_D				
300				
	-6	-12	-20	-29
350				
	-6	-12	-19	-27
400				
	-5	-11	-18	-25
450				
	-5	-10	-17	-24
500				
	-5	-10	-16	-22
550				
	-4	-9	-15	-20
600				
	-4	-8	-14	-19
650				
	-4	-8	-13	-18
700				
	-3	-7	-12	-17
750				
	-3	-6	-11	-16
800				
	-3	-6	-10	-15
850				
	-2	-5	-9	-14
900				

TABLE X1.3 Impact Direction Corrections, Probe E

L_E				
300				
	-5	-9	-18	-26
350				
	-4	-9	-17	-24
400				
	-4	-9	-16	-22
450				
	-4	-8	-15	-21
500				
	-4	-8	-14	-20
550				
	-4	-8	-13	-18
600				
	-3	-7	-12	-17
650				
	-3	-7	-12	-16
700				
	-3	-6	-11	-15
750				
	-3	-6	-10	-14
800				
	-3	-5	-9	-13
850				
	-2	-5	-8	-12
900				

X1.4 Guidelines for Selection and Use of the Different Impact Devices

Impact Device *D*

max. hardness	dimensions
up to 68 HRC	ø 20 × 147 mm

X1.4.1 The universal unit for the majority of hardness measurements with a wide measuring range. Applications on steel and cast steel, cold work tool steel, stainless steel, cast iron (lamellar and nodular graphite), cast aluminium alloys, brass, bronze, wrought copper alloys low alloyed. Impact bodies tend to wear out at the high end of hardness range.

Impact Device *DC*

max. hardness	dimensions
up to 68 HRC	ø 20 × 86 mm

X1.4.2 Short impact device which has the same properties and applications like the impact device *D*. Special applications in very confined spaces like holes, cylinders or measurements inside of assembled machines and constructions.

TABLE X1.4 Impact Direction Corrections, Probe D+15

L_D				
300				
	-7	-14	-26	-38
350				
	-7	-13	-25	-36
400				
	-6	-12	-23	-34
450				
	-6	-12	-22	-32
500				
	-6	-11	-21	-30
550				
	-6	-11	-20	-28
600				
	-5	-10	-19	-27
650				
	-5	-10	-18	-25
700				
	-5	-9	-17	-24
750				
	-4	-9	-16	-25
800				
	-4	-8	-15	-21
850				
	-4	-8	-14	-20
900				

TABLE X1.5 Impact Direction Corrections, Probe C

L_E		
300		
	-7	-15
350		
	-7	-14
400		
	-7	-13
450		
	-6	-13
500		
	-6	-12
550		
	-6	-11
600		
	-5	-10
650		
	-5	-10
700		
	-4	-9
750		
	-4	-8
800		
	-4	-7
850		
	-3	-6
900		

Impact Device *D*+15

max. hardness up to 68 HRC

dimensions ø 20 × 162 mm

X1.4.3 Same range of applications like *D/DC* but particularity is slim front section which allows hardness measurements in holes and grooves and on recessed surfaces (elongated impact body and coil position 15 mm elevated).

TABLE X1.6 Impact Direction Corrections, Probe G, Steel

L_D				
300				
	-2	-5	-12	-18
350				
	-2	-5	-11	-17
400				
	-2	-5	-11	-16
450				
	-2	-5	-10	-15
500				
	-2	-5	-9	-14
550				
	-2	-5	-9	-13
600				
	-2	-5	-8	-12
650				
	-2	-5	-8	-11
700				
	-2	-5	-7	-10
750				

TABLE X1.7 Impact Direction Corrections, Probe G, Cast Materials

L_E				
350				
	-2	-5	-11	-17
400				
	-2	-5	-11	-16
450				
	-2	-5	-10	-15
500				
	-2	-5	-9	-14
550				
	-2	-5	-9	-13
600				

TABLE X1.8 Impact Direction Corrections, Probe DL

L_D				
550				
	-3	-6	-11	-16
600				
	-3	-5	-10	-14
650				
	-2	-5	-9	-13
700				
	-2	-4	-7	-12
750				
	-2	-3	-6	-10
800				
	-2	-3	-5	-9
850				
	-2	-2	-4	-7
900				
	-2	-2	-3	-6
950				

Impact Device *G*

max. hardness	dimensions
up to 646 HB	ø 30 × 254 mm

X1.4.4 Increased impact energy (approx. 9 times of that for the standard impact device *D*). Application in the Brinell-range on heavy coarse grained castings and forgings, on steel and cast steel, cast iron (lamellar and nodular graphite) and cast aluminium. Requires less surface finish than impact device *D* for accurate readings.

Impact Device *E*

max. hardness	dimensions
up to 72 HRC	ø 20 × 155 mm

X1.4.5 Synthetic diamond test tip (approx. 5000 HV). Same materials to be tested like standard *D* unit but at extended hardness range. Applications for measurement in the high end range, for example, on steel and cast steel, stainless steel, cold work tool steel with carbide inclusions and on rolls in the hardness range up to 1200 HV. Impact bodies show no fading even at high hardness levels compared to *D* device.

Impact Device *C*

max. hardness	dimensions
up to 70 HRC	ø 20 × 141 mm

X1.4.6 Reduced impact energy (approx. ¼ of that for impact device *D*) and therefore covers slightly wider hardness range than device *D*. Applications on surface hardened components, coatings. Min. layer thickness of 0.3 mm. Applications on walled or impact sensitive components (small measuring indentation) too. Measurements on steel and cast steel, cold work tool steel and cast aluminium alloys. Requires better surface finish than impact device *D*.

Impact Device *DL*

max. hardness	dimensions
up to 68 HRC	ø 20 × 202 mm

X1.4.7 Same range of applications like *D*+15 but has the speciality of more slim front section (ø 4 × 50 mm) for use in confined spaces and at the base of grooves, drill holes, and gears respectively.

X2. GENERAL DESCRIPTION AND TEST PROCEDURE FOR LEEB HARDNESS TEST ACCORDING TO THE MULTIPLE-COIL INSTRUMENT

X2.1 Scope

X2.1.1 The patented rebound method by Krautkramer is a further development of the original Leeb method (see Appendix X1). The measurement readings determined by the latter method are erroneous due to gravitational acceleration and are not independent of direction. The results must therefore be correspondingly corrected. This disadvantage is not apparent in instruments which operate according to the Krautkramer rebound method.

X2.1.2 The direction-dependence of the measurement readings result essentially from:

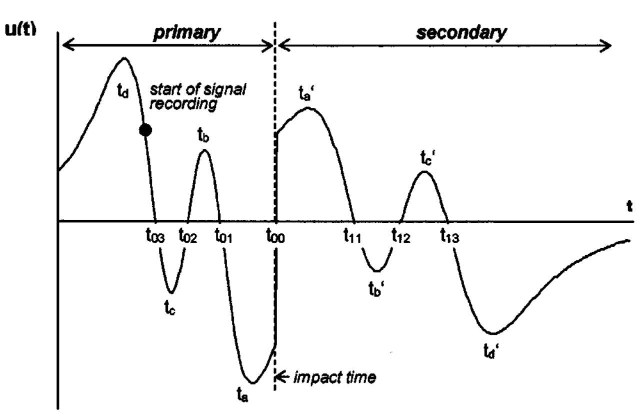


FIG. X2.1 Schematic Voltage Signal Generated By the Impact Body Travelling Through the Krautkramer Coil System

X2.1.2.1 A kinematic error caused by gravitational force and friction (at the measurement location t_a resp. t_a'), if not measured within the impact time t_{00} (refer to Fig. X2.1); and

X2.1.2.2 A change in the effective, influencing energy depending on the position resp. direction being applied.

X2.1.3 The first effect is avoided by evaluation of a time signal correlated with location information of the impact body. It is of advantage to arrange the impact body (magnets) and the coil so, that the impact signal as well as the rebound signal uses at least two zero transitions (in this case 3) of the induced voltage as support points for the evaluation of the curve. The complete curve is digitised for evaluation and mapped into the instrument's memory.

X2.1.4 The second effect is compensated by calibration of the impacting device in the various application positions and at various degrees of hardness.

X2.2 General Description of Instruments and Test Procedure for Leeb Hardness Test According to the Krautkramer Instrument

X2.2.1 *Compensation of Kinematic Error*

X2.2.1.1 The signal curve according to Fig. X2.1 is produced, during the impact and rebound trip of the impact body, using the sophisticated coil arrangement outlined in Fig. X2.2. The primary part of the curve (index prefixed with "0") is produced by the impact and the secondary part of the curve (indicated with the prefix "1") by the return trip. The moments t_{01}, t_{02}, t_{03} correspond to t_{11}, t_{12}, t_{13}, that is, at these times the impact body is correspondingly at the same position $x(t_0) = x(t_1)$, also $x(t_{01}) = x(t_{11})$; $x(t_{02}) = x(t_{12})$ and $x(t_{03}) = x(t_{13})$.

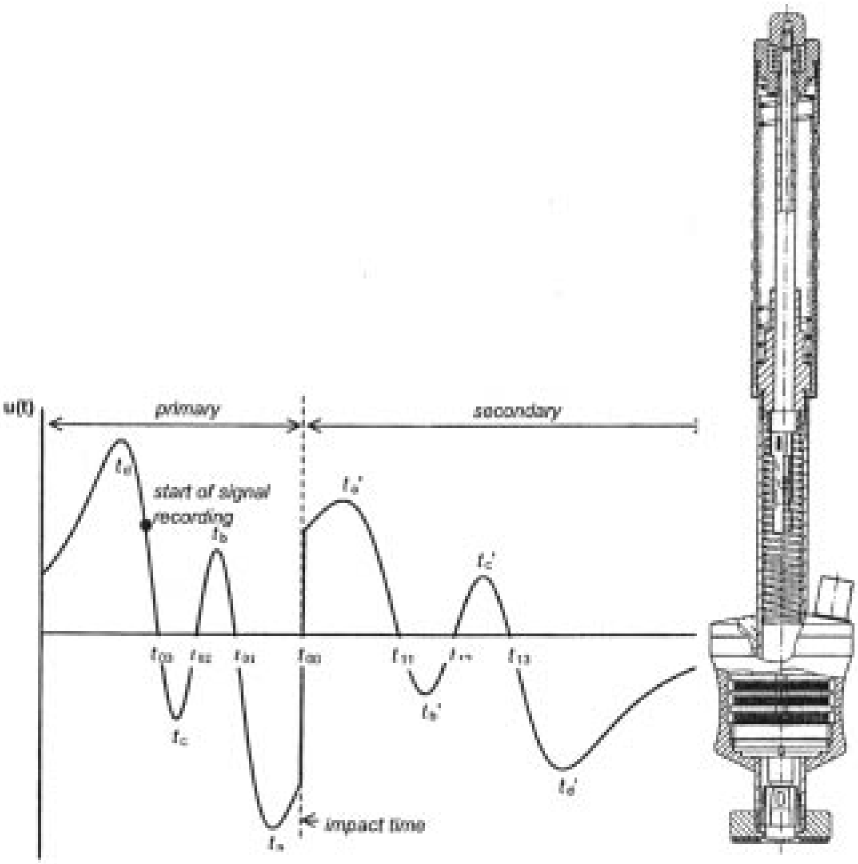


FIG. X2.2 Design of the Kraukramer Impact Device D

X2.2.1.2 Using the magnetic flow through a coil with the surface A:

$$\Phi(t) = \int_A B(r,t) \cdot dA \qquad \text{(X2.1)}$$

where:

$B(r,t)$ = magnetic field,
t = time, and
r = position.

X2.2.1.3 The time progression of the coil voltage can be calculated:

$$u(t) = c(x(t))v(t) \qquad \text{(X2.2)}$$

where:

$c(x(t)$ = function of the position of the impact body, and
$v(t)$ = velocity of the impact body.

X2.2.1.4 The ratio of the voltage at the moment of impact must be found, that is:

$$h = \frac{v_1(0)}{v_0(0)} \qquad \text{(X2.3)}$$

X2.2.1.5 Using the reproduction law $t_1(t_0)$ produces $x\ (t_0) = x\ (t_1(t_0))$ also at the same position as $c\ (t_0) = c\ (t_1(t_0))$ which in turn produces:

$$\frac{u(t_1(t_0))}{u(t_0)} = \frac{c(x(t_1(t_0)))}{c(x(t_0))}\frac{v(t_1(t_0))}{v(t_0)} = \frac{v(t_1(t_0))}{v(t_0)} = v_{10}(t_0) \qquad \text{(X2.4)}$$

X2.2.1.6 The ratio of the induction voltages is therefore the same as the ratio of the velocity to the corresponding times.

X2.2.1.7 Three curve points for the reproduction law $t_1(t_0)$ can be found after determination of the zero points from the measurement signal. The complete reproduction law is obtained by interpolation between these curve points so that the corresponding amplitude value $u\ (t_1)$ can be allocated to each voltage value $u\ (t_0)$ enabling the velocity ratio (except at the zero positions themselves) to be calculated. Finally extrapolation takes places at the required impact time. The starting point is the ratio $t_a' \ / \ t_a$ which corresponds to the uncorrected measurement reading according to Leeb (see Appendix X1).

X2.2.1.8 The method guarantees a considerable tolerance with regard to the characteristics of the impact device enabling exchange of the impact body without any difficulty and without having to recalibrate the instrument. Only the mass must be kept within narrow tolerances. As opposed to this, the position of the zero points, and to a certain amount also the minimum at t_a, vary (magnetic field geometry) without causing any incorrect readings worth mentioning about.

X2.2.2 *Correction of the Impact Energy at Different Impact Directions and Production Tolerances of the Impact Devices*

X2.2.2.1 The impact devices are calibrated in order to compensate the dependence of the velocity ratio on the impact energy as well as the differences in the mechanical design of the impact device. To do this, the rebound values are measured, as described above, on two hardness reference blocks having different, known hardness values. Three measurements are made for each of the five impact directions, +90° (vertically downwards), +60°, 0° (horizontal), -60° and -90° (vertically upwards). In addition to the hardness, the time interval Δt between the zero transitions t_{03} and t_{01} is recorded in units having 1⁄64 scanning steps (approx. 0.7 µs). This is a measure for the velocity of the impact body: high velocities correspond to small Δt, lower velocities to large Δt. Owing to the different orientations during the measurement sequence, one obtains complete coverage of the impact energy range occurring when in operation.

X2.2.2.2 The difference Δh between the uncalibrated, measured Leeb hardness and the prespecified reference block hardness against Δt is plotted for all measurement points and both the resulting relationships are corrected by straight lines. The gradients of the correction lines are stored in the serial EPROM in the impact device together with the reference block hardness and the position (Δt_0, Δh_0) of the intersection points of both lines.

X2.2.2.3 If the measurement produces an uncalibrated hardness in Leeb according to see Appendix X1, then the corresponding gradient of the correction lines are determined by linear interpolation of the gradient established during the calibration process.

X2.2.2.4 The dependence of the measurement reading on the changed friction is, within certain limits, also taken into consideration (in addition to the dependence on impact direction). Both effects lead to a change in impact energy. Furthermore, small differences, caused by production, in potential energy of the impact body in the tensioned state are compensated. Whereas the information about the required velocity correction is essentially contained in the line gradient, deviations of the probe's mechanical characteristics are essentially reflected in a vertical shift of the curve.

Designation: A 965/A 965M – 02

Standard Specification for Steel Forgings, Austenitic, for Pressure and High Temperature Parts[1]

This standard is issued under the fixed designation A 965/A 965M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers austenitic stainless steel forgings for boilers, pressure vessels, high temperature parts, and associated equipment.

1.2 Supplementary requirements are provided for use when additional testing, inspection, or processing is required. In addition, supplementary requirements from Specification A 788 may be specified when appropriate.

1.3 This specification includes the austenitic steel forgings that were a part of A 336/A 336M.

1.4 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text and tables, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independent of the other. Combining values from the two systems may result in nonconformance with the specification.

1.5 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:*

A 336/A 336M Specification for Alloy Steel Forgings for Pressure and High-Temperature Parts[2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

A 788 Specification for Steel Forgings, General Requirements[2]

E 112 Test Methods for Determining the Average Grain Size[4]

2.2 *Other Standards:*

ASME Boiler and Pressure Vessel Code, including Section VIII Pressure Vessels and Section IX Welding Qualifications[5]

3. Ordering Information and General Requirements

3.1 In addition to the ordering information required by Specification A 788, the intended use should be stated if 5.1 is to be applicable.

3.2 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

3.3 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

3.4 If the forgings are intended for use under the ASME Boiler and Pressure Vessel rules at temperatures exceeding 1000°F [540°C], then use Supplementary Requirement S7. Grain size requirements for service exceeding 1000°F [540°C] should be specified unless the required grade has the suffix "H."

4. Melting and Forging

4.1 In addition to the melting and forging requirements of Specification A 788, which may include Supplementary Requirement S8, the following condition applies:

4.1.1 A sufficient discard shall be made to secure freedom from injurious pipe and undue segregation.

NOTE 1—Because of difficulties in retaining nitrogen, vacuum melting or remelting processes should not be specified for Grades F304N, F304LN, F316N, F316LN, and FXM-11.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved March 10, 2002. Published May 2002. Originally published as A 965/A 965M-96. Last previous edition A 965/A 965M-01.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] Available from ASME International, Three Park Ave., New York, NY 10016–5990.

5. Machining

5.1 Forged pressure vessels for steam power service shall have the inner surface machined or ground. Unfired pressure vessels shall have the inner surfaces sufficiently free of scale to permit inspection.

5.2 When rough machining is performed, it may be done either before or after heat treatment.

6. Heat Treatment

6.1 Forgings shall be furnished in the solution treated condition. On completion of forging operations, the forgings shall be solution annealed and quenched in water, oil, or a polymer water solution. Direct quenching after completion of forging without subsequent reheating to the temperatures prescribed in 6.2-6.5 is not permissible.

6.2 For Grades F304H, F309H, F310H, F316H, F321H, F347H, and F 348H, the minimum solution annealing temperature shall be 1925°F [1050°C].

6.3 Grades FXM-11 and FXM-19 shall be solution annealed at 1950°F [1065°C].

6.4 Grade F46 shall be solution annealed in the temperature range of 2010–2140°F [1100–1170°C].

6.5 The remaining grades in Table 1 shall be solution annealed at a minimum temperature of 1900°F [1040°C].

7. Chemical Composition

7.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788 shall comply with Table 1.

7.2 *Product Analysis*—The manufacturer shall use the product analysis provision of Specification A 788 to obtain a product analysis from a forging representing each heat or multiple heat.

7.3 Types (common names) and UNS designations follow:

Grade	Type	UNS Designation
F304	304	S30400
F304H	304H	S30409
F304L	304L	S30403
F304N	304N	S30451
F304LN	304LN	S30453
F309H	309H	S30909
F310	310	S31000
F310H	310H	S31009
F316	316	S31600
F316H	316H	S31609
F316L	316L	S31603
F316N	316N	S31651
F316LN	316LN	S31653
F321	321	S32100
F321H	321H	S32109
F347	347	S34700
F347H	347H	S34709
F348	348	S34800
F348H	348H	S34809
FXM-19	XM19	S20910
FXM-11	XM11	S21904
F46		S30600

8. Mechanical Properties

8.1 *Requirements*—The material shall conform to the requirements for mechanical properties prescribed in Table 2 and Supplemental Requirement S2. The largest obtainable tension test specimen as specified in Test Methods and Definitions A 370 shall be used.

8.2 *Number of Tests*—The number and location of tests are based on the heat-treated weight of the forging(s) from the same heat, solution annealed in the same furnace charge.

8.2.1 For forgings weighing less than 5000 lb [2250 kg] as heat treated, one tension test shall be required. This shall be taken from a prolongation of one of the forgings from the same heat in the same heat treatment load.

8.2.2 When heat treatment is performed in continuous type furnaces equipped with recording pyrometers, such that complete heating records are available, a solution annealing charge may be considered as any continuous run not exceeding an 8 h period.

8.2.3 For forgings weighing over 5000 lb [2250 kg], as heat treated, one tension test shall be taken from a prolongation on each forging.

8.3 The longitudinal axis of the tension test specimen shall be parallel to the direction of major working of the forging, except when Supplementary Requirement S2 is specified. For upset disk forgings the longitudinal axis of the specimen shall be in either the tangential or radial direction.

8.3.1 The location of the longitudinal axis of the tension test specimen shall be located midway between the parallel surfaces of the test extension, if added to the periphery of disks, or midway between the center and surface of solid forgings. For hollow forgings, or those heat treated after boring, the specimen shall be located at midwall. For the special case of forgings that are heat treated solid, but are subsequently bored, the tension test specimen may be taken at the location of the minimum inside diameter after boring instead of the mid-radius position.

9. Grain Size

9.1 For Grades F304H, F316H, F309H, F310H, F321H, F347H, and F348H, the grain size of the forgings shall be ascertained according to Test Methods E 112, after solution treatment. One sample shall be examined for each tensile specimen required in 8.2 and shall be taken from the tension test location. The grain size shall be number 6, or coarser, over at least 75 % of the surveyed area.

10. Repair Welding

10.1 Repair welding of forgings may be permitted but only at the option of the purchaser. Such repair welds shall be made in accordance with Section IX of the ASME Boiler and Pressure Vessel Code.

11. Marking

11.1 The marking requirements of Specification A 788 apply.

12. Test Reports

12.1 The certification requirements of Specification A 788 shall apply.

TABLE 1 Chemical Requirements

	Austenitic Steels																				
	Grade																				
Element	F 304	F 304H	F 304L	F 304N	F 304LN	F 309H	F 310	F 310H	F 316	F 316H	F 316L	F 316N	F 316LN	F 321	F 321H	F 347	F 347H	F 348	F 348H	FXM-19	FXM-11	F46[A]
Carbon	0.08 max	0.04–0.10	0.030 max	0.08 max	0.030 max	0.04–0.10	0.15 max	0.04–0.10	0.08 max	0.04–0.10	0.035 max	0.08 max	0.030	0.08 max	0.04–0.10	0.08 max	0.04–0.10	0.08 max	0.04–0.10	0.06 max	0.04 max	0.018 max
Manganese	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	2.00 max	4.0–6.0	8.0–10.0	2.00 max
Phosphorus, max	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.040	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.020
Sulfur, max	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.020
Silicon	1.00 max	1.00 max	1.00	1.00 max	1.00 max	1.00 max	1.00 max	1.00 max	1.00 max	1.00 max	1.00 max	1.00 max	1.00 max	1.00 max	1.00 max	1.00 max	1.00	1.00	1.00	1.00	1.00 max	3.7–4.3
Nickel	8.0–11.0	8.0–11.0	8.0–12.0	8.0–11.0	8.0–11.0	12.0–15.0	19.0–22.0	19.0–22.0	10.0–14.0	10.0–14.0	10.0–15.0	10.0–13.0	10.0–13.0	9.0-12.0	9.0–12.0	9.0–12.0	9.0–12.0	9.0–12.0	9.0–12.0	11.5–13.5	5.5–7.5	14.0–15.5
Chromium	18.0–20.0	18.0–20.0	18.0–20.0	18.0–20.0	18.0–20.0	22.0–24.0	24.0–26.0	24.0–26.0	16.0–18.0	16.0–18.0	16.0–18.0	16.0–18.0	16.0–18.0	17.0-19.0	17.0–19.0	17.0–19.0	17.0–19.0	17.0–19.0	17.0–19.0	20.5–23.5	19.0–21.5	17.0–18.5
Molybdenum	...	...	...	...	...	...	...	...	2.00–3.00	2.00–3.00	2.00–3.00	2.00–3.00	2.00–3.00	...	...	...	...	...	...	1.50–3.00	...	0.20 max
Nitrogen	...	...	...	0.10–0.16	0.10–0.16	...	...	...	...	...	...	0.10–0.16	0.10–0.16	0.10 max	...	...	...	...	...	0.20–0.40	0.15–0.40	...
Columbium and tantalum	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	[B]	8×C min to 1.10 max	10×C min to 1.10 max	8×C min to 1.10 max	0.10–0.30	...	...
Titanium	...	...	...	...	...	...	...	...	...	...	...	...	...	[C]	[D]	...	...	...	...	...	...	...
Tantalum	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0.10 max	0.10 max	...	...	...
Vanadium	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0.10–0.30	...	...
Cobalt, max	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0.020	0.020	...	...	...
UNS Designation	S30400	S30409	S30403	S30451	S30453	S30909	S31000	S31009	S31600	S31609	S31603	S31651	S31653	S32100	S32109	S34700	S34709	S34800	S34809	S20910	S21904	S30600

[A] F46 shall have a maximum copper content of 0.50.

[B] F347 shall have a columbium content of not less than ten times the carbon content and not more than 1.10 %. (Alternatively, tantalum may be substituted for part of the columbium as approved by the purchaser.)

[C] F321 shall have a titanium content of not less than 5x (C+N) and not more than 0.70 %.

[D] F321H shall have a titanium content of not less than 4x (C+N) and not more than 0.70 %.

TABLE 2 Tensile Requirements

	Austenitic Steels																					
	Grade																					
	F304	F304H	F304L	F304N	F304LN	F309H	F310	F310H	F316	F316H	F316L	F316N	F316LN	F321	F321H	F347	F347H	F348	F348H	FXM-11	FXM-19	F46
UNS Designation	S30400	S30409	S30403	S30451	S30453	S30909	S31009	S31600	S31609	S31603	S31651	S31653	S32109	S34700	S34709	S34800	S34809	S32100	S31000	S21904	S20910	S30600
Tensile strength min, ksi [MPa]	70 [485]	70 [485]	65 [450]	80 [550]	70 [485]	70 [485]	75 [515]	70 [485]	70 [485]	70 [485]	65 [450]	80 [550]	70 [485]	70 [485]	70 [485]	70 [485]	70 [485]	70 [485]	65 [450]	100 [690]	90 [620]	78–100 [540–690]
Yield strength (0.2 % offset), min, ksi [MPa]	30 [205]	30 [205]	25 [170]	35 [240]	30 [205]	30 [205]	30 [205]	30 [205]	30 [205]	30 [205]	25 [170]	35 [240]	30 [205]	30 [205]	30 [205]	30 [205]	30 [205]	30 [205]	25 [170]	55 [380]	50 [345]	32 [220]
Elongation in 2 in. or 50 mm, min,%	30	30	30	25	30	30	30	30	30	30	30	25	30	30	30	30	30	30	30	30	40	40
Reduction of area, min,%	45	45	45	45	45	45	35	45	45	45	45	45	45	45	45	45	45	45	45	50	50	50

13. Keywords

13.1 austenitic stainless steel forgings; high temperature service; pressure containing parts; pressure vessel service

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, and order. Details of these supplementary requirements shall be agreed upon between the manufacturer and the purchaser.

S1. Rough Turning and Boring

S1.1 The position of the rough turning and boring in the sequence of manufacturing operations shall be specified.

S2. Transverse Tension Test

S2.1 Instead of test specimens taken in accordance with 8.3.1, the longitudinal axis of the test specimens shall be transverse to the direction of major working of the forging. The results shall conform with requirements of Table S2.1, with the exception of the ductility limits which shall be as prescribed in Table S2.1.

S3. Hydrostatic Test

S3.1 A hydrostatic pressure test shall be applied. The details of the test, including its position in the sequence of manufacturing operations, shall be specified.

S4. Stabilization Heat Treatment

S4.1 When specified, Grades F347 and F321 shall receive stabilization treatment, which shall consist of holding the forging at 1500 to 1600°F [815 to 870°C], for not less than 2 h/in. of thickness and then cooling in the furnace or in still air.

S5. Marking

S5.1 Forgings shall be marked at a location indicated by the purchaser in the purchase order or drawing.

S6. Individual Forging

S6.1 Forgings, whether identical or not identical, shall be produced individually. They shall not be forged in multiple and separated prior to or after heat treatment.

S6.2 The shape and size of individual forgings shall be agreed between the manufacturer and the purchaser by means of a forging drawing or the purchase order.

S7. Grain Size Requirements for Service Exceeding 1000°F [540°C]

S7.1 For design metal temperatures above 1000°F [540°C], the forgings shall have a grain size of 7 or coarser as determined in accordance with Test Method E 112. The actual grain size shall be reported on the certificate of test.

TABLE S2.1 Ductility Limits

	Grade																				
	F304	F304H	F304L	F304N	F304LN	F309H	F310	F310H	F316	F316H	F316L	F316N	F316LN	F321	F321H	F347	F347H	F348	F348H	FXM19	FXM11	F46
Elongation in 2 in. or 50 mm, min,%	30	30	30	25	30	30	30	30	30	30	30	25	30	30	30	30	30	30	30	30	40	40
Reduction of area, min,%	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	37	35	35	35	35	40	40
UNS Designation	S30400	S30409	S30403	S30453	S30451	S30909	S31000	S31009	S31600	S31609	S31603	S31653	S31657	S32100	S32109	S34700	S34709	S34800	S34809	S20910	S21904	S30600

Designation: A 966/A 966M – 96 (Reapproved 2001)

Standard Test Method for Magnetic Particle Examination of Steel Forgings Using Alternating Current[1]

This standard is issued under the fixed designation A 966/A 966M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers a procedure for the magnetic particle examination of steel forgings using alternating current as the power source. The procedure will produce consistent results upon which acceptance standards can be based. This test method does not contain acceptance limits or recommended quality levels.

1.2 Only alternating 50–60 cycle current shall be used as the electric power source for any of the magnetizing methods. The ability to detect subsurface discontinuities is very limited when using an alternating power source, and therefore the test surfaces should be in the final thermally treated and finish machined condition.

1.3 When subsurface indications are sought in forgings, then dc magnetization in accordance with Test Method A 275/A 275M should be used.

1.4 The values stated in either inch-pound units or SI units are to regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification. Unless the order specifies the applicable "M" specification designation [SI units], the inch-pound units shall be used.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings[2]

2.2 *Other Document:*

Practice No. SNT-TC-1A, Supplement B—Magnetic Particle Method[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *(ac) magnetic particle method of examination*—a method for detecting discontinuities on the surface in suitably magnetized materials, which employs finely divided magnetic particles that tend to congregate in regions of leakage fields.

3.1.2 *indication*—the visual magnetic particle buildup resulting from leakage fields in the magnetic field.

3.1.3 *linear indication*—an indication in which the length is at least three times the width. The minimum length of indications to be considered linear shall be 1⁄16 in. [1.5 mm].

3.1.4 *magnetic flux*—the product of the magnetic induction and the area of a surface (or cross section) when the magnetic induction is uniformly distributed and normal to the plane of the surface. The concept that the magnetic field is flowing along the lines of force suggests that these lines are therefore "flux" lines, and they are called magnetic flux.

3.1.5 *nonrelevant indications*—indications produced by leakage fields where the conditions causing them are present by accident or part design, or other features of the part having no relation to the damaging flaws being sought. This term signifies that such an indication has no relation to the discontinuities that might constitute defects.

4. Basis of Application

4.1 When in accordance with the requirements of the inquiry, contract, order, or specifications, forgings are to be examined by the magnetic particle method using alternating current; the manufacturer and the supplier shall be in agreement concerning the following:

4.1.1 The locations on the forging that are to be subjected to magnetic particle examination.

4.1.2 The type, size, number, location, and orientation of indications that are to be considered injurious.

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[1] This test method is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved Sept. 10, 1996. Published December 1996.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] Available from American Society for NonDestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, OH 43228-0518.

4.1.3 The method of application and type of magnetic particles, demagnetization requirements, and magnetic field strengths.

4.1.4 Acceptance standards.

5. Personnel Requirements

5.1 Personnel performing the magnetic particle examination in this test method shall be qualified and certified in accordance with a written procedure conforming to Practice No. SNT-TC-1A or another national standard that is acceptable to both the purchaser and supplier.

6. Stage of Examination

6.1 Unless otherwise specified by the purchaser, acceptance examination shall be performed on a forging in the final machined surface condition.

7. Magnetizing Apparatus

7.1 A 50 or 60 cycle alternating current shall be used. When current is passed through the forging itself, the equipment shall consist of contacting or clamping elements with sufficient surface area and clamping pressure to allow the required current to flow without damaging (burning) the part being examined.

7.2 Portable electromagnetic alternating current yokes may be used as a magnetizing apparatus.

8. Magnetic Particles

8.1 The inspection medium shall consist of finely divided ferromagnetic particles (which may be coated with a fluorescent material) suspended in a suitable liquid medium or used in dry powder form.

9. Surface Preparation

9.1 The sensitivity of the magnetic particle examination will depend to a considerable extent upon the condition of the surface being examined. While defects may be satisfactorily revealed on shot-blasted or otherwise cleaned forged surfaces, without any further surface treatment, all heat treatment or forging scale must be removed. However to reveal fine defects of ⅛ in. [3 mm] or less in length, the surfaces to be examined shall be smooth machined to at least a 250-µin. [6.35-µm] finish.

9.2 The surfaces shall be free from grease, oils, or other substances to which the particles may adhere.

10. Methods of Magnetization

10.1 The forging may be magnetized either by passing current through the piece or by inducing a magnetic field by means of a central conductor, by coils, or by yoke.

10.1.1 *Continuous Method*—In the continuous method the inspection medium is applied to the surface under examination while the current is still flowing. The alternating current source generates high amperage current in pulses of up to 1 s duration. The duration of this flow shall allow at least three pulses of current, or in the case where machines supply continuous current flow, a minimum shot of ⅕ to ½ s duration should be applied.

10.1.2 The surge and residual methods are not applicable to this test method.

10.2 At least two separate examinations shall be carried out on each area. The second examination shall be with the lines of magnetic flux approximately perpendicular to those used for the first examination in that area. A different means of magnetization may be used for the second examination. Magnetizing in more than one direction cannot normally be accomplished simultaneously. An exception to the above rule is overall sequential multivector magnetization whereby several magnetizing circuits are provided for sequentially magnetizing a part in multiple directions depending on the locations of the current connectors. By this technique, indications of any orientation can be detected with a single application of magnetic particles.

10.3 The two general types of magnetization with regard to direction are longitudinal and circular as follows:

10.3.1 *Longitudinal*—When a forging is magnetized longitudinally, the magnetic flux lines are usually parallel to the axis of the piece. A longitudinally magnetized piece always has definite poles, readily detectable by compass or magnetometer. Longitudinal magnetization is usually accomplished by placing the forging within a solenoid, frequently formed by wrapping cable around the piece (Fig. 1). For special applications, magnetic yokes can be used (Fig. 2).

10.3.2 *Circular*—Circular magnetization is obtained by passing a current through the piece (Fig. 3) or by induced by passing current through a conductor or conductors threaded through an opening in the piece (Fig. 4 or Fig. 5). By agreement with the purchaser (see 10.5.3) localized circular magnetization may be obtained by passing current through local areas by the use of prod-type contacts (Fig. 6).

10.4 The magnetic field is confined almost entirely to the piece and there may be no external manifestation of the magnetized condition. Indications will appear strongest in the direction perpendicular to the direction of the magnetic field.

10.5 *Field Strength*—The minimum field strength that will reveal and permit classification of all objectionable defects shall be used. The maximum field strengths practical are the ones just below the point at which excessive adherence of the particles begins to occur over the surface being inspected.

10.5.1 *Coil Magnetization*—When coil magnetization is used, the magnetic field strength is directly proportional to the

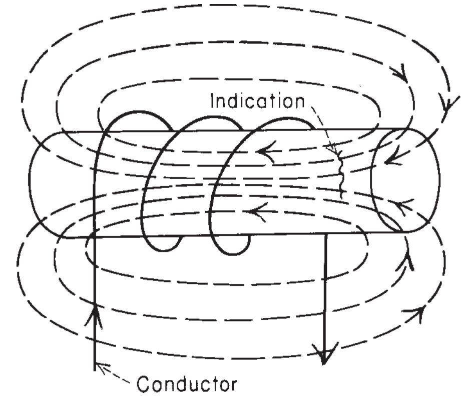

FIG. 1 Longitudinal Magnetization

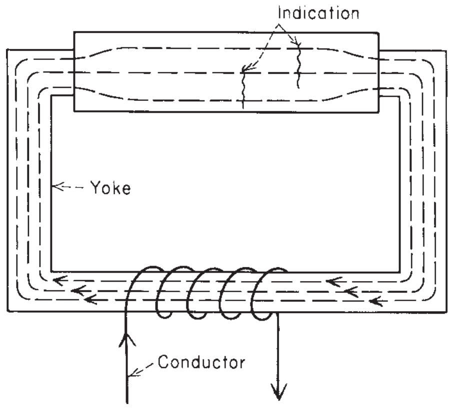

FIG. 2 Longitudinal Magnetization, with Yoke

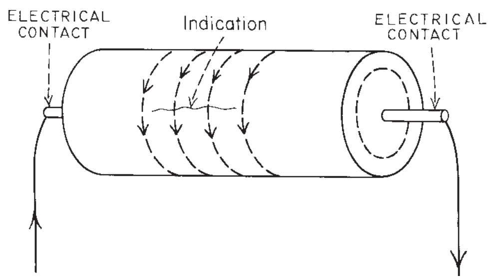

FIG. 3 Circular Magnetization, Current Directly Through Forging

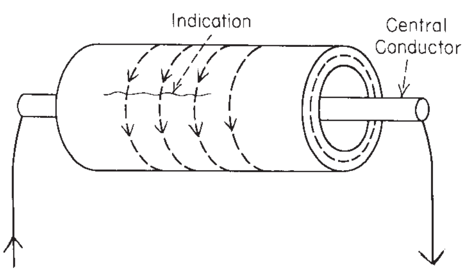

FIG. 4 Circular Magnetization, Current Through a Conductor

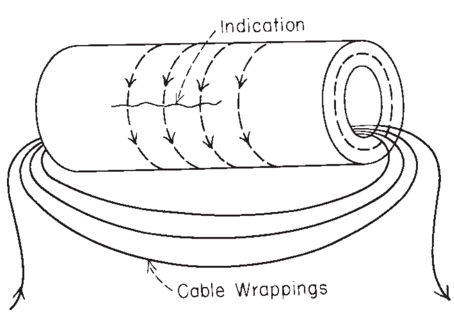

FIG. 5 Circular Magnetization, Current Through Conductors Threaded Through Forging

current (ampere-turns if a coil or solenoid is used) and inversely proportional to the thickness of the section being inspected.

10.5.1.1 *Longitudinal Magnetization*—For encircling coils (Fig. 1), the turns of the coil shall be kept closely together. The field strength decreases as distance from the coil increases and long parts must be magnetized in sections. If the area to be inspected extends beyond 6 in. [150 mm] on either side of the

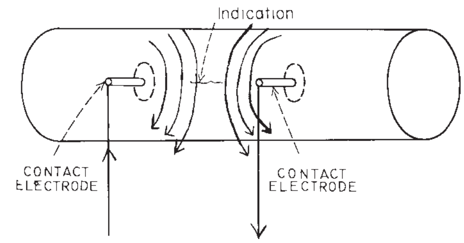

FIG. 6 Circular Magnetization with "Prod" Type Contact Electrodes

coils, the adequacy of the field shall be demonstrated by the use of field indicators (see 10.5.6).

(*1*) *Small Forgings*—Magnetizing force shall be 35 000 ampere-turns divided by the sum of 2 plus the "length over diameter" ratio of the test part. For example, a part 10 in. [250 mm] long by 2 in. [50 mm] in outside diameter has an L/D ratio of 5. Therefore, 35 000/(2 + 5) = 5000 ampere-turns; if a 5-turn coil is used, the current required is 5000/5 or 1000 A. This formula provides an adequate field strength on small parts having an L/D ratio of 4 or greater. For parts having a smaller L/D ratio, adequate field strengths shall be demonstrated by the use of a field indicator (see 10.5.6). The graph in Fig. 7 may be used to determine the ampere-turns required for each L/D relationship.

(*2*) *Large Forgings*—For large forgings the magnetizing force shall be in the range from 1200 to 4500 ampere-turns. A field indicator (see 10.5.6) shall be used to demonstrate the presence of an adequate field strength over the area to be inspected.

10.5.1.2 *Circular Magnetization (*Fig. 5*)*—For circular magnetization with through coils, use the current with amperage as specified in 10.5.2 divided by the number of turns in the coil.

10.5.2 *Direct Magnetization*—When current is passed directly through the part to be examined, the current shall be between 100 and 900 A [4 and 35 A per millimetre] per inch of diameter or cross section (per inch or millimetre of greatest width in a plane at right angles to current flow). For hollow

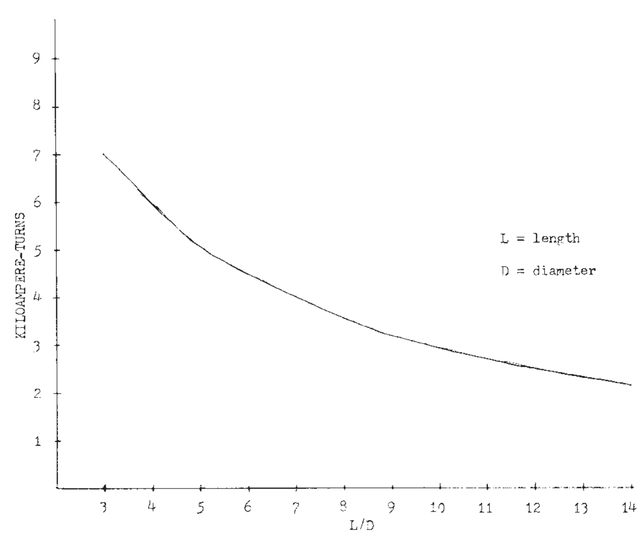

FIG. 7 Longitudinal Magnetization

parts this would be wall thickness when cables are clamped to the wall. Suggested current for diameters or sections up to 5 in. [125 mm] are 600 to 900 A/inches [25 to 35 A per millimetre]; for diameters or sections between 5 and 10 in. [125 to 250 mm], 400 to 600 A/inches [15 to 25 A per millimetre]; and 100 to 400 A/inches [4 to 15 A per millimetre] for outside diameters or sections over 10 in. [250 mm]. If it is not practical to obtain these current levels for diameters over 10 in. [250 mm], the presence of an adequate field strength shall be demonstrated using a field indicator. In all other instances the adequacy of the magnetizing force shall be demonstrated by means of a field indicator (see 10.5.6). When large parts have been examined by clamping contacts to the wall thickness, the adequacy of the field in the circumferential direction shall also be determined by the field indicator.

10.5.3 *Prod Magnetization*—Since this method may induce arcing or burning at the contact areas, and the inspection is intended to be performed on finished surfaces, the use of prod magnetization is not permissible without the prior approval of the purchaser. For the same reason magnetic leaches may not be used to introduce current into the part without the prior approval of the purchaser. If the use of prods or magnetic leaches should be permitted, then the following conditions shall apply:

10.5.3.1 A magnetizing force of 75 to 100 A per linear inch [3 to 4 A per millimetre] of prod spacing shall be used for material under ¾ in. [20 mm] thick, and 100 to 125 A per linear inch [4 to 5 A per millimetre] of prod spacing shall be used for material ¾ in. [20 mm] and over in thickness.

10.5.3.2 Prod spacing shall be a maximum of 8 in. [200 mm]. Prod spacing less than 3 in. [75 mm] usually is not feasible due to banding of the particles around the prods. Care shall be taken to prevent local overheating or burning of the surface being examined. Steel- or aluminum-tipped prods or copper-brush-type prods rather than solid copper-tipped prods are recommended where the magnetizing voltage is over 25 V open circuit (bad contact) in order to avoid copper penetration. Permanent magnetic leeches may be used as a pair or in conjunction with a prod. Leeches should not be used in excess of 1500 A because loss of magnetization occurs.

10.5.3.3 A remote control switch, which may be built into the prod handles, shall be provided to permit the current to be turned on after the prods have been properly positioned and to turn off before the prods are removed in order to prevent arcing.

10.5.3.4 *Examination Coverage*—Examinations shall be conducted with sufficient overlap to ensure 100 % coverage at the established sensitivity.

10.5.3.5 *Direction of Magnetization*—At least two separate examinations shall be carried out on each area. The prods shall be placed so that the lines of flux during one examination are approximately perpendicular to the lines of flux during the other.

10.5.4 Indirect circular magnetization of forgings may be accomplished by the use of a central conductor as shown in Fig. 4. The recommended current level is 100 to 125 A per inch [4 to 5 A per millimetre] of bore diameter. Alternatively a field indicator may be used to establish the adequacy of the magnetic field (see 10.5.6).

10.5.5 An ammeter shall be used to measure the specified or agreed upon current.

10.5.6 A magnetic particle field indicator as shown in Fig. 8 shall be used to establish the adequacy of the magnetic field.

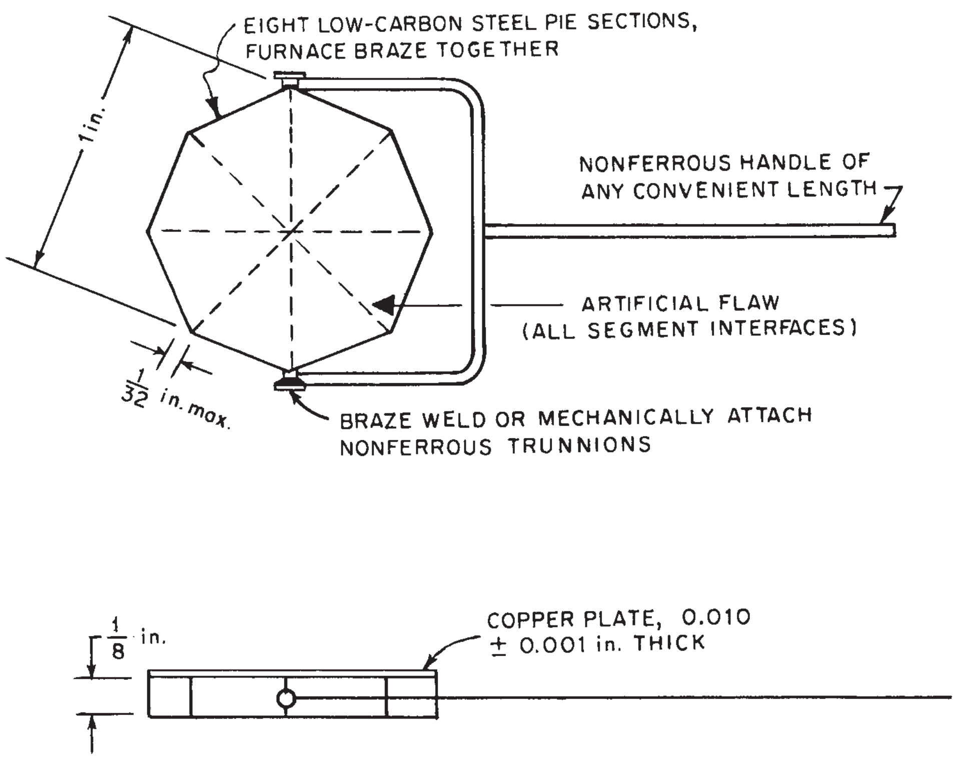

FIG. 8 Magnetic Particle Field Indicator

The magnetizing current shall be sufficient to develop the pattern in the indicator clearly.

10.5.6.1 The magnetic particle field indicator shall be used by positioning it copper side up on the surface of the forging being examined, while applying the magnetizing current and the particles used in the examination. Suitable magnetic field strength is indicated when the field indicator lines at 45° and 90° to the applied magnetic field are outlined by magnetic particles.

10.5.7 *Yoke Magnetization*—When ac electromagnetic yokes are used to magnetize a local area, a longitudinal field is formed between the poles.

10.5.7.1 *Equipment*—Alternating current yokes may be of the fixed or articulated leg types.

10.5.7.2 *Yoke Qualification*—Alternating current electromagnetic yokes shall have a minimum lifting power of 10 lbf [45 N] at a pole spacing of 6 in. [150 mm].

10.5.7.3 *Direction of Magnetization*—At least two separate examinations shall be carried out on each area. In the second examination, the lines of magnetic flux shall be approximately perpendicular to those used for the first examination in that area.

10.5.7.4 *Pole Spacing*—Pole spacing shall be limited to a maximum of 6 in. [150 mm].

10.5.7.5 *Examination Area*—The examination area shall be limited to a maximum distance of ¼ of the pole spacing on either side of a line joining the two poles. Overlapping of pole spacing shall be a minimum of 1 in. [25 mm].

11. Application of Particles

11.1 *Visible Light*—Except for the fluorescent method, the intensity of the visible light at the surface of the part under examination shall be maintained at a minimum of 100 fc [1000 lux].

11.2 While the forging is properly magnetized, the particles may be applied by one of the following methods:

11.2.1 *Dry Method*—In the dry method the particles shall be applied from a hand shaker (such as a shaker can), mechanical shaker, bulb blower, or mechanical blower. The use of the shaker shall be limited to flat and nearly horizontal surfaces, whereas the blowers may be used on vertical or overhead surfaces. The powder shall be applied evenly on the surface of the forging. The color of the dry powder should be chosen to provide suitable contrast. Too much powder is disadvantageous as it masks the patterns.

11.2.2 Care shall be exercised in blowing off excess powder so as not to disturb the indications.

11.3 *Wet Methods*:

11.3.1 *Oil*—The material for the wet method is usually supplied in concentrate form, and the inspection medium shall be prepared by mixing the concentrate with a suitable light oil. The liquid recommended for the inspection vehicle is a well refined, light, petroleum distillate having a relatively high flash point. The approximate characteristics of a suitable liquid are as follows:

API gravity, °	46
Viscosity, SUS	31
Flash point (Tag Open Cup), °F [°C]	155 to 175 [65 to 80]
Initial boiling point, °F [°C]	390 [200]
End point, °F [°C]	490 [255]
Color, Saybolt	25

A suspension of from 1 to 2 % solid material by volume shall generally be used. The inspection medium shall be flowed or sprayed over the area being inspected. The color of the particles should be chosen to provide suitable contrast.

11.3.2 *Water*—Magnetic particles suspended in clean water, or clean water with suitable wetting agents may be used. Suspension of from 2 to 2½ % solid magnetic material shall generally be used.

11.4 *Fluorescent Method*—Fluorescent magnetic particle inspection is a variation of the wet method. A concentrate, similar to that used in the wet method, shall be used, except that the magnetic particle shall be coated with material that fluoresces when activated by "black" light.

11.4.1 The same procedure specified when mixing the wet medium shall be followed, except that the suspension shall contain 0.1 to 0.7 % of solid material by volume when petroleum distillate or water is used.

11.4.2 The vehicle shall not be fluorescent.

11.4.3 When fluorescent particles are used, the examination shall be conducted in a darkened area where the maximum white light permitted shall be 2 fc. Black light shall be used, and the light intensity at the examination surface, 15 in. [375 mm] from the face of the light source lens filter shall be not less than 1000 μw/cm^2 when measured with a suitable black light meter.

11.4.4 The black light shall emit ultraviolet radiation of a wavelength within the range from 3300 to 3900 Å. The particles shall emit a bright fluorescence when subjected to this light. The bulb shall be allowed to warm up for a minimum of 5 min prior to its use in examination.

12. Demagnetization

12.1 Unless otherwise specified parts shall be sufficiently demagnetized after examination so that the residual field will not interfere with subsequent machining or welding operations or the intended use of the part, or that leakage fields will not occur in areas of dynamic contact surfaces.

12.2 Demagnetization may be accomplished by decreasing the magnetizing current in small steps, or continuously to a very low value. Alternatively the part may be withdrawn slowly from the magnetizing field. Demagnetization shall be verified by the use of a suitable magnetic field indicator.

13. Interpretation and Evaluation of Indications

13.1 Test Method A 275/A 275M describes in some detail the interpretation and evaluation of magnetic particle indications.

14. Report of Indications

14.1 Based on the agreement between manufacturer and purchaser, or on the acceptance criteria of an applicable material specification, the size, number, and location of all ratable indications shall be recorded in the inspection report, using sketches if necessary. Methods for the permanent recording of magnetic particle indications are included in Test Method A 275/A 275M.

15. Acceptance Standards

15.1 The standards for acceptance of magnetic particle indications detected by magnetic particle examination shall be as specified in the applicable ASTM product specification, contract, or order.

16. Keywords

16.1 ac magnetization; circular magnetization; dry method; ferritic steel forgings; fluorescent method; longitudinal magnetization; surface flaw detection; wet method

Standard Specification for Grade 100 Alloy Steel Chain[1]

This standard is issued under the fixed designation A 973/A 973M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers Grade 100 heat-treated alloy steel chain for such applications as slings, lifting assemblies, and load binding.

NOTE 1—This specification does not cover alloy steel chain for pocket wheel applications.

1.2 This specification is a performance standard for Grade 100 chain used between −20 and 400°F [−29 and 205°C]. The chain manufacturer should be contacted for use at temperatures outside this range.

1.3 The values stated in either SI units or in other units shall be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system must be used independently of the other, without combining values in any way.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished, General Requirements for[2]

A 919 Terminology Relating to Heat Treatment of Metals[3]

E 30 Test Methods for Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron[4]

E 350 Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron[5]

E 415 Test Method for Optical Emission Vacuum Spectrometric Analysis of Carbon and Low-Alloy Steel[5]

2.2 *SAE Standard:*

SAE J422 Microscopic Determination of Inclusions in Steels[6]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *breaking force, minimum*—the minimum force in pounds or newtons at which the chain, during manufacture, has been found by testing to break when a constantly increasing force is applied in direct tension. This test is a manufacturer's attribute acceptance test and shall not be used as criteria for service.

3.1.2 *lot*—for the purpose of acceptance testing, a lot shall consist of 3000 ft [1000 m], or fraction thereof, of the same size chain. If a continuous length of chain exceeds 3000 ft [1000 m], it shall also be considered a lot.

3.1.3 *proof test*—a quality control tensile test applied to chain for the purpose of verifying weld and material quality. It is the minimum force in pounds or newtons which the chain has withstood at the time it left the producer, under a test in which a constantly increasing force has been applied in direct tension to a straight length of chain. Proof test loads are a manufacturing integrity test and shall not be used as criteria for service or design purposes.

3.1.4 *working load limit (WLL)*—the maximum combined static and dynamic load in pounds or kilograms that shall be applied in direct tension to an undamaged straight length of chain.

4. Ordering Information

4.1 It shall be the responsibility of the purchaser to specify all requirements that are necessary for material ordered under this specification. Such requirements include, but are not limited to, the following:

4.1.1 Product to conform to Specification A 973/A 973M and date of issue,

4.1.2 Nominal size of chain (in. or mm),

4.1.3 Quantity of chain (ft or m),

4.1.4 Length of each piece, if required,

4.1.5 Finish, if required,

4.1.6 Certification of test(s), if required,

4.1.7 Acceptance of inspection by purchaser, if required, and

4.1.8 Supplementary requirements, if required.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.27 on Steel Chain.

Current edition approved Sept. 10, 2001. Published November 2001. Originally published as A 973/A 973M-97. Last previous edition A 973/A 973M-00.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] Discontinued. See *1998 Annual Book of ASTM Standards*, Vol 01.02.

[4] Discontinued. See *1995 Annual Book of ASTM Standards*, Vol 03.05.

[5] *Annual Book of ASTM Standards*, Vol 03.05.

[6] Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

***A Summary of Changes section appears at the end of this standard.**

5. Manufacturing

5.1 *Melting Process*—The alloy steel shall be fully killed and have an austenitic grain size of five or finer.

5.2 *Welding Process*—Alloy steel chain may be made by the electric welding or gas welding process.

5.3 *Heat Treatment*—After welding, alloy steel chain shall be heat treated before applying the proof test. Heat treatment shall include quenching and tempering as defined by Terminology A 919.

6. Material Requirements

6.1 *Heat Analysis*—The selection and amounts of the alloying elements in the steel are left to the judgment of the individual chain manufacturer provided the steel meets the following criteria: carbon = 0.35 % max; phosphorous = 0.025 % max; sulfur = 0.025 % max. The following elements must all be present in alloying amounts, nickel (0.40% min), chromium (0.40% min), and molybdenum (0.15% min). The steel shall have oxide and silicate inclusions of 4 or less as determined by SAE J422.

6.2 *Product Analysis*—The steel used may be analyzed by the purchaser and shall conform to the requirements of 6.1 subject to the product analysis tolerances specified in Specification A 29/A 29M. Test samples may be taken from rods, bars, or finished chain. Samples for analysis shall be so taken as to represent the full cross section of the specimen.

6.3 Test Methods E 30, E 350, or E 415 shall be used for referee purposes.

7. Mechanical Requirements

7.1 *Proof Test*—All chain shall be tested to at least the proof load prescribed in Table 1 for the appropriate size chain. When so tested it shall withstand these loads without loss of chain integrity. Links or chain segments not withstanding the proof test load shall be removed from the chain.

7.2 *Breaking Force*—The breaking force test specimen shall consist of a length from the lot containing at least the number of links in Table 2. All chain shall be in the quenched and tempered condition before the breaking force is measured.

7.2.1 Fixtures for securing chain in a testing machine shall be properly designed to support securely the shoulder of the link (see Note 2). The opening in the fixture shall not be more than 125 % of the stock diameter being tested. Links engaged in the testing fixture shall not be considered part of the test specimen.

TABLE 2 Mechanical Test Sample Length Requirements

Size of Chain	Minimum Number of Links in Test Specimen
7⁄32 in. [5.5 mm]	9
Larger than 7⁄32 in. [5.5 mm] but less than 3⁄4 in. [20.0 mm]	7
3⁄4 in. [20.0 mm] and larger	3

NOTE 2—"U" bolts of the same or larger diameter and the same or greater strength may be used to secure the chain to the jaws of the testing machine.

7.2.2 Test results shall meet or exceed the minimum breaking force values given in Table 1 for the appropriate size chain.

7.3 *Elongation*:

7.3.1 All chain must be in the quenched and tempered condition before the elongation is measured.

7.3.2 The elongation test specimen shall consist of a length from the lot containing at least the number of links in Table 2.

7.3.3 A positive load not exceeding 10 % of the proof test shall be applied for determining the original gage length ($L\{0\}$).

7.3.4 The elongation shall be based on the total extension at fracture. This is expressed as a percentage of the change in length (ΔL) divided by the original gage length ($L\{0\}$). The elongation may be determined by the equation below or by autographic recorder or side scale.

$$\text{Elongation (\%)} = \left\{\Delta L \,/\, L\{0\}\right\} \times 100$$

where:

ΔL = test specimen final length at fracture – test specimen original gage length ($L\{0\}$), and

$L\{0\}$ = original gage length (sum or the inside lengths of the test chain links, not counting the fixture links, or as determined in 7.3.3).

7.3.5 The elongation shall be a minimum of 20 %.

7.4 One test for breaking strength and elongation shall be made from each lot. The elongation and breaking force tests may be performed at the same time on the same test specimen.

8. Dimensional Requirements

8.1 The chain shall conform to the dimensional requirements specified in Table 1 for the appropriate size chain.

8.2 *Diameter*—The diameter of the material from which the chain is manufactured shall not be smaller than the material

TABLE 1 Grade 100 Alloy Chain Mechanical and Dimensional Requirements

Nominal Chain Size		Material Diameter		Working Load Limit (max)		Proof Test (min)		Minimum Breaking Force		Inside Length (max)		Inside Width Range	
in.	mm	in.	mm	lb	kg	lb	kN	lb	kN	in.	mm	in.	mm
7⁄32	5.5	0.217	5.5	2700	1220	5400	23.8	10 800	47.6	0.69	17.6	0.281 to 0.325	7.14 to 8.25
9⁄32	7	0.276	7.0	4300	1950	8600	38.5	17 200	77	0.90	22.9	0.375 to 0.430	9.53 to 10.92
5⁄16	8	0.315	8.0	5700	2600	11 400	51	22 800	102	1.04	26.4	0.430 to 0.500	10.92 to 12.70
3⁄8	10	0.394	10.0	8800	4000	17 600	79	35 200	158	1.26	32.0	0.512 to 0.600	13.00 to 15.20
1⁄2	13	0.512	13.0	15 000	6800	30 000	134	60 000	268	1.64	41.6	0.688 to 0.768	17.48 to 19.50
5⁄8	16	0.630	16.0	22 600	10 300	45 200	201	90 400	402	2.02	51.2	0.812 to 0.945	20.63 to 24.00
3⁄4	20	0.787	20.0	35 300	16 000	70 600	315	141 200	630	2.52	64.0	0.984 to 1.18	25.0 to 30.0
7⁄8	22	0.866	22.0	42 700	19 400	85 400	381	170 800	762	2.77	70.4	1.08 to 1.30	27.5 to 33.0

diameter listed in Table 1 within the following tolerance: –3 %. Oversized material may be used for all applications.

9. Workmanship, Finish, and Appearance

9.1 The chain at the time of shipment shall be free of discontinuities that would prevent the chain from enduring the working load limit forces.

9.2 The manufacturer may apply a surface treatment or coating of their own choice for identification or corrosion resistance unless the customer specifies otherwise.

10. Retests

10.1 If the original test specimen fails to conform to the requirements in 7.2.2, two additional test specimens from the same lot may be tested, each of which shall conform to the requirements in 7.2.2. If both additional tests are satisfactory, the chain will be considered acceptable.

11. Rework and Retreatment

11.1 Materials that fail to conform to the requirements for dimensions and mechanical tests may be resubmitted after being reworked.

12. Inspection

12.1 When requested on the purchase order or contract, the chain shall be free of paint or other coatings which could mask surface discontinuities at the time of inspection.

12.2 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to verify that the chain produced is being furnished in accordance with this specification. Inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspection shall be made at the place of manufacture, unless otherwise agreed upon.

12.3 The purchaser may make the tests to govern acceptance or rejection of the chain at their own laboratory or elsewhere. Tests and acceptance criteria shall conform to the requirements contained in this specification unless otherwise stated in the purchase order or contract. Tests at the purchaser's laboratory or elsewhere shall be made at the expense of the purchaser.

13. Rejection and Rehearing

13.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection shall be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of any test, the producer or supplier may make claim for a rehearing.

13.2 In the case of dissatisfaction with the results of the test in 12.3, the manufacturer may make claim for a rehearing.

14. Certification

14.1 A manufacturer's certification that the chain conforms to the ordered specification (including year or issue) shall be furnished when requested on the purchase order or contract.

14.2 When requested on the purchase order or contract, the manufacturer shall furnish a certificate of proof test to the purchaser or his representative.

15. Product Marking

15.1 Body chain links shall not be marked with indented characters.

15.2 Body chain links shall be marked for identification purposes at intervals no greater than 3 ft [0.9 m].

15.3 The embossing shall consist of at least the manufacturer's grade identification.

15.4 The marking for Grade 100 shall be at least 10, 100, or 1000, or any combination.

16. Keywords

16.1 chain; steel chain

SUPPLEMENTARY REQUIREMENTS

The following Supplementary Requirements shall apply only when specified in the purchasing order or contract.

S1. Weld Bend Test

S1.1 When specified by the purchaser in the order or contract, each chain lot shall be subjected to the weld bend test.

S2. Test Requirements

S2.1 *Test Equipment*—The bend test equipment shall comply with the requirements shown in Fig. S1.1, where the V-Block angle shall be 90° and the diameter of the anvil shall be approximately twice the diameter of the chain being tested.

S2.2 *Test Procedure*—A shock-free force is applied to the center of the link by the anvil and each single link shall be deformed a distance of 0.8 times the diameter of the chain link.

S2.3 *Selection of Samples*—Samples shall be tested from each lot and shall be in the final heat treated condition. One sample per welding head shall be tested for all sizes.

S2.4 *Acceptance Criteria*—The link shall be examined after testing and shall be free of any visible defects such as cracks in the area at and around the weld.

S2.5 *Retests*—If both original samples for ⅝ in. [16 mm] or smaller chain fail the weld bend test, the lot is considered rejected. If only one sample for the ⅝ in. [16 mm] and smaller chain fails, or the original sample for ¾ in. [20 mm] or larger chain fails, two additional test samples from the same lot may be tested. If both retests conform to the acceptance criteria in S2.4, the chain will be considered acceptable.

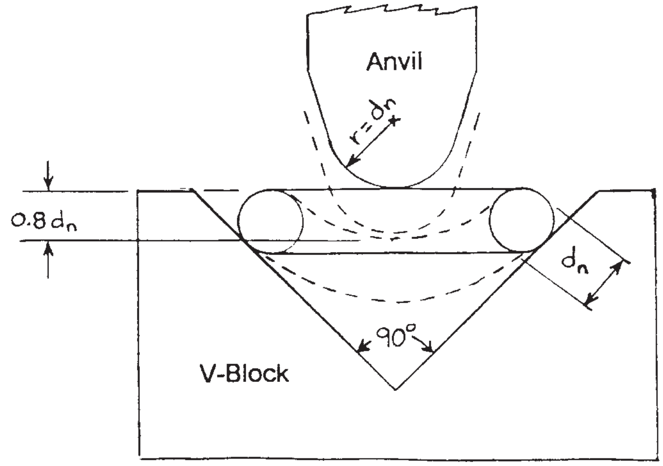

FIG. S1.1 Test Equipment

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since A 973/A 973M that may impact the use of this standard.

(1) Revised Paragraphs 3.1.1, 7.2, 7.3, 7.4, and 15.4.

(2) Deleted Figs. 1 and 2.

Designation: A 982 – 02

Standard Specification for Steel Forgings, Stainless, for Compressor and Turbine Airfoils[1]

This standard is issued under the fixed designation A 982; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers stainless steel forgings for compressor and turbine bucket, blade, and airfoil applications.

1.2 The values stated in inch-pound units are to be considered the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275 Test Method for Magnetic Particle Examination of Steel Forgings[2]

A 788 Specification for Steel Forgings, General Requirements[2]

E 381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings[3]

E 562 Practice for Determining Volume Fraction by Systematic Manual Point Count[3]

3. Ordering Information

3.1 In addition to the ordering information required by Specification A 788, the purchaser shall include a sketch or written description of the forging with the inquiry and order.

4. General Requirements

4.1 Materials supplied to this specification shall conform to the requirements of Specification A 788 which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations and additional supplementary requirements.

4.2 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

5. Manufacture

5.1 *Melting Process*—All melting processes of Specification A 788 are permitted unless Supplementary Requirement S1 is invoked by the purchaser.

5.2 *Forging Process*—Either the closed impression die or the open die forging processes may be utilized unless the purchaser specifies one or the other.

5.2.1 *Forging Temperature*—The maximum part temperature during forging shall be 2150°F.

5.3 *Heat Treatment*—Heat treating all forgings is required in accordance with Table 1 to develop the required mechanical properties.

5.3.1 *Number of Heat Treatments*—Two complete heat treatments, consisting of an austenitize, quench and temper, are permitted. Purchaser approval is required prior to any additional heat treatments.

5.3.2 *Temperature Variation*—Heat treating temperatures shall be controlled in the range of ±25°F.

5.4 *Stress Relief*—When heat treatment for mechanical properties is followed by straightening, a stress relieving heat treatment is required at a temperature meeting the requirements of Table 1.

5.4.1 *Quenching after Stress Relief*—Water or oil quenching of stress relieved forgings is prohibited.

6. Chemical Composition

6.1 The steel shall conform to the requirements for chemical composition prescribed in Table 2.

7. Mechanical Properties

7.1 *Tension, Impact and Hardness Tests*—All testing shall be performed after heat treatment and stress relief, as applicable. The test specimens shall meet the requirements of Table 3.

7.1.1 *Number of Tests*—A minimum of two forgings from each lot shall be randomly selected for longitudinal tensile, impact, and hardness testing. Hardness values of the tension test specimen shall be reported with the tensile data.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved Sept. 10, 2002. Published June 2003. Originally published in 1998. Last previous edition approved in 2001 as A 982–001.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

***A Summary of Changes section appears at the end of this standard.**

TABLE 1 Heat Treatment, °F

	Grade A	Grade B	Grade C		Grade D	Grade E		Grade F
	Classes 1 & 2	Class 1	Class 1	Class 2	Classes 1 & 2	Class 1	Class 2	Class 1
Austenitizing	1725-1775	1600-1750	1825-1875	1725-1875	1875-1925	2075-2125	1725-1775	1875-1925
Quenching	Air or liquid	Air or liquid	Air or liquid	Air or liquid	Air or liquid	Air or liquid	Air or liquid	Air or liquid
Single tempering	1050 min	1050 min	1050 min	1050 min	1150 min	1250 min	1100 min	. . .
Double tempering	. . .	. . .	1025 min	1025 min	. . .	. . .	. . .	. . .
Aging	. . .	. . .	. . .	. . .	. . .	. . .	. . .	1135-1165
Stress Relieving	1025 min	1025 min	1000 min	1000 min	1100 min	1200 min	1050 min	1100 min

TABLE 2 Chemical Requirements

	Composition %					
	Grade A	Grade B	Grade C	Grade D	Grade E	Grade F
UNS Designation	S41000	S41005	S41428	S42225	S41041	S17400
Carbon	0.15 max	0.10-0.15	0.10-0.17	0.20-0.25	0.13-0.18	0.07 max
Manganese	1.0 max	0.25-0.80	0.65-1.05	0.5-1.0	0.4-0.6	1.0 max
Phosphorus, max	0.018	0.018	0.020	0.020	0.030	0.040
Sulfur, max	0.015	0.015	0.015	0.010	0.030	0.030
Silicon	0.5 max	0.5 max	0.10-0.35	0.20-0.50	0.5 max	1.0 max
Nickel	0.75 max	0.75 max	2.25-3.25	0.5-1.0	0.5 max	3.0-5.0
Chromium	11.5-13.0	11.5-13.0	11.25-12.75	11.0-12.5	11.5-13.0	15.0-17.5
Molybdenum	0.5 max	0.5 max	1.5-2.0	0.9-1.25	0.20 max	. . .
Vanadium	. . .	Report only	0.25-0.40	0.20-0.30	. . .	. . .
Tungsten	. . .	0.10 max	0.10 max	0.9-1.25	. . .	. . .
Nitrogen	. . .	0.08 max	0.020-0.045	Report only	. . .	. . .
Aluminum	. . .	0.025 max	0.025 max	0.025 max	0.05 max	. . .
Columbium	. . .	0.20 max	. . .	0.05 max	0.15-0.45	0.15-0.45
Cobalt	. . .	. . .	. . .	0.20 max	. . .	. . .
Titanium	. . .	0.05 max	0.05 max	0.025 max	. . .	. . .
Copper	. . .	0.15 max	0.15 max	0.15 max	. . .	3.0-5.0
Tin	. . .	0.05 max	0.05 max	0.02 max	. . .	. . .

TABLE 3 Tensile, Impact, and Hardness Requirements

	Grade A		Grade B	Grade C		Grade D		Grade E		Grade F
	Class 1	Class 2	Class 1	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2	Class 1
Tensile strength, min, ksi	100	110	110	145	160	140	140	115	110	135
Yield strength, min, ksi, 0.2 % offset	70	80	90	115	120	90	100	75	80	105
Elongation in 2 in., min, %	20	18	18	15	16	13	13	15	18	16
Reduction of area, min, %	60	50	50	30	50	30	35	50	55	50
Impact strength, min, av., Cv, Rt, ft-lb	30	25	30	30	40	8	13	20	25	41
Hardness, Brinell, max	255	269	269	352	375	331	331	277	262	341

7.1.1.1 *Lot Size*—A lot shall consist of all forgings of the same size from one electric furnace heat of steel and heat treated either in the same charge in either a batch furnace or a continuous type furnace.

7.1.1.2 *Continuous Heat Treating Furnaces*—Test forgings shall be taken from each of the first and last push or tray to exit the furnace. Additional forgings shall be taken so that the maximum time between samples is 4 h.

7.1.1.3 *Test Locations*—One tension test specimen and one set of three impact test specimens shall be machined from the center portion of the air foil vane section.

7.1.2 *Forging Hardness Testing*:

7.1.2.1 *Batch Type Furnaces*—A minimum of 10 % of the forgings in each lot shall be hardness tested.

7.1.2.2 *Continuous Type Furnaces*—Samples for hardness testing shall be taken from every other tray or push.

8. Nondestructive Examination

8.1 *General Requirements*—All forgings shall be free of cracks, seams, laps, shrinkage, and similar discontinuities.

8.2 *Nondestructive Tests*—Nondestructive testing and corresponding acceptance criteria shall be as specified by the purchaser.

9. Certification and Reports

9.1 All tests required by this specification shall be made by the manufacturer and reported on a certificate of test to the purchaser. Each test certificate shall include the following items:

9.1.1 Purchase order number.

9.1.2 Forging identification number.

9.1.3 Specification number and yeardate of issue, grade, and class.

9.1.4 Heat number.

9.1.5 Lot number and size.

9.1.6 Mechanical properties including tension, impact, and hardness.

9.1.7 Hardness data tabulation for each forging tested.

9.1.8 Heat treating and stress relieving temperature and times.

9.1.9 Results of any specified supplementary requirements.

9.1.10 Statement that the forgings were manufactured, sampled, tested, and inspected in accordance with this specification and that the results satisfied the requirements.

10. Marking

10.1 The part number and a unique lot control designator, or heat number, shall be stenciled or legibly painted on each forging. Material shall be segregated according to drawing, heat, and lot numbers.

11. Keywords

11.1 compressor airfoils; stainless steel forgings; turbine airfoils

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, and order. Details of these supplementary requirements shall be agreed upon by the manufacturer and purchaser.

S1. Secondary Melting and Refining

S1.1 ESR or VAR is required. Use of either is permitted unless otherwise specified.

S2. Ingot Chemical Analysis

S2.1 If consumable electrode remelting is used, then chemical analyses of each remelted ingot shall meet the chemical composition requirements listed and shall be reported.

S3. Macrostructure

S3.1 Samples shall be taken from the top and bottom of the first and last ingot of each heat. The structure of the starting billets shall meet the criteria of Method E 381, S-3, R-2, C-3 $\leq$ 36 in.^{2} and S-3, R-3, C-3 > 36 in.^{2}

S4. Root Attachment Zone Mechanical Properties

S4.1 Testing for mechanical properties of the root attachment area is required. The type, number, location, and orientation of the tests shall be specified by the purchaser.

S5. Magnetic Particle Inspection

S5.1 Each forging shall be magnetic particle inspected in accordance with Test Method A 275. The maximum acceptable indication size shall be ⅛ in. unless otherwise specified by the purchaser.

S6. Ultrasonic Inspection

S6.1 Ultrasonic inspection is required. The test method, location, and acceptance criteria shall be as agreed upon by the purchaser and producer.

S7. Microstructure

S7.1 The microstructure shall be uniformly fine grain tempered martensite with no more than 1 % delta ferrite.

S7.2 Metallographic inspection shall be performed at 100x magnification to determine the metallurgical structure, grain size, decarburization, and delta ferrite content. Visual estimation for the volume fraction of delta ferrite of various representative areas of examination is acceptable. When the visual estimation method indicates the delta ferrite content is greater than the allowed limit, the manufacturer may employ Practice E 562 for determining the acceptability of a lot.

S7.3 A specimen shall be removed from the airfoil section on one test forging per heat treat lot. The plane of polish of the specimen shall be parallel to the axial centerline of the forging. The area examined shall include both the concave and convex vane surfaces.

S7.4 Surface decarburization of forgings shall not exceed 0.06 in.

S8 Hardness Testing

S8.1 One hardness test is required on the surface of the turbine rotor attachment portion on each forging. When specified by the purchaser, forgings shall be hardness tested for surface hardness on the air foil vane section.

S9. Minimum Hardness Requirements

S9.1 When agreed upon by the purchaser and producer, a minimum hardness value is required.

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 982/A 982M-01 that may impact the use of this standard.

(1) Added UNS Numbers to Table 2.

Designation: A 983/A 983M – 04

Standard Specification for Continuous Grain Flow Forged Carbon and Alloy Steel Crankshafts for Medium Speed Diesel Engines[1]

This standard is issued under the fixed designation A 983/A 983M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers continuous grain flow forged carbon and alloy steel crankshafts for medium speed diesel and natural gas engines.

1.2 The steel used in the manufacture of the forgings is required to be vacuum degassed.

1.3 Provision is made for treatment of designated surfaces of the crankshaft to provide enhanced fatigue strength, or wear resistance, or both.

1.4 The values stated in either inch-pound units or SI (metric) units are to be regarded separately as standards. Within the text and tables the SI units are shown in brackets. The values stated in each system are not exact equivalents, therefore each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.5 Unless the order specifies the applicable "M" specification designation, the material shall be furnished to the inch-pound units.

1.6 Except as specifically required in this specification, all provisions of Specification A 788 apply.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 503 Specification for Ultrasonic Examination of Forged Crankshafts

A 788 Specification for Steel Forgings, General Requirements

A 966/A 966M Test Method for Magnetic Particle Examination of Steel Forgings Using Alternate Current

A 986/A 986M Specification for Magnetic Particle Examination of Continuous Grain Flow Crankshaft Forgings

E 45 Practice for Determining the Inclusion Content of Steel

E 112 Test Methods for Determining Average Grain Size

E 340 Test Method for Macro Etching Metals and Alloys

2.2 *Other Standards:*

AWS D1.1 Structural Welding Code[3]

DIN 50 602[4]

JIS G 0555[5]

3. Ordering Information

3.1 In addition to the ordering requirements of Specification A 788, the following items should be included:

3.2 Whether surface hardening in designated areas is required, referencing Supplementary Requirements S10, S11, or S12, and providing the necessary instructions.

3.3 For crankshafts designed to include welded counterweights the purchaser may specify an alternate welding code to AWS D1.1 Structural Welding Code.

3.4 For alternate tensile and hardness test requirements specify Supplementary Requirement S2.

4. Materials and Manufacture

4.1 *Melting Practice*:

4.1.1 The steel making section of Specification A 788 shall apply together with mandatory vacuum degassing.

4.1.2 Supplementary Requirement S1 may be used if nonmetallic inclusion rating of the steel is required.

4.2 *Forging*:

4.2.1 The use of bar from starting stock produced by slitting a rectangular section is not permitted.

4.2.2 The procedure used in forging the crankshaft shall ensure that the centerline of the starting forged or rolled bar will follow the centerline contour of the main bearings, webs, and crankpins of the crankshaft.

4.2.3 The grain flow present between adjacent main bearing journals, webs, and the intervening crankpin shall be demonstrated for the first article testing of a new crankshaft design by

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved March 1, 2004. Published April 2004. Originally approved in 1998. Last previous edition approved in 2001 A 983/A 983M–01.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Welding Society, 550 NW Le Jeune Rd., Miami, FL 33126.

[4] Available from Verlag Stahleisen mbh, Postfach 8229, D-4000 Dusseldorf, Germany.

[5] Available from Japanese Standards Association, 1-24 Akasaka 4, Minato-Ku, Tokyo 107, Japan.

***A Summary of Changes section appears at the end of this standard.**

a given forging facility. This need not be repeated for other crankshafts of the same design that differ from the first article crankshaft by the number of crankpin throws or, by agreement with the purchaser, for V-Cylinder configurations of the same engine. The axial grain flow shown after etching a centerline longitudinal section of the *main bearing-web-crankpin-web-main bearing* section shall be approved by the purchaser. Etching shall be done in accordance with Test Method E 340. Using Supplementary Requirement S2, additional grain flow sections may be taken by agreement between the manufacturer and purchaser.

4.3 *Heat Treatment for Mechanical Properties*:

4.3.1 Heat treatment of crankshaft forgings may be done either before or after rough machining, at the manufacturer's option. By the use of Supplementary Requirement S3 the purchaser can specify that heat treatment be done after rough machining.

4.3.2 When counterweights are to be attached to the crankshaft by welding (see 4.3.4), then the heat treatment for mechanical properties shall follow after completion of the welding. Intermediate post weld heat treatment may be applied to the assembly at the manufacturer's option.

4.3.3 Heat treatment for mechanical properties shall consist of normalizing followed by tempering at a subcritical temperature, or austenitizing, liquid quenching and subcritical tempering. A normalizing cycle may precede the austenitizing stage.

4.3.4 If the crankshaft design includes attaching counterweights to the webs by welding, then the manufacturer shall qualify the weld procedure and welders in accordance with a written procedure acceptable to the purchaser. The procedure shall incorporate AWS specifications.

4.3.5 If forgings receive thermal stress relief after completion of heat treatment, then the stress relieving temperature shall not exceed a temperature of (T-50)°F, [(T-30)°C] where T is the tempering temperature. If this stress relieving temperature is exceeded, then the mechanical testing required in Section 6 shall be repeated.

4.3.6 If crankshaft counterweights are to welded to the webs, then the welding shall be done to a written, and qualified procedure conforming to AWS D1.1 Structural Welding Code or another similar welding code acceptable to the purchaser. This procedure shall contain instructions concerning repair of counterweight welds, including preheat and post weld heat treatment requirements.

5. Chemical Composition

5.1 *Heat Analysis*— The heat analysis obtained after sampling in accordance with Specification A 788 shall comply with Table 1 for the chosen grade, and the requirements agreed upon by Supplementary Requirement S4 if this was selected.

6. Mechanical Requirements

6.1 *Tension Testing*:

6.1.1 The heat treated forging shall comply with the requirements of Table 2 for the selected grade when tested in accordance with this section. See also Test Methods and Definitions A 370. It should be noted that when the SI system is specified the gage length for the tension test shall be measured over a length of 5D.

6.1.2 *Test Material*—An integral test prolongation equal in diameter to that of the starting bar diameter shall be provided at one end of each crankshaft subject to mechanical testing.

6.1.3 *Sampling*—The longitudinal axis of the axially oriented tension test specimen shall be located at the mid-radius position in the integral crankshaft test prolongation. Supplementary Requirement S5 provides for a tension test prolongation to be provided at both ends of the heat treated crankshaft, and Supplementary Requirement S6 provides for testing of each crankshaft in lieu of the test frequency specified in Supplementary Requirement S5.

6.1.4 *Orientation*—Longitudinal tension test specimens shall be taken from the crankshaft prolongation.

6.1.5 *Number of Tests*—Unless Supplementary Requirements S5 or S6, or both, are specified, one tension test specimen shall be tested to the requirements of Table 2, for the selected grade, at a frequency of one test per heat treatment load.

6.2 *Impact Testing*—If charpy impact testing of the crankshaft is required, Supplementary Requirement S7 shall be specified.

7. Grain Size

7.1 The grain size of the forging following heat treatment shall be ASTM 5 or finer when tested at the tension test location(s) in accordance with Test Methods E 112.

8. Surface Hardening

8.1 When required by the purchaser, and indicated in the crankshaft drawing, the crankshaft shall be surface hardened in designated areas for purposes of wear resistance, and when the bearing fillets are included, enhanced fatigue strength.

8.2 The method and extent of the surface hardening shall be specified by the purchaser by including reference to Supplementary Requirements S9 (nitriding), S10 (induction hardening of the bearing journals), or S11 (full induction hardening of bearing journals and fillets).

TABLE 1 Chemical Requirements Composition %

	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 7A	Grade 8	Grade 8A
Carbon	0.43-0.53	0.43-0.52	0.28-0.33	0.38-0.48	0.30-0.48	0.35-0.45	0.28-0.35	0.38–0.48	0.30-0.35	0.38–0.48
Manganese	0.60-1.10	0.75-1.10	0.40-1.00	0.75-1.10	0.65-1.00	0.65-1.00	0.40-1.00	0.40–1.00	0.40-0.80	0.40–0.80
Phosphorous	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max
Sulfur	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max
Silicon	0.15-0.40	0.15-0.40	0.15-0.040	0.15-0.40	0.15-0.40	0.15-0.40	0.15-0.40	0.15–0.40	0.15-0.40	0.15–0.40
Nickel	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	1.30-1.70	1.30–1.70
Chromium	. . .	0.20-0.35	0.80-1.20	0.80-1.20	0.80-1.20	0.80-1.20	2.8-3.3	2.8–3.3	1.00-1.40	1.00–1.40
Molybdenum	. . .	0.10 max	0.15-0.25	0.15-0.25	0.15-0.25	0.30-0.50	0.30-0.50	0.30–0.50	0.20-0.35	0.20–0.35
Vanadium	0.10 max	0.10 max	0.10 max	0.10 max	0.10 max	0.10 max	0.10 max	0.10 max	0.15 max	0.15 max

TABLE 2 Tensile and Hardness Requirements

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
Tensile Strength, ksi [Mpa] min	80 [550]	100 [690]	110 [760]	120 [830]	130 [900]	140 [965]	150 [1035]
Yield Strength, (0.2% offset), ksi [Mpa] min.	45 [310]	70 [485]	80 [550]	90 [620]	100 [690]	110 [760]	120 [830]
Elongation, min % in 2 in. (4D) [% in 62.5mm] (5D)	20 [18]	18 [16]	18 [16]	17 [15]	16 [14]	15 [13]	14 [12]
Reduction of Area, % min	45	45	45	45	40	40	40
Brinell Hardness, min	163	207	229	248	262	285	302
Brinell Hardness, max	217	255	269	293	302	331	341

9. Nondestructive Examination

9.1 Because ac magnetizing equipment is required to be used, the magnetic particle examination of the crankshaft shall be done on completion of all machining operations. The examination shall be in accordance with Specification A 966/A 966M.

9.1.1 Acceptance criteria for the magnetic particle examination shall be in accordance with Specification A 986/A 986M.

9.2 Supplementary Requirement S8 shall be specified if ultrasonic examination of the crankshaft bar, or the crankshaft forging is required.

10. Workmanship

10.1 In addition to the specific order or drawing requirements for surface finish, the general appearance with respect to soundness and finish shall be consistent with good crankshaft practice, as determined by ordinary visual inspection.

11. Certification

11.1 When certification of a crankshaft includes inspection by a classification agency, the manufacturer shall be notified of this provision, so that arrangements can be made to allow for witnessing of such manufacturing and testing operations as needed.

12. Delivery

12.1 In addition to the requirements of Specification A 788, the purchaser shall notify the producer on any special corrosion protection and packing instructions. Supplementary Requirement S12 may be used to call for specific packing instructions, otherwise the producer's normal product protection practices shall apply.

13. Keywords

13.1 crankshafts, continuous grain flow; medium speed diesel engines; steel forgings; surface hardening

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry or order. Details of these supplementary requirements shall be agreed upon by the manufacturer and the purchaser.

S1. Nonmetallic Inclusion Rating

S1.1 The nonmetallic inclusion rating for steel bars or billets to be used for making CGF crankshafts shall be done in accordance with an agreed upon practice, or one of the following standards: Practice E 45—Method D, DIN 50 602, or JIS G 0555.

S1.2 The acceptance criteria for the nonmetallic inclusion rating shall be specified by the purchaser.

S2. Alternate Tensile and Hardness Requirements

S2.1 The purchaser shall specify alternate tensile strength and hardness requirements to those specified in Table 2.

S2.2 The alternate tensile strength values shall be interpolated from the values given in Table 2. For strength levels higher than Class 7 in Table 2 the requirements shall be agreed between the purchaser and the manufacturer.

S2.3 The alternate hardness values shall be interpolated from the values given in Table 2, but shall be in increments of 0.05 mm.

S3. Machining Before Heat Treatment

S3.1 Forgings shall be rough machined to agreed upon dimensions prior to heat treatment. for mechanical properties

S4. Additional Chemical Elements

S4.1 In addition to the elements specified in Table 1 for a specific grade, additional elements shall be added to the steel within, ranges agreed upon between manufacturer and producer.

S4.2 The chemical analysis of the modified grade shall be reported as required by the certification section.

S5. Mechanical Testing

S5.1 For each crankshaft, tension testing at the prolongation mid radius position shall be done at both ends of the crankshaft. A heat treatment weight, excluding test prolongations, in excess of 6000 lb [3000 kg] may be specified by the purchaser as the point at which testing both ends of the crankshaft is required.

S5.2 The maximum difference in ultimate tensile strength between tests taken at opposite ends of the crankshaft shall be specified by the purchaser.

S6. Test Frequency

S6.1 Instead of the tension testing frequency specified in 6.1.5, each crankshaft shall be tested from an integral prolongation.

S7. Charpy Impact Testing

S7.1 From each crankshaft test prolongation used for tension testing, one set of three longitudinal charpy V-notch specimens shall be taken at the mid radius position, for testing at room temperature. The notch shall be oriented at right angles to the surface of the prolongation, that is, radially. The absorbed energy requirements shall be specified by the purchaser.

S8. Ultrasonic Examination

S8.1 Ultrasonic examination of the starting crankshaft bar, or the forged and heat treated crankshaft, or both, shall be done according to the requirements in Specification A 503 for continuous grain flow crankshafts. In the event that the purchaser does not state in the inquiry or order that ultrasonic examination of the starting bar is required, then only the heat treated crankshaft shall be examined.

S8.2 The acceptance criteria for the ultrasonic examination(s) shall be specified by the purchaser.

S9. Surface Nitriding

S9.1 The surfaces designated in the crankshaft drawing shall be nitrided. Significant details such as the surface hardness, disposition of white layer, case depth, and limitations on localized imperfection removal shall be as agreed upon between the manufacturer and purchaser.

S9.2 Magnetic particle examination of the crankshaft shall follow final grinding or polishing and agreed upon white layer removal.

S9.3 Special identification marking, as instructed by the purchaser, shall be included with the crankshaft marking requirements specified in the drawing or order.

S10. Induction Hardening

S10.1 The crankshaft crankpin and main bearing journal surfaces shall be induction hardened as specified in the crankshaft drawing. The depth of hardening, hardness requirements, and location limits for the hardened zones shall be as specified in the drawing or in written instructions from the purchaser. Unless otherwise specified the producer may temper the crankshaft on completion of hardening to obtain the required hardness.

S10.2 The hardening pattern and the hardness profile through the hardened case shall be established by sectioning test pieces representative of the crankpin and main bearing journals. The material, contour, and diameter of these test pieces shall closely approximate those of the crankshaft so that it can be shown that the hardening process can meet the drawing requirements, including the extent of hardening at the oil holes.

S10.3 Final magnetic particle examination of the crankshaft shall follow finish grinding and polishing of the crankshaft.

S10.4 If required by the purchaser the marking requirements for the crankshaft shall be augmented to denote that the crankshaft has been induction hardened on the bearing surfaces.

S11. Fully Induction Hardened Crankshafts

S11.1 Full induction hardening of a crankshaft indicates that all designated surfaces including bearing fillets have been hardened. The designated surfaces shall be as shown in the crankshaft drawing. The required surface hardness and depth of hardening shall be as described in the crankshaft drawing or as agreed to between purchaser and producer.

S11.2 The producer shall establish that the required hardness pattern on the crankpin and main bearing journals, and at the oil holes, together with the necessary fillet hardening can be achieved by means of representative test sections that replicate the material, major dimensions, excess stock, and surface finish of the crankshaft at the time of hardening.

S11.3 Magnetic particle examination of the crankshaft shall follow final grinding and polishing of the crankshaft.

S11.4 Marking of the crankshaft may be specified by the purchaser to indicate that the crankshaft has been fully induction hardened.

S12. Special Packaging

S12.1 When specified by the purchaser special packaging shall be done to help preclude corrosion or mechanical damage during shipping and storage.

S13. Additional Macro Examination

S13.1 Additional grain flow macro sections or sections from other forged shapes in the crankshaft shall be taken as agreed upon between manufacturer and purchaser.

S14. Near Surface Nonmetallic Inclusion Rating

S14.1 Heat qualification based on nonmetallic inclusion rating in accordance with Specification E 45, shall be established by sampling according to the following plan, depending on the steel teeming system.

S14.2 For top poured ingots samples representing the top and bottom of the first, middle and last ingots of the heat shall be used.

S14.3 For bottom poured ingots, samples representing the top and bottom of one ingot from the first plate poured, and samples representing the top and bottom of two ingots from each additional plate shall be examined.

S14.4 For steel bars produced from hot worked continuously cast steel billets or blooms the bars shall be sampled from product representing each strand from the start of the heat and from each 10 tons [9t] thereafter.

S14.5 The samples for inclusion rating shall be located ½ in. [12mm] from the bar surface and oriented parallel to the major direction of working.

S14.6 Acceptance shall be based on the following inclusion ratings:

Type	Rating Units Thin Series	Heavy Series
A	1.5	1.5
B	1.5	1.5
C	1.5	1.5
D	1.5	1.5

S14.6.1 For alternate inclusion rating systems the acceptance criteria shall be specified by the purchaser.

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 983/A 983M-01 that may impact the use of this standard.

(1) New supplementary requirement S14 was added.

Designation: A 986/A 986M – 01

Standard Specification for Magnetic Particle Examination of Continuous Grain Flow Crankshaft Forgings[1]

This standard is issued under the fixed designation A 986/A 986M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers the magnetic particle examination of forged continuous grain flow (CGF) crankshafts intended for medium speed diesel engines.

1.2 For the purpose of magnetic particle indication assessment, the crankshaft is divided into four zones of decreasing operational stress. Acceptance criteria have been set for each zone.

1.3 The engines to which these crankshafts are fitted are commonly used for diesel electric locomotives, marine propulsion, and power generation. Engines fueled by natural gas also fall into this medium speed category.

1.4 Specification A 983/A 983M is a product specification that covers the manufacture of CGF crankshafts.

1.5 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 *ASTM Standards:*

A 456/A 456M Specification for Magnetic Particle Examination of Large Crankshaft Forgings[2]

A 788 Specification for Steel Forgings, General Requirements[2]

A 966/A 966M Test Method for Magnetic Particle Examination of Steel Forgings Using Alternating Current[2]

A 983/A 983M Specification for Continuous Grain Flow Forged Carbon and Alloy Steel Crankshafts for Medium Speed Diesel Engines[2]

3. Ordering Information

3.1 Specification A 983/A 983M requires that crankshafts made to that specification be examined in accordance with Specification A 986/A 986M for magnetic particle examination. It is the responsibility of the purchaser to specify any changes to the zone allocations for the crankshaft surfaces.

4. Procedure

4.1 Magnetic particle examination shall be conducted in accordance with Test Method A 966/A 966M. The use of prod type contacts is not permitted on finished crankshaft surfaces. Magnetic leeches may be used only on flat noncritical surfaces, and within the limitations specified in Test Method A 966/A 966M.

4.2 The magnetic particle examination shall be conducted using the wet fluorescent method described in Test Method A 966/A 966M.

5. Areas of Examination

5.1 *Zone 1—Major Critical Areas*:

5.1.1 *Crankpin Journals*—The major critical area of each crankpin journal shall include that area ±60 from the 6 o'clock position of the crankpin and extend ⅜ in. [10 mm] above the fillet collar and ⅝ in. [15 mm] along the crankpin surface as measured from the blend of the fillet radius and the journal surface. These positions are shown in Fig. 1.

5.1.2 *Main Bearing Journals*—The major critical areas of any main bearing journal shall include that area ±60 from the 12 o'clock position on top of the journal and extend ⅜ in. [10 mm] above the fillet collar and ⅝ in. [15 mm] along the journal as measured from the blend of the fillet radius and the journal surface. These positions are shown in Fig. 1.

5.1.3 *Oil Holes*—The major critical areas in also shall include the surfaces surrounding the journal oil holes. The diameter of this critical area shall be 3d, where d is the oil hole diameter before the radius. The critical area shall be centered on the centerline of the oil hole. In addition, the Zone 1 critical area shall extend down the oil hole for a distance from the journal surface equal to the hole diameter.

5.2 *Zone 2—Minor Critical Areas*:

5.2.1 The Zone 2 minor critical areas shall include the balance of the fillet radii of the crankpin and main bearing journals not included in the major critical areas.

5.2.2 When counterweights are attached to the crankshaft webs by welding, the weld surfaces and ½ in. [13 mm] of the adjacent surfaces shall be considered minor critical areas.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] *Annual Book of ASTM Standards*, Vol 01.05.

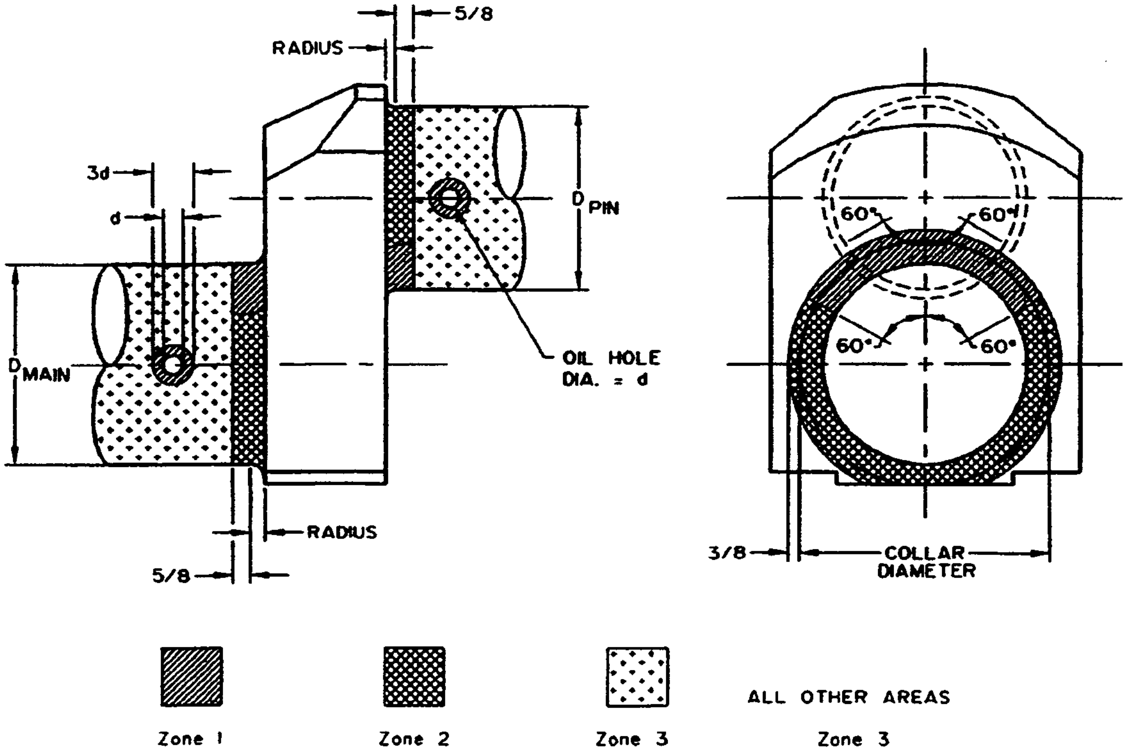

FIG. 1

5.3 *Zone 3—Journal Running Surfaces*:

5.3.1 Zone 3 includes the remainder of the crankpin and main bearing journal surfaces not covered by the major and minor critical areas.

5.3.2 Zone 3 also includes the bearing journal surfaces for auxiliary drives, gear fit surfaces, keyways, and coupling flange radii.

5.4 *Zone 4—All Other Areas*:

5.4.1 Zone 4 includes the crankpin web surfaces, excluding areas covered by the major and minor critical areas, flange faces and periphery, and any other surfaces not included in Zones 1, 2, or 3.

6. Classification of Indications

6.1 Surface magnetic particle indications shall be classified as open or non-open.

6.1.1 Open indications are defined as those being visible after removal of the magnetic particles under a minimum 5 times optical magnification.

6.1.2 Non-open indications are not visible after removal of the magnetic particles.

7. Acceptance Criteria

7.1 *Zone 1*:

7.1.1 Indications are not permitted and must be removed by grinding or polishing. The original shape of the fillet must be maintained, when indications have been removed. The blended area shall not be deeper than 0.006 in. [0.15 mm] below the minimum drawing fillet dimension for the location.

7.1.2 The total area blended at less than the relevant minimum dimension shall not exceed 5 % of the major critical area of the particular crankpin or main bearing fillet or designated surface at an oil hole.

7.2 *Zone 2*:

7.2.1 Open indications are not permitted and must be removed. The depth of the resulting depression shall not exceed 0.010 in. [0.25 mm] below the minimum fillet dimension for the location. The total area of depressions or dimples in a Zone 2 fillet shall not exceed 5 % of the Zone 2 fillet area.

7.2.2 Non-open indications are permitted up to a maximum length of 2 % of D, where D is the diameter of the journal in question. The maximum total length of non-open indications in a Zone 2 fillet location shall not exceed 0.75 in. [20.0 mm], and the individual indications must be separated from each other by a minimum length of 2 % of D.

7.2.3 Non-open indications exceeding the length limitations of 7.2.2, either individually or in total, may be dimpled to a maximum depth of 0.010 in. [0.25 mm] below the minimum drawing dimension, but the aggregate length and area limitations of 7.2.1 and 7.2.2 shall apply.

7.2.4 The combined dimple areas in any main or crankpin journal fillet shall not exceed 8 % of the total fillet area.

7.2.5 For welds attaching counterweights to crankshaft webs, the following acceptance criteria apply.

7.2.5.1 The surfaces to be examined shall be prepared to give a surface finish of at least 250 µin. [6.35 µm]

7.2.5.2 Linear indications shall not exceed 1⁄32 in. [1 mm] in length in the weld areas of the counterweight sides (posts). Indications exceeding this size shall be ground to a maximum depth of 1⁄8 in. [3 mm] below the minimum weld dimension and reexamined. If the indication has been removed, or reduced to an acceptable length, the resulting dimple shall be blended to transition smoothly with the surrounding surface. If the indication is still unacceptable in length, it shall be removed completely and the area restored by welding in accordance with the qualified welding procedure.

7.2.5.3 The end faces and corners of the counterweight welds, and 1 in. [25 mm] along each side extending from the corners shall exhibit no indications. Any indications shall be removed by grinding, and the resulting dimple shall not exceed 3⁄16 in. [5 mm] in depth below the minimum weld dimension, and ½ in. [13 mm] in length. If the dimple extends beyond these dimensions, the area shall be repair welded in accordance with the qualified procedure. If more than ¼ in. [6 mm] of stock is removed from any weld corner, the area shall be restored by repair welding, again in accordance with the qualified procedure.

7.3 *Zone 3*:

7.3.1 Open indications not exceeding 0.20 in. [5.0 mm] in length individually in any one Zone 3 location, provided that the total length does not exceed 0.50 in. [13.0 mm] in any 1 in.^{2} [650 mm ^{2}] of surface area.

7.3.2 Open indications in excess of 0.20 in. [5.0 mm] in length may be removed by dimpling to a maximum depth of 0.010 in. [0.25 mm] below the minimum drawing dimension for the location. The area of the resulting dimples shall not exceed 3 % of the Zone 3 location area.

7.3.3 Non-open indications exceeding 0.20 in. [5.0 mm] in length are considered to be relevant. Relevant indications exceeding the greater of 0.5 in. [13.0 mm] or 6% of D, where D is the diameter of the journal in question, are unacceptable, but may be reduced to an acceptable length by dimpling to a depth not to exceed 0.010 in. [0.25 mm]. The total length of relevant non-open indications in any one Zone 3 location shall not exceed 2.0 in. [50 mm].

7.4 *Zone 4*:

7.4.1 Open indications exceeding 0.25 in. [6.0 mm] are considered to be relevant, and the total length of such indications in any one Zone 4 location shall not exceed 1.0 in. [25 mm]. Open indications, regardless of length, separated by less than ⅛ in. [3 mm] shall be considered to be a single indication.

7.4.2 Dimpling of relevant open indications may be done to meet the requirements of 7.4.1 up to a maximum depth of 0.25 in. [5.0 mm].

7.4.3 Non-open indications not exceeding 1.0 in. [25.0 mm] in length are acceptable, provided that the total length of indications exceeding 0.25 in. [6.0 mm] does not exceed 4.0 in. [100.0 mm] in any 25 in. ^{2}[16 000 mm^2] area.

7.4.4 Dimpling of non open indications to a maximum depth of 0.40 in. [10.0 mm] in a particular Zone 4 location may be done to bring the length limitation requirements into compliance with 7.4.3.

8. Dimpling

8.1 To dimple means to stone or grind to remove stock in an area that contains an unacceptable indication. In order to minimize stress concentrations, all dimples shall have a bottom radius of approximately three times the dimple depth, and shall be smoothly blended to the surface area. The finish in the dimple shall be at least equal to that of the adjacent surface.

8.2 When making a dimple in a surface to remove a visual or magnetic particle indication, care must be taken to avoid the unnecessary reduction in bearing surface on a bearing journal. When a crankshaft has been surface hardened by nitriding or induction hardening, caution must be exercised to avoid excessive penetration into the case, particularly in the critical areas.

9. Inspection

9.1 The requirements of Specification A 788 shall apply.

10. Rejection

10.1 The requirements of Specification A 788 shall apply.

11. Certification

11.1 The requirements of Specification A 788 shall apply.

Designation: A 1021 – 02

Standard Specification for Martensitic Stainless Steel Forgings and Forging Stock for High-Temperature Service[1]

This standard is issued under the fixed designation A 1021; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers martensitic chromium stainless steel forgings, forged bar, and forging stock for high temperature service. The mechanical properties are developed by suitable heat treatment, as indicated for each alloy.

1.2 The values stated in inch-pound units are to be regarded as standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275 Test Method for Magnetic Particle Examination of Steel Forgings[2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

A 788 Specification for Steel Forgings, General Requirements[2]

E 112 Test Methods for Determining Average Grain Size[4]

E 292 Test Methods for Conducting Time-For-Rupture Notch Tension Tests of Materials[4]

E 381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings[4]

E 562 Test Method for Determining Volume Fraction by Systematic Manual Point Count[4]

3. Ordering Information

3.1 In addition to the ordering information required by Specification A 788, the purchaser shall specify the grade designation, heat treatment condition, class and finish, and include a sketch or written description of the forging with the inquiry and order.

4. General Requirements

4.1 Materials supplied to this specification shall conform to the requirements of Specification A 788, including any supplementary requirements that are indicated in the purchase order. Failure to comply with the general requirements of Specification A 788 constitutes non-conformance with this specification. In case of conflict between the requirements of this specification and Specification A 788, this specification shall prevail.

5. Manufacture

5.1 *Melting Process*—All melting processes of Specification A 788 are permitted unless the purchaser invokes Supplementary Requirement S1.

5.2 *Forging Process*—Either the closed impression die or the open die, including ring rolling, forging processes may be utilized unless the purchaser specifies a process.

5.3 *Heat Treatment*—Quenched and tempered classes shall be heat-treated in accordance with Table 1.

5.3.1 *Number of Heat Treatments*—Heat treatment as defined in Table 1 shall consist of austenitizing, quenching, and tempering. Retempering is permitted but purchaser approval is required for more than one complete reheat treatment.

5.4 *Stress Relief*—When heat treatment for mechanical properties is followed by straightening, a stress-relieving heat treatment is required in accordance with Table 1.

5.4.1 *Quenching after Stress Relief*—Liquid quenching of stress-relieved forgings is prohibited.

5.5 *Finish*—Forgings may be furnished in one of the following hot-finished conditions:

5.5.1 *Finish F*—As forged without descaling.

5.5.2 *Finish FD*—Forged and descaled.

5.5.3 *Finish RT*—Rough turned or rough machined to specified dimensions. Billets or blooms ordered as forging stock shall be furnished with a ground, machined, or descaled surface unless otherwise specified in the ordering document.

5.6 *Camber*—Camber shall not exceed ¼ in. (5 mm) in 5 ft (150 cm).

6. Chemical Composition

6.1 The steel shall conform to the requirements for chemical composition prescribed in Table 2.

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[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

Current edition approved Sept. 10, 2002. Published June 2003.

[2] *Annual Book of ASTM Standards*, Vol 01.05.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

***A Summary of Changes section appears at the end of this standard.**

TABLE 1 Heat Treatment, °F (°C)

	Grade A	Grade B	Grade C		Grade D	Grade E	
	Class 1 & 2	Class 1	Class 1	Class 2	Class 1 & 2	Class 1	Class 2
Austenitizing	1725-1775 (940-970)	1600-1750 (870-955)	1825-1875 (995-1025)	1725-1875 (940-1025)	1875-1925 (1025-1050)	2075-2125 (1135-1165)	1725-1775 (940-970)
Quenching	Air or liquid	Air or liquid	Air or liquid	Air or liquid	Air or liquid	Air or liquid	Air or liquid
Single Tempering	1050 min (565 min)	1050 min (565 min)	1050 min (565 min)	1050 min (565 min)	1150 min (620 min)	1250 min (675 min)	1100 min (595 min)
Double Tempering	. . .	. . .	1025 min (550 min)	1025 min (550 min)	. . .	. . .	. . .
Stress Relieving	1025 min (550 min)	1025 min (550 min)	1000 min (540 min)	1000 min (540 min)	1100 min (595 min)	1200 min (650 min)	1050 min (565 min)

TABLE 2 Chemical Requirements[A]

	Composition %				
	Grade A	Grade B	Grade C	Grade D	Grade E
UNS Designation		S41005	S41428	S42225	
Type—Similar to	403/410 SS UNS S41000	403/410 SS MOD.	XM-32 Mod	422 SS	UNS S41041
Carbon	0.15	0.10-0.15	0.10-0.17	0.20.-0.25	0.13-0.18
Manganese	1.00	0.25-0.80	0.65-1.05	0.50-1.00	0.40-0.60
Phosphorus	0.018	0.018	0.020	0.025	0.030
Sulfur	0.015	0.015	0.015	0.010	0.030
Silicon	1.00	0.50	0.35	0.50	0.50
Nickel	0.75	0.75	2.25-3.25	0.50-1.00	0.50
Chromium	11.5-13.5	11.5-13.0	11.25-12.75	11.0-12.5	11.5-13.0
Molybdenum	0.50	0.50	1.50-2.00	0.90-1.25	0.20
Vanadium	. . .	Report only	0.25-0.40	0.20-0.30	. . .
Tungsten	. . .	0.10	0.10	0.9-1.25	. . .
Nitrogen	. . .	0.08	0.020-0.045	Report only	. . .
Aluminum	. . .	0.025	0.025	0.025	0.050
Columbium	. . .	0.20	. . .	. . .	0.15-0.45
Cobalt	. . .	. . .	. . .	0.20	. . .
Titanium	. . .	0.05	0.05	0.025	. . .
Copper	. . .	0.50	0.50	0.50	. . .
Tin	. . .	0.05	0.05	0.02	. . .

[A] Maximum or range unless otherwise specified.

7. Mechanical Properties

7.1 *Tension, Impact and Hardness Tests*—All testing shall be performed after heat treatment and stress relief, as applicable. The material and test specimens shall meet the requirements of Table 3 if fully heat-treated or Table 4 if annealed. Mechanical property requirements, including hardness, do not apply to forging stock when it is to be tested after forging and heat treatment.

TABLE 4 Mechanical Properties—Annealed Classes

	Grade A Class 3	Grade B Class 2	Grade C Class 3	Grade D Class 3	Grade E Class 3
Hardness, Brinell, max	248	248	311	248	248
Hardness, Rockwell C, max	24	24	33	24	24

7.2 *Test Specimens*—Forgings may be lot tested. Test specimens may be obtained from production forgings or from

TABLE 3 Mechanical Properties—Quenched & Tempered Classes

	Grade A		Grade B	Grade C		Grade D		Grade E	
	Class 1	Class 2	Class 1	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2
Tensile strength, KSI min (MPa)	100 (690)	110 (760)	110 (760)	145 (1000)	160 (1105)	140 (965)	140 (965)	115 (795)	110 (760)
Yield Strength min, KSI (MPa), 0.2 % Offset	70 (485)	80 (550)	90 (620)	115 (795)	120 (825)	90 (620)	100 (690)	75 (515)	80 (550)
Elongation in 2 in., min %	20	18	18	15	16	13	13	15	18
Reduction of area, min, %	60	50	50	30	50	30	35	50	55
Impact Strength, min, avg., CV, RT, ft-lb (J)	30 (41)	25 (34)	30 (41)	30 (41)	40 (54)	8 (11)	13 (18)	20 (27)	25 (34)
Impact Strength, min of one specimen per Test Methods A 370, CV, RT, ft-lb (J)	20 (27)	17 (23)	20 (27)	20 (27)	27 (36)	5 (7)	9 (12)	13 (18)	17 (23)
Hardness, Brinell, max	255	269	269	352	375	331	331	277	262
Hardness, Rockwell C, max	26	28	28	38	40	36	36	29	27

separately forged test blanks prepared from the stock used to make the finished part. Forgings that are lot tested shall be produced from the same heat of steel and heat treated at the same time. Separately forged test blanks shall receive essentially the same type of hot-working and forging reduction as the production forgings; however, a longitudinally forged bar with dimensions not less than *T* by *T* by 3 *T* may be used to represent a ring forging. The dimension *T* shall be representative of the heaviest effective cross section of the forging.

7.3 *Test Specimen Orientation*—Mechanical property requirements are for samples oriented in the direction of grain flow. Unless otherwise specified in the purchase order, manufacturers may orient the samples in any direction provided the mechanical property requirements are met.

7.4 *Test Specimen Location*—When transverse or circumferential specimens are tested, they shall be taken from as close as possible to a mid-radius or mid-wall location of the forging. When longitudinal specimens are tested, they shall be taken from extensions. Extending the axial length of a larger section of a forging for a sufficient distance over a smaller section is also an acceptable location for transverse or circumferential specimens.

7.5 *Number Of Tests*—Where more than one location is designated on a forging drawing, tension tests shall be made from each location.

7.6 *Hardness*—The manufacturer shall perform Brinell or Rockwell hardness testing after final heat treatment and after machining to the forging drawing requirements.

8. Keywords

8.1 martensitic stainless steel; stainless steel billets; stainless steel forgings

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the contract or order.

S1. Secondary Melting and Refining

S1.1 ESR or VAR is required. Use of either is permitted unless otherwise specified.

S2. Ingot Chemical Analysis

S2.1 If consumable electrode remelting is used, then chemical analyses of each remelted ingot shall meet the chemical composition requirements listed and shall be reported.

S3. Macrostructure

S3.1 Samples shall be taken from the top and bottom of the first and last ingot of each heat. The structure of the starting billets shall meet the criteria of Method E 381, S-3, R-2, C-3 ≤ 36 in.^{2} (0.84 m^2) and S-3, R-3, C-3 > 36 in.^{2} (0.84 m^2).

S4. Magnetic Particle Inspection

S4.1 Each forging shall be magnetic particle inspected in accordance with Test Method A 275. The maximum acceptable indication size shall be ⅛ in. (3 mm) unless otherwise specified by the purchaser.

S5. Ultrasonic Inspection

S5.1 Ultrasonic inspection is required. The test method, location, and acceptance criteria shall be as agreed upon by the purchaser and producer.

S6. Microstructure

S6.1 The microstructure shall be tempered martensite with no more than 2 % delta ferrite.

S6.2 Metallographic inspection shall be performed at 100× magnification to determine the metallurgical structure, grain size, and delta ferrite content. Visual examination for the volume fraction of delta ferrite of various representative areas of examination is acceptable. When the visual estimation method indicates the delta ferrite content is greater than the allowed limit, the manufacturer may employ Test Method E 562 for determining the acceptability of the lot.

S7. Stress Rupture Testing—Grade D

S7.1 Stress rupture testing shall be conducted at 1200°F and 26 000 psi using a combination test bar in accordance with Test Methods E 292. Rupture must occur in the smooth section of each test specimen. The test may be discontinued after 25 h provided the certification so notes. Stress rupture testing is not required on bars less than ½ in. in diameter or thickness.

S8. Grain Size—Grade D

S8.1 The average grain size shall be 4 or finer. The maximum size of individual grains, distributed at random, shall be a 2. When the average grain size is 5 or finer, only the average size need be reported. Grain size determination shall be performed in accordance with Test Method E 112.

S9. Mechanical Properties

S9.1 Test samples shall be taken from an integral part of each forging whose drawing weight is over 500 lb (227 kg).

S10. Forging Temperature

S10.1 The maximum part temperature during forging is 2150°F (1175°C).

S11. Decarburization

S11.1 Surface decarburization of forgings shall not exceed 0.06 in. (1.5 mm).

S12. Forging Stock

S12.1 Forging stock shall be supplied in the annealed condition meeting the requirements of Table 4.

S13. Stress Relief

S13.1 Material shall be stress relieved in accordance with the requirements of Table 1.

SUMMARY OF CHANGES

Committee A01 has identified the location of the following changes to this standard since A 1021/A 1021M-01 that may impact the use of this standard.

(1) Added UNS Numbers to Table 2.

Designation: E 588 – 03

Standard Practice for Detection of Large Inclusions in Bearing Quality Steel by the Ultrasonic Method[1]

This standard is issued under the fixed designation E 588; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This practice covers a procedure for the rating of rectangular steel sections by immersion ultrasonic techniques. Its purpose is to provide information on the content of large inclusions or clusters of small inclusions for determining the suitability of a steel lot for bearing applications. This practice in no manner defines or establishes limits of acceptability.

1.2 For this document, large inclusions are defined in ultrasonic terms as those having a reflecting area equivalent to or larger than a 1⁄64-in. diameter flat-bottom hole in a steel reference block of similar properties and thickness. In metallographic terms, large inclusions, defined in this way, are of approximately the same size as the smallest detectable sizes revealed by the macroscopic methods of Practice E 45. In some cases, inclusions smaller than those described previously can be detected either individually or in clusters, depending on their type, chemical composition, orientation to the ultrasonic beam and distance from the sound entry surface of the specimen.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 45 Test Methods for Determining the Inclusion Content of Steel[2]

E 214 Practice for Immersed Ultrasonic Examination by the Reflection Method Using Pulsed Longitudinal Waves[3]

E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Examination[3]

E 543 Practice for Agencies Performing Nondestructive Testing[3]

E 1316 Terminology for Nondestructive Examinations[3]

2.2 *ASNT Documents:*

SNT-TC-1A Recommended Practicefor Personnel Qualification and Certification in Nondestructive Testing[4]

ASNT-CP-189 STandard for Qualification and Certification of Nondestructive Testing Personnel[4]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, see Terminology E 1316.

4. Basis of Application

4.1 *Agreements Between Using Parties*—In order for this practice to be effectively used, the following items require agreement between the using parties.

4.1.1 *Evaluation of Nondestructive Testing Agencies*—An agreement is required as to whether the nondestructive testing agency, as defined in Practice E 543, must be formally evaluated and qualified to perform the examination. If such an evaluation is specified, a documented procedure such as Practice E 543 shall be used as the basis for evaluation.

4.1.2 *Personnel Qualification*—Nondestructive testing (NDT) personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ASNT CP-189, SNT-TC-1A, or a similar document. The practice or standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

4.1.3 *Search Unit Performance Tests*—Annex A1 defines the minimum manufacturer's specifications for search units to be used with this practice. The extent of testing and verification of these parameters to be performed by the manufacturer shall be specified in the contractual agreement between the using parties.

5. Summary of Practice

5.1 The general technique used is immersion ultrasonic testing by the reflection method using pulsed longitudinal waves such as described in Practice E 214. Specific additional requirements for sample preparation, equipment operating parameters and calibration, and expression of results are

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[1] This practice is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.28 on Bearing Steels.

Current edition approved April 10, 2003. Published July 2003. Originally approved in 1976. Last previous edition approved in 1995 as E 588 – 95.

[2] *Annual Book of ASTM Standards*, Vol 03.01.

[3] *Annual Book of ASTM Standards*, Vol 03.03.

[4] Available from the American Society for Nondestructive Testing, 1711 Arlingate Plaza, P.O. Box 28518, Columbus, OH 43228-0518.

***A Summary of Changes section appears at the end of this standard.**

delineated in this procedure. Special focused search units having operating characteristics as defined in Annex A1 are required.

6. Significance and Use

6.1 *Comparison with Other Inclusion Rating Methods*—Because the test is performed on a volumetric rather than a surface-examination basis, the ultrasonic method is inherently better able to detect infrequently occurring large inclusions or clusters of small inclusions than eddy current, magnetic particle, microscopical, or macroscopic examination procedures.

6.2 *Limitation of Inclusion Size and Type*—A limitation of the method is that it will not detect all inclusions. Inclusion chemistry, size, shape, location, and distribution may limit the ability of the method to provide indications distinct from those generated by the surrounding metallurgical structure. The recommended practice is only meaningfully applicable to examination of steel wherein the inclusion size and type are within the detection capabilities of the method. For steel wherein inclusion size, dispersion, and chemistry prevent optimum inclusion detection by ultrasonics, microscopical methods detailed in Practice E 45 may be applied.

7. Interference

7.1 *Reflections from Multiple Inclusions*—An ultrasonic indication can represent the reflection from a single inclusion; however, it typically represents the vector summation of reflections from clusters of small inclusions contained within a volume of a few cubic millimetres.

7.2 *Response as a Function of Inclusion Type*—The individual inclusion reflections can have different amplitudes because of different inclusion characteristics. In addition, the individual reflections may have different phase characteristics when arriving at the search unit if the travel distances are different.

8. Apparatus

8.1 *Equipment Required*—An equipment system with the following components is needed to conduct this test: ultrasonic test instrument, search unit, a means of recording signals of various amplitudes, a system reference block, instrument calibration block, and an immersion tank with suitable scanning accessories.

8.2 *Ultrasonic Instrument*—The ultrasonic instrument shall be capable of generating and receiving electrical pulses of 10-MHz frequency at levels compatible with the test requirements. It shall have both an A-scan presentation and an analog or digital output. It shall be the ultrasonic instrument manufacturer's responsibility that instruments supplied for use with this test meet the minimum requirements delineated in this recommended practice.

8.2.1 *Receiver Characteristics*—The center frequency shall be 10 ± 0.5 MHz. The bandpass of the receiver shall be at least 1.3 MHz (3 dB points).

8.2.2 *Dynamic Range*—The dynamic range of the instrument shall permit detection of steel balls with a 16-to-1 diameter ratio at a given sensitivity. Balls shall be placed in water at the focal point of the search unit. Each size ball within this range shall give a significantly different amplitude of indication.

8.2.3 *Stability*—The signal amplitude of a usable full-scale indication shall not vary more than 5 % after 1 h of instrument warm-up, and preferably by less than 2 % (4-h test with air temperature being held to ±1.2°C over a temperature range of 17.5 to 25.5°C).

8.2.4 *Sweep Length and Linearity*—Sweep length of oscilloscope presentation shall be capable of being adjusted to represent 1 mm = 1.27 mm of steel. A minimum of 80 mm of the sweep display shall be linear to within 5 % of full scale. The signal amplitude of an indication from a target shall not vary more than ±4 % over the gated portion of the sweep employed in calibration and testing.

8.2.5 *Repetition Rate*—The repetition rate of the pulser shall not be less than 500 pulses per second.

8.3 *Search Units*—Ultrasonic search units for this test shall be spherically focused immersion-type units. Uniform performance characteristics of search units are critical for obtaining reproducible test measurements. (See Annex A1, which delineates search unit performance characteristics to be met by search unit manufacturers.) Performance characteristics of search units requiring consideration are: the uniformity of focal distance in water, center frequency, frequency spectrum, lens radius, width of field, and beam symmetry.

8.3.1 *Focal Length*—A focused beam of radiated ultrasonic energy is recommended to provide lateral resolution of small defects and to improve testing sensitivity in the region near the focal point. The focal length of a search unit is defined in this discussion as the distance in water, on the search unit axis, between the search unit and the surface of a ½-in. or 12-mm diameter ball target at which the highest reflection amplitude indication is obtained. Different focal length transducers may be used to obtain optimum response at selected distances below the test sample surface. (Variation of search unit-to-specimen surface water path would also affect the focal point within the test sample.)

8.3.2 *Search Unit Characteristics*—Search units generally employed have the following frequency and focal length as purchased:

Frequency	Focal Length in Water
10 ± 0.5 MHz	8.2 ± 0.3 in. (208.3 ± 7.6 mm)

8.3.3 *Beam Symmetry*—Each search unit should be rotated on its ultrasonic beam axis (not necessarily geometric axis) until a particular circumferential orientation is found which gives a maximum severity, or count, from the system reference block. This search unit orientation shall be identified and employed in subsequent tests. Search units that exhibit variations in indication amplitude in excess of 15 % during rotation shall not be considered satisfactory for the test. There are other methods, such as optimum response over a precision and uniform taut wire, that have been found to be usable.

8.3.4 *Performance*—The performance capabilities of all new search units shall be verified by an actual test on the system reference block. The data obtained for new search units should be compared with that obtained for other search units having the same specifications and tested under identical conditions.

8.4 *Immersion Tank and Accessories*—An immersion tank with associated scanning and indexing facilities shall be used.

8.4.1 *Search Unit Angulation*—The tank shall be provided with a manipulator capable of continuously angulating the search unit in two vertical mutually perpendicular planes permitting the required normalization.

8.4.2 *Scanning and Indexing*—The tank bridge and carriage assemblies shall provide *X-Y* motion to the search unit. The scanning shall be parallel or perpendicular (depending on the procedure) to the test specimen axis and the indexing shall be perpendicular to the scanning.

8.4.3 *Test Specimen Mounting*—The tank shall be provided with fixturing permitting the mounting of the entry surface of the test specimen parallel to the bridge travel so that the distance between search unit and specimen remains constant within $\pm 1/64$ in. (0.4 mm).

8.4.4 *Couplant*:

8.4.4.1 The inspection solution shall consist of tap or distilled water to which a wetting agent has been added to disperse air bubbles. The pH of the water shall be maintained within 7½ to 8½ . Rust preventives may also be added. All chemical additives shall be held within concentrations that do not adversely affect test performance. Water temperature must be held between 19.5 and 25.5°C. It is important that excessive thermal gradients do not exist between the search unit and the calibration standards.

8.4.4.2 A means of circulating the immersion inspection solution shall be employed, when necessary, to dissipate thermal gradients.

8.5 *Readout Equipment*—Various types of instrumentation have been employed in conjunction with ultrasonic instruments for many years to determine the number of occurrences of various amplitude indications. These include level counters, pulse counters, integrators, strip chart recorders, B-scan recorders, C-scan recorders, memory oscilloscopes, and computer techniques. With pulse counters, both repetition rate and scanning speed must be held within a 5 % tolerance and, preferably, 2 %.

8.6 *System Reference Block*—A system reference block (defined dimensionally in Section 9.2) is required for initial adjustments and operational testing of the equipment. This sample should be selected to provide reflection signals at all counting levels. Depth distribution of inclusions in the selected reference block should make its response characteristics relatively insensitive to minor focal length variations between different search units. The reference block should give a minimum change in total counts of 10 % for each 10 % increase or decrease in amplitude setting. A maximum of 30 % change in count for each 10 % change in amplitude setting should not be exceeded. It should be suitably protected from corrosion to assure its longevity.

9. Test Specimens

9.1 *General*—Test specimens must be either in the rolled or forged condition. If forged, upset forging is prohibited in order to maintain the rolling direction. Care should be taken not to overheat the forging to avoid spurious ultrasonic indications. Specimen location and frequency shall be as agreed upon between the supplier and the purchaser.

9.2 *Specimen Size and Shape*—Specimens shall have a minimum cross-sectional dimension after preparation of 3½ in. (88.9 mm). The area scanned shall be sufficient to permit testing of a minimum of 25 $in.^3$(410 cm^3) of the specimen. The tested volume equals the scanned area multiplied by the gated depth. If special consideration is given, thinner samples may be tested.

9.3 *Entry Surface Finish*—The test surface through which the sound enters the specimen shall be machined and ground. This finish in any direction over the surface shall be preferably 10 to 80 µin. (.25 to 2.0 µm). Final material removal may require a dressed grinding wheel to avoid spurious, near-surface indications. All four sides are to be ground.

9.4 *Heat Treatment*—Thermal conditioning of the specimens is required to minimize acoustic anomalies. Typical heat treatment may consist of normalizing or quenching and tempering, depending on steel type, to meet the ultrasonic penetrability requirement of Section 9.5. Certain steels may require special thermal treatment such as a double temper to obtain suitable acoustic properties.

9.5 *Ultrasonic Penetrability*—The ultrasonic penetrability shall be determined to be suitable for the inspection. The penetrability is acceptable if the third back reflection of the specimen is 25 % of full screen height, over the center of the billet specimen, at standard test conditions and test sensitivity.

10. Procedure

10.1 *General*:

10.1.1 *Operating Frequency*—The operating frequency for most bearing steels is 10 MHz. Ten megahertz is recommended as the highest practical frequency available within existing manufacturing capabilities to produce search units with uniform performance characteristics. Higher frequencies give better resolution, while lower frequencies give better penetration.

10.1.2 *Normalizing Search Unit*—Normalizing the search unit beam to the entry surface is a precise adjustment and requires extreme care. Normalizing can be accomplished over billet specimens with parallel ground sides by adjusting for a maximum first far field back reflection in an area where no material discontinuities are present to distort the ultrasonic beam. An alternative method that has been found useful is to maximize the far field reflections from a hardened steel plate with parallel ground sides, such as a 58 to 64 HRC hardness test block, placed on top of the ground billet surface.

10.1.3 *Water Distance*—The water distance between the search unit and entry surface shall not be less than $1 \pm 1/16$ in. (25.4 ± 1.6 mm) for every 4 in. (102 mm) of specimen thickness. In no case should the water distance be less than $1 \pm 1/16$ in.

10.1.4 *Monitoring Gates*—Either single or multiple gates may be employed.

10.1.5 *Scanning of Specimen*—Scanning of the specimen must be perpendicular to the rolling direction with a scan index of 0.050 in. (1.27 mm). Scanning closer than ½ in. (12.7 mm) to the prepared surface edge should be avoided because of false echoes from the edge. Two adjacent sides are to be inspected. Test specimens must be at room temperature before scanning.

10.1.6 *Scanning Speed*—Permissible scanning speed is a function of counter response and instrument repetition rate. A generally accepted speed is 4 in. (101.6 mm)/s. It shall be limited to that which gives a recorded evaluation of a sample within 5 % of that obtained when the sample is scanned at less than 1 in. (25.4 mm)/s, or one third of normal operating speed, whichever is the slower.

10.1.7 *Sensitivity*—The test sensitivity shall not produce background material indications exceeding an amplitude of one half of the lowest counting level.

10.1.8 *Operational Performance*—Periodically check overall equipment performance by conducting a test on the system reference block specimen. The deviation permitted shall not exceed the variation in counts obtained by altering the electronic gain by ±10 %. For practical purposes, the ±10 % electronic gain shall be defined as equivalent to the difference in response from ball targets varying by 10 % in diameters.

10.2 *Description of Method*—This method is applicable to the determination of the relative cleanliness of bearing-quality steel. Equipment, calibration, and method of analyzing test results have been made as simple as possible within the limits of having a workable test. An immersed ultrasonic test is conducted with a 10-MHz focused search unit, three-level type counter to indicate test results, steel balls to establish counter levels, an instrument calibration block, and a system reference block specimen. The specimen is scanned in a direction perpendicular to the rolling direction, and counts are recorded only when the search unit passes transversely over either a single inclusion or a cluster of inclusions which give rise to a discrete ultrasonic indication exceeding a counting level.

10.2.1 *Special Equipment and Accessories*:

10.2.1.1 A three-level pulse counter having separate adjustable thresholds for each level shall be used to determine the number of occurrences of various amplitude indications. The input circuits to the counters shall employ sufficient filtering to eliminate counter operation from extraneous high-frequency signals. The equipment shall have sufficient hysteresis to prevent counting spurious variations (jitter).

10.2.2 *Calibration Standards*:

10.2.2.1 Counter calibration requires a set of three ball targets with size ratio of 12:7:4. Highly polished stainless steel ball sets with a surface roughness of 2 µin. (.05 mm) Ra maximum and with diameters of ¾ in., 7⁄16 in., and ¼ in., or 12 mm, 7 mm, and 4 mm, may be employed. (A ½ in. ball is an acceptable substitute for the 7⁄16 in. ball.)

10.2.2.2 Test instrument calibration is performed with a 10-mm hemispherically shaped hole instrument calibration block described in Annex A2. This reference target shall be 1.7 in. (43.2 mm) below the entry surface of the standard.

10.2.2.3 A system reference block specified in 8.6 shall be employed to verify instrument calibration and to cross reference equipment performance between a number of instruments.

10.2.3 *Equipment Calibration Procedures*:

10.2.3.1 Equipment calibration is a two-step procedure that requires counter level calibration followed by ultrasonic test instrument sensitivity calibration.

10.2.3.2 Adjust the three-level counter using a set of highly polished stainless steel balls with a surface roughness of 2 µin. (.05 µm) Ra maximum and having a diameter ratio of 12:7:4. Position the search unit above the largest ball at a distance for maximum signal amplitude corresponding to the focal distance specified in 8.3.2. Adjust the test instrument sensitivity to produce a signal at 80 % of full screen height. At this setting, record the signal amplitude and adjust the level-three counter to count. This procedure determines the Level 3 (high) amplitude counting threshold. Without changing the test instrument sensitivity setting, position the search unit at its focal distance over the medium- and small-size balls. Adjust counter thresholds similar to the procedure for Level 3 and record the signal amplitudes for the Level 2 (medium) and Level 1 (low) amplitude counting thresholds.

10.2.3.3 The instrument test sensitivity is established by using a 10 mm sensitivity block as defined in Annex A2. Center the transducer over the hemispherically shaped hole of the sensitivity block using a water path distance between 1.1 to 1.7 in. Adjust for maximum signal strength in the XY axes. In the Z axis, adjust the water path distance between 1.1 and 1.7 in. to maximize signal strength. Adjust instrument sensitivity to the sensitivity of the Level 3 threshold (as established in 10.2.3.2). Increase the instrument sensitivity by 24dB for billet inspection.

10.2.4 *Cross Referencing Between Equipment Users*—If cross referencing of system reference blocks has been performed with other users of the method (as delineated in Annex A3), a fine adjustment of sensitivity (not to exceed ±1.5 dB) may be performed to discount variations in search unit response, counter hysteresis, and other instrumentation variables

10.2.5 *General Instructions and Procedures*:

10.2.5.1 Adjust the water path distance so that the search unit face is located 1 ± 1⁄16 in. (25.4 ± 1.6 mm) from the test specimen entry surface. This adjustment may be performed with a rule, reference spacer, or by use of calibrated water path measurements on the test instrument display.

10.2.5.2 Adjust the position of alarm/threshold gate(s) to evaluate indications that occur in the zone 0.7 to 0.9 in. (17.8 to 22.9 mm) from the entry surface to 0.3 to 0.5 in. (7.6 to 12.7 mm) from the bottom of the specimen.

10.2.5.3 Scan the specimen in a direction perpendicular to the rolling direction with a scan index of 0.050 in. (1.27 mm). The scanned area shall be bound by a perimeter that is not within 0.5 in. (12.7 mm) of the prepared surface edge. If the sides of the specimen are rough, a greater distance from the edge may be required to avoid spurious signals.

10.2.6 *System Reference Block Equipment Performance Test*—Verify the overall performance of equipment by conducting a test on the system reference block.

10.2.7 *Test Result Computation*:

10.2.7.1 For each side inspected, test result computation shall consist of counting the number of high-, medium-, and low-level indications and dividing by the volume tested. This provides a rating of the cleanliness, defined as counts per cubic inch.

$$S = \frac{N_l + N_m + N_h}{V}$$

where:

S = severity rating,
N_l = number of low-level indications counted,
N_m = number of medium-level indications counted,
N_h = number of high-level indications counted, and
V = volume of material tested (gated depth × scanned area).

10.2.8 *Report*—The reported results should contain all the information about the test that is necessary in order to duplicate results at the same or some other location. As a minimum, this report should include sample identification, test results on system reference sample, manufacturer's name and type designation of instruments and search units, and date of test. It also may be desirable to keep certain additional information on record, such as: number of counts at each level, severity, volume tested, gate length, total index, scan length, water temperature, sensitivity setting, name of operator, etc. Other information may be reported as agreed upon between the supplier and the purchaser.

10.2.9 *Reduction Ratio*—The reduction ratio from the original as-cast section to the sample size inspected must be reported.

11. Keywords

11.1 bearing steel; cleanliness; nondestructive examination; steel; ultrasonic testing

ANNEXES

(Mandatory Information)

A1. MINIMUM REQUIREMENTS FOR THE MANUFACTURE OF SEARCH UNITS

A1.1 General Characteristics

A1.1.1 The general characteristics of the search units presently used and their tolerances are as follows:

Frequency, MHz	Focal Length in Water, in. (mm)
10 ± 0.5	8.2 ± 0.3 (208.3 ± 7.6)

A1.1.2 The focal length shall be measured while using an instrument of the type employed for testing billet sections. A ½-in. or 12-mm diameter highly polished stainless steel ball target with a surface roughness of 2 µin. (.05 µm) Ra maximum shall be used for this measurement.

A1.2 Spectrum Analysis

A1.2.1 A spectrum analysis of the radiated signal of the transducer shall be performed to determine operating frequency characteristics. The requirements of the spectrum analysis test are as follows:

A1.2.1.1 Pulse-generating equipment shall be used that produces unidirectional voltage pulses having a duration no greater than one-half period of the nominal test frequency, a maximum rise time of 10 ns, and a trace-to-peak amplitude adjustable to 150 ± 5 V when loaded by the search unit and cable.

A1.2.1.2 A ½-in. or 12-mm diameter ball target in water shall be used. The ball target shall be placed in the search unit's far radiated field at 1.2 times the focal distance.

A1.2.1.3 The analyzed radiated signal shall be the front surface reflection from the ball target.

A1.2.1.4 A gate that does not modify signals should be used to avoid interference with the spectrum analysis by signal components from the gate.

A1.2.1.5 A linear oscilloscope presentation (or equivalent) should be used.

A1.2.1.6 The main peak radiation frequency as revealed by this analysis must be within ±0.5 MHz of the specified frequency. No secondary peaks should be within 5 dB of the peak radiation frequency.

A1.2.1.7 The maximum band width as revealed by this analysis must be 4 ± 0.5 MHz measured between points one half the amplitude of the peak radiation.

A1.3 Beam Symmetry Characteristics

A1.3.1 The symmetry of the beam of a search unit affects test sensitivity. Ideally, a search unit will radiate a beam whose cross section is essentially circular. If a search unit radiation beam has an elliptical or other asymmetrical shape, the unit's sensitivity, particularly on elongated targets, can vary considerably with search unit orientation. The symmetry of the radiated beam of search units used in this test shall be evaluated by both of the following methods:

A1.3.1.1 *Method I—Near-Field Beam Symmetry*:

(a) Pulse generation shall be the same as in A1.2.1.1

(b) An amplitude versus position recording shall be taken at the $y - 1$ point (first null on principal axis closest to focal point in near-field) in water along four planes 45° apart. A ½-in. or 12-mm diameter ball target shall be used.

(c) A photographic image of the oscilloscope presentation or chart recording of the signals shall be used to produce a recording of the beam profile.

(d) A symmetry factor shall be calculated by measuring the relative difference of the recorded lobes. A symmetry factor of no greater than 18 is suggested as calculated by adding the amplitude difference units between lobes for each of the four profiles.

A1.3.1.2 *Method II—Far-Field Beam Symmetry*:

(a) The instrument employed shall be of the same type as used for testing billet sections. The far-field beam symmetry shall be measured by observing the radiated field dimensions from the search unit while directed toward a target in water.

(b) A ½-in. or 12-mm diameter ball target shall be placed at 1.2 times the focal length.

(c) The width to the one-half amplitude point of the radiated field shall be measured in four planes 45° apart.

(d) The ratio of the shortest width of field to the longest width of field suggested limit shall be equal to or greater than 0.85.

A1.4 Distance Amplitude Characteristics

A1.4.1 The distance amplitude curve of the search unit shall be determined by observing the amplitudes of reflections, measured with an instrument of the type employed for testing billet sections, from a ½-in. or 12-mm diameter ball target in water.

A1.4.2 The tolerances of the distance amplitude measurements shall be specified at search unit-to-target distances of the following:

A1.4.2.1 The focal length of the search unit.

A1.4.2.2 1.3 times the focal length.

A1.4.2.3 0.8 times the focal length.

A1.4.3 *Amplitude Range*—Amplitude of all indications shall be within linear range of the instrument.

A1.4.3.1 *Ten-megahertz Search Units*:

(a) At 1.3 times the focal length, the amplitude range of the indication shall be 57 % to 83 % of the amplitude at focal distance.

(b) At 0.8 times the focal length, the amplitude range of the indication shall be 67 % to 93 % of the amplitude at focal distance.

A1.5 Minimum Sensitivity of Response

A1.5.1 The search units shall have a minimum sensitivity of response as determined by the following method:

A1.5.1.1 The excitation pulses shall be in accordance with A1.2.1.1 such that their maximum duration at the half-amplitude points is 50 ns for 10-MHz search units.

A1.5.1.2 Measure the received reflected signal amplitude after 40 dB of r-f amplification. The amplitude shall be at least 3.5 V.

A1.6 Search Unit Element

A1.6.1 A ¾-in. (19.1-mm) lithium sulfate (or equivalent) search unit active element is recommended because it provides sufficient area and sensitivity for conducting this test. A disadvantage of lithium sulfate elements is that as a monohydrate piezoelectric crystal, any minute quantity of water entering the element will destroy it. Extreme precautions in manufacture to provide perfect sealing and careful drying after use in testing must be exercised to prevent its destruction from absorption of water.

A1.7 Damping Characteristics

A1.7.1 Acoustic damping shall be incorporated in the transducer to improve its ability to discern closely spaced discontinuities of nearly the same depth.

A1.7.2 Laboratory measurements of damping shall be made by observation of the rate of decay of the pulse envelope of a search unit observed on an oscilloscope. An interpretation called Damping Factor (*D*) shall be made by counting the number of cycles in the pulse envelope greater than one half the initial pulse amplitude. The damping factor (*D*) should be less than five units.

A1.7.3 This search unit characteristic affects the sensitivity of a search unit. The condition of the bond between the active element and the damping element may be estimated from an increase in the damping factor. Bond imperfections cause the radiation beam to be asymmetrical and increase the damping factor and search unit operating frequency.

A2. FABRICATION OF 10-mm HEMISPHERICALLY SHAPED HOLE SENSITIVITY BLOCK

A2.1 Ten-millimetre hemispherically shaped hole test blocks shall be fabricated as shown in Fig. A2.1 in accordance with the following description:

A2.1.1 Employ CEVM (or equivilalent) 8620, 4330, or 4340 steel.

A2.1.2 Normalize steel 90°C above the Ac_3 point, holding the steel at temperature for a minimum of 4 h, and furnace cool.

A2.1.3 Rough out blocks to permit compliance with finish dimensions shown in Fig. A2.1. Surface *X* shall be ground.

A2.1.4 Mill a flat-bottom plug recess (approximately ⅞ in. (22 mm) in diameter and 0.150 in. (3.81 mm) deep).

A2.1.5 Mill a 0.4-in. (10.2-mm) diameter hemispherical hole 0.1 in. (3 mm) deep in center of recess.

A2.1.6 Test the bottom of the hole for Brinell hardness using a standard Brinell machine (10-mm ball and 3000-kg load).

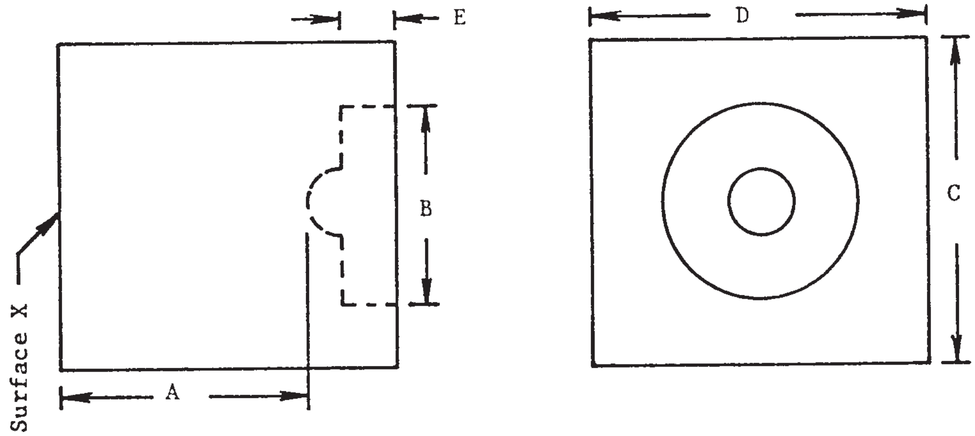
A2.1.7 Braze the 10-mm ball on a rod and insert the rod in a drill press or milling machine.

A2.1.8 Lap the bottom of the hole until no visible imperfections are discernible with a 3× magnifier. The axis of the hemispherical hole and of the rotating rod shall always be kept inclined since the bottom of the ball along the rod's axis will have a zero velocity.

A2.1.9 Grind the block so the *A* dimension is 1.70 ± 0.005 in. (43.2 ± 0.13 mm). The surface finish of surface *X* shall be 15 to 25 rms (0.34 to 0.57 µm aa).

A2.1.10 Plate the block with nickel or chrome (approximately 0.001 in. (0.03 mm) thick).

A2.1.11 Cement the flat plug in the flat-bottom recess.



Dimensions
A = 1.70± 0.005 in. (43.2 ± 0.13 mm)
B = 0.875± 0.125 in. (22.22 ± 3.18 mm)
C = 1.5 in. (38 mm) minimum
D = 1.5 in. (38 mm) minimum
E = 0.15± 0.050 in. (3.8 ± 1.27 mm)

FIG. A2.1 Fabrication of a 10-mm Hemispherically Shaped Hole Sensitivity Block

A3. METHOD OF CROSS REFERENCING SYSTEM REFERENCE BLOCKS

A3.1 Assurance of Proper Equipment Performance

A3.1.1 Assurance of proper equipment performance can only be obtained by periodically conducting tests of a system reference block. Unfortunately, response sensitivity (percent change in counts) for different test specimens or blocks is not a constant for all instrumentation variables.

A3.2 Factors Affecting Counts from a Specimen

A3.2.1 The distribution, type, shape, and location of inclusions in a test billet specimen can cause the response in counts to be either sensitive or insensitive to minor differences in instrumentation, search units, or setup. Consequently, a simple specification for limits on a system reference block, such as permitting a set percentage deviation in counts from an established median, is not practical. The response sensitivity of the particular reference test block as a function of instrumentation gain, etc., must be accounted for.

A3.3 Method of Cross Referencing Different Reference Blocks

A3.3.1 Cross referencing of test blocks may be accomplished by first making a test run on two or more system reference blocks at standard sensitivity. The reference blocks are then rerun using selected higher and lower gain settings. In order to prevent instrumentation inaccuracies, such as linearity differences, from influencing the test, the slightly higher and lower gain settings can be delineated to be the difference of energy reflections between different size balls. This is feasible since amplitude of indications from balls varies directly with ball diameter.

A3.3.2 Test runs of reference blocks at high, low, and standard sensitivity provide correlated data enabling the permissible deviation in counts of each system reference block to be specified.

A3.3.3 Fig. A3.1 illustrates counts obtained on two reference blocks for three different search units. Cross referencing of test blocks in this manner enables one to make minor adjustments in sensitivity to discount variations in search units and instrumentation so as to obtain the desired counts on each system reference block relative to other users of the method.

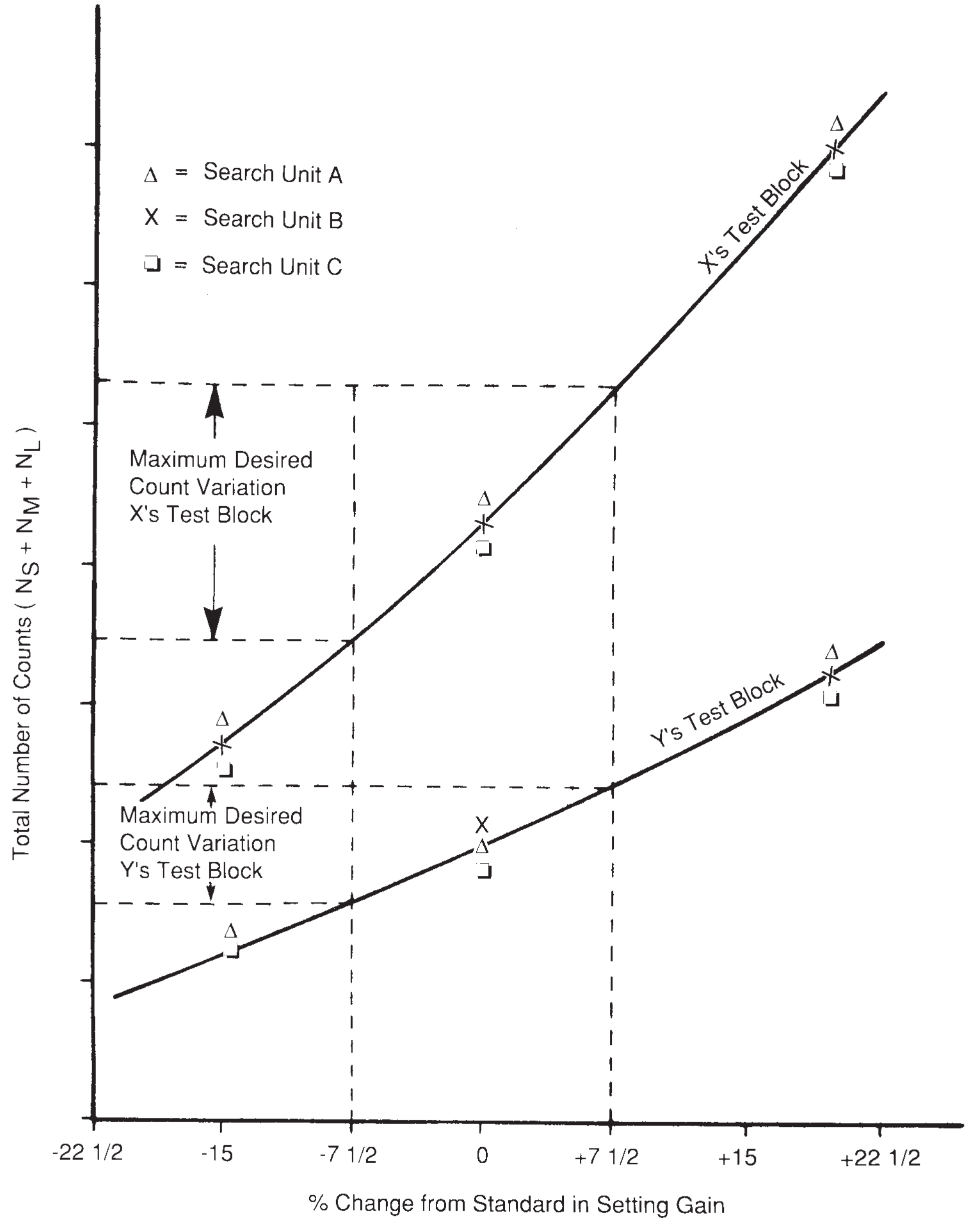


FIG. A3.1 Method of Reference Block Comparison

SUMMARY OF CHANGES

This edition is a complete revision of the standard with changes made to clarify and simplify the testing procedure, and to recognize improvements in testing equipment. Numerous sections have been revised, renumbered, or deleted. The entire standard should be reviewed before use.

Standard Test Method for Evaluating Machining Performance of Ferrous Metals Using an Automatic Screw/Bar Machine[1]

This standard is issued under the fixed designation E 618; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

This test method was written to fill a requirement for a standard test for determining the machinability of ferrous metals using automatic screw/bar machines. (Hereafter, these machines will be referred to as automatic screw machines.) Although a variety of short-time laboratory tests have demonstrated different machining characteristics among ferrous metals, it has been difficult to apply the resulting data to commercial automatic screw machine practice.

In this test method a standard test piece is machined using tools and machining operations typical of automatic screw machine practice.

Through the use of this test method, the relative machining performance of a metal can be evaluated even though different automatic screw machines are used. Further, comparisons can be made among different lots of the same grade or different grades to determine relative machining performance.

1. Scope

1.1 This test method covers a production-type test for evaluating the machining performance of ferrous metals as they are used in single-spindle or multiple-spindle automatic screw machines. It is based on producing parts of a standard design in such machines to uniform levels of quality with respect to surface roughness and size variation. The standard test piece, designed for this test, is machined from bars using a specified number of tools in a specified sequence. Nothing in this test method should be construed as defining or establishing limits of acceptability for any grade or type of metal.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *American National Standard*:

B46.1 Surface Texture[2]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *average surface roughness (per set of samples)*—for each surface (the major and minor diameter formed surfaces) the surface roughness per set of samples is the average of the roughnesses recorded as in 3.1.5.1 for the six test pieces per set. A test set is described in 9.3.

3.1.2 *calculated hourly production rate (in pieces per hour)*—3600 s/h divided by the cycle time in seconds per piece. (Unit: pieces per hour.)

3.1.3 *cycle time*—the time in seconds per piece from bar feed-out to bar feed-out, or from cutoff to cutoff, during uninterrupted operation of the machine. It includes all stock, machine, and tool movements.

3.1.4 *surface speed*—the product of the original bar circumference (in feet or metres) and the spindle speed in revolutions per minute. (Unit: ft/min or m/min.)

3.1.5 *surface-roughness average value (R_a)*—the surface-roughness average value is the mean reading around which the needle tends to dwell or fluctuate under small amplitude when a continuously averaging meter is used. (Refer to 3.8.1.1 in ANSI B46.1). The surface-roughness value obtained by a continuously averaging digital readout meter is acceptable.

3.1.5.1 The surface-roughness recorded for each surface on the test piece is the maximum of the surface-roughness average values measured on that surface at a minimum of four places equispaced around the circumference and measured as described in 3.1.5.

[1] This test method is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A1.15 on Bars.

Current edition approved March 27, 1981. Published July 1981. Originally published as E 618 – 77 T. Last previous edition E 618 – 77 T.

[2] Available from American National Standards Institutes, 25 W. 43rd Street, 4th Floor, New York, NY 10036.

3.1.6 *surface-roughness range (per set of samples)*—the lowest and highest values of the surface roughnesses recorded for each surface as in 3.1.5.1 for each set.

3.1.7 *surface-roughness range (per test)*—the lowest and highest values of surface roughnesses recorded for each surface as in 3.1.5.1 during the test.

3.1.8 *theoretical hourly production rate (in pieces per hour)*—3600 s/h divided by the cycle time in seconds per piece diminished by: (*1*) the indexing time or high-speed time in seconds per piece for a multiple-spindle machine, or (*2*) the time in seconds per piece when no tools are cutting for a single-spindle machine.

3.1.9 *tool feed rate*—the distance traveled by the tool at a uniform rate divided by the number of spindle revolutions during which this travel occurs. (Units: decimal inch or decimal millimetre per revolution.)

3.1.10 *tool life (for a form tool)*—the hours of machine time determined from the calculated hourly production rate and the total number of test pieces produced from the start of the test to the earliest point at which the average of the recorded surface-roughness average values or the average of sizes of the test pieces in a sample set consistently exceed either the surface-roughness limits or the size limits specified in 9.7.1, 9.7.2, and 9.7.3 for the piece diameter produced by that tool.

3.2 Machining performance in this test method is evaluated by the following criteria:

3.2.1 Tool life as described in 3.1.10.

3.2.2 Cutting speed and tool-feed rate as described in 3.1.4 and 3.1.9.

3.2.3 Hourly rate of production as described in 3.1.2 or 3.1.8.

3.2.4 A test sample set is described in 9.3.

4. Summary of Test Method

4.1 A standard test piece, shown in Fig. 1, is machined from bar stock in an automatic screw machine.

4.2 Specified tools are used in a standard sequence to shape the test piece. Drills and form tools are used simultaneously to provide a typical machining condition during the test.

4.3 Cutting speed and tool feed rate for the metal being tested are varied from one test run to another to determine the maximum rate at which test pieces can be produced for the

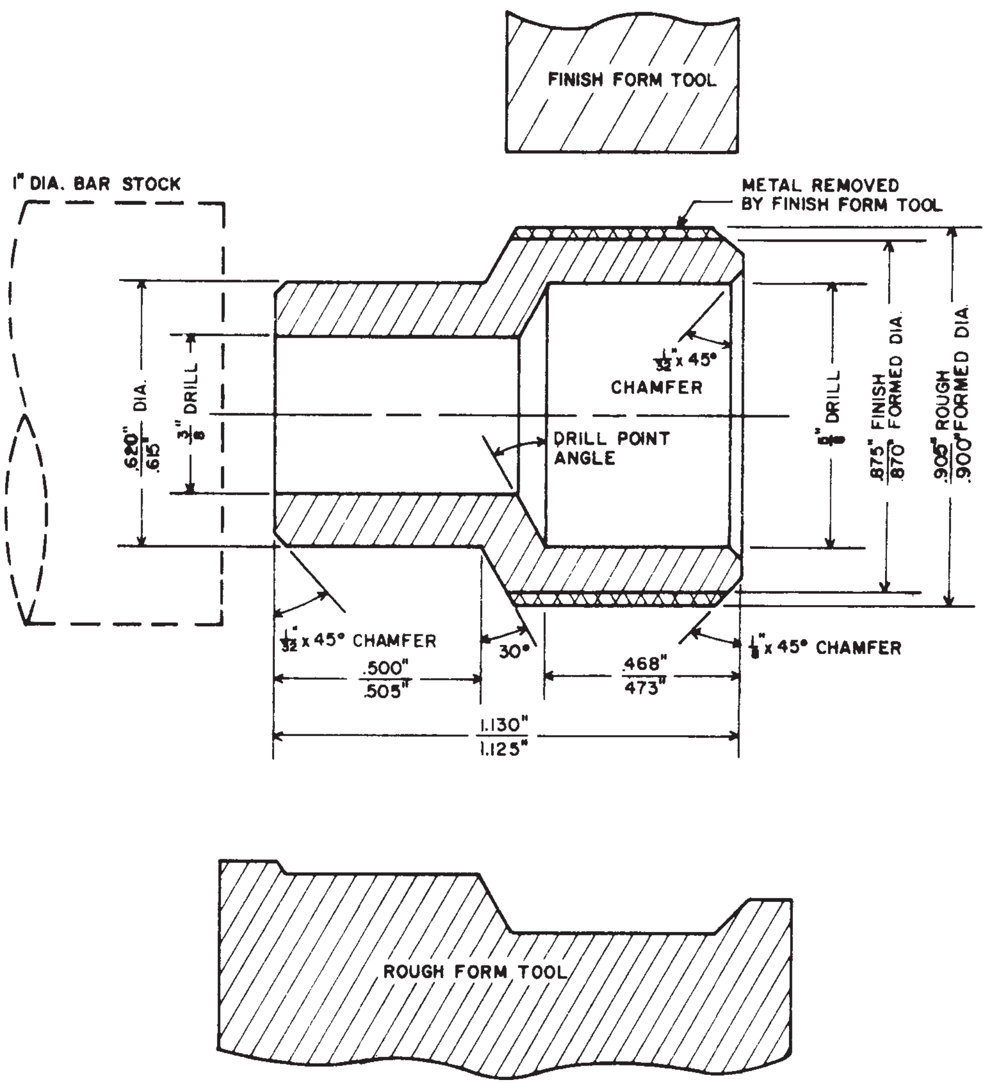


FIG. 1 Details of the ASTM Machinability Test Specimen and the Relative Positions of Form Tools

specified length of time without exceeding the specified limits for surface roughness and size dimensions.

4.4 When measured as specified, the level of and changes in surface roughness and the size of pieces produced are used to evaluate the machining performance of the metal being tested.

5. Significance and Use

5.1 This test method can be used to evaluate the machining performance of a single grade or type of metal or to compare one grade or type with another.

5.1.1 The machining performance of the test metal is measured by the maximum rate at which test pieces can be produced within specified surface roughness and dimensional limits for a specified length of time and also by the cutting speed and tool feed employed to attain that rate.

5.1.2 The relative machining performance of the various metals tested using this test method may be evaluated only at operating conditions that produce test pieces of like quality with respect to surface roughness and dimensional limits for comparable periods of machining time.

6. Apparatus

6.1 *Automatic Screw Machine*:

6.1.1 A single-spindle automatic screw machine with a six- or eight-hole turret, with adequate spindle capacity, and with sufficient feed, speed, and power to machine a 1-in. round bar of free-machining, alloy or high-strength steel, or

6.1.2 A multiple-spindle automatic screw machine with a spindle capacity and with sufficient feed, speed, and power to machine 1-in. round bars of free-machining, alloy or high-strength steel simultaneously at all spindles.

6.2 *Metal-Cutting Tools*—On the basis of current use for general applications for automatic screw-machine production, two tool-steel grades (M7 for drills and M2 for form tools) are suggested in 6.2.1 through 6.2.5. This is not intended to preclude the use of other grades. This test method does require that the use of tool materials, other than those suggested, be recorded and reported together with the reason(s) for the change.

6.2.1 A ¾-in. (19.05-mm) diameter or larger spot drill with a 90° included point angle may be used.

6.2.2 Two ⅜-in. (9.52-mm) diameter and one ⅝-in. (15.88-mm) diameter drills ground as specified in 8.6.

6.2.3 Either a dovetail or a circular rough-form tool of M2 steel designed as shown in Fig. 2.

6.2.4 A flat, circular, or dovetail finish-form tool at least 9⁄16 in. (14.29 mm) wide made from M2 steel as shown in Fig. 3.

6.2.5 A cutoff tool as described in 8.5.

6.3 *Stylus-Type Standard Commerical Surface-Roughness-Measuring Instrument*, capable of measuring surface roughness in microinches arithmetic average (AA) and having a stroke of at least ¼ in. (6.35 mm).

6.3.1 In all cases an electric cutoff of 0.030 in. (0.8 mm) is used. The stylus and skids of the tracer head must be compatible with a 0.030-in. (0.8-mm) cutoff. (See 3.6.2 in ANSI B46.1 for a definition of cutoff.)

6.3.2 The length of trace is the maximum possible on the surface being measured but must be at least 0.150 in. (3.81 mm).

6.4 *Micrometer(s),* capable of indicating to 0.0001 in. or 0.002 mm.

6.5 *Toolmaker's Microscope* or equivalent.

6.6 *Commercially Available Coolant*.

7. Test Specimen

7.1 The test specimen detailed in Fig. 1 shall be machined from 1-in. (25.4-mm) diameter bars.

7.2 Different bar sizes may be used to produce a different size test piece provided that the material removed and the material remaining is in the same cross-sectional proportion as in the test piece shown in Fig. 1. When a different bar size is used a proportionate change is made in all dimensions, except that both formed surfaces must be at least ⅜ in. (9.5 mm) long. This is to ensure accurate surface-roughness measurements.

7.3 When a different size test piece is used the bar size and test piece dimensions shall be recorded on the test report.

8. Procedure for Machine Setup

8.1 Since there is a difference between automatic screw machines as to how movement is conveyed to the end and side working tools, cams must be designed or selected to provide a uniform rate of tool feed for a distance greater than that necessary to remove the required metal. This will ensure a uniform feed rate throughout the cut.

8.2 Feeds and speeds on the initial test run should be selected on the basis of experience or general guide lines for a ferrous metal of similar composition and condition.

8.2.1 The positive stop pressure maintained during the test shall be that which is recommended by the machine tool builder.

8.3 Place the cutting tools so they cut in the following sequence. The form tools and drills shall cut at the same time.

8.3.1 Spot drill (optional).

8.3.2 Rough form and drill to depth with ⅝-in. (15.88-mm) diameter drill.

8.3.3 Finish form to 0.875-in. (22.22-mm) outside diameter and drill 11⁄32 in. (8.73 mm) deep with the first ⅜-in. (9.52-mm) diameter drill.

8.3.4 Drill 11⁄32 in. (8.73 mm) deep (through the cutoff) with the second ⅜-in. (9.52-mm) diameter drill.

8.3.5 An optional sequence of tooling for a single-spindle automatic machine uses only three drills in the turret; namely, one spot drill, one ⅝-in. (15.88-mm) drill, and one ⅜-in. (9.52-mm) drill with double indexing of the turret between successive drilling operations.

8.3.6 Cut off the finished piece.

8.4 *Form Tool Conditions*:

8.4.1 Using the most rigid cross-slide, set the rough-form tool so that the part of the tool forming the 0.615 to 0.620-in. (15.62 to 15.75-mm) or minor diameter will cut on center.

8.4.2 Set the finish-form tool to cut the rough-formed 0.900 to 0.905-in. (22.86 to 22.99-mm) or major diameter on center and remove 0.030 in. (0.76 mm) from that diameter to form the 0.870 to 0.875-in. (22.10 to 22.22-mm) diameter. When a different size test piece is used, proportionately more or less metal will be removed by the finish-form tool.

8.4.3 Grind and mount all form tools in the machine with an effective positive top rake angle of 10°, a front clearance angle

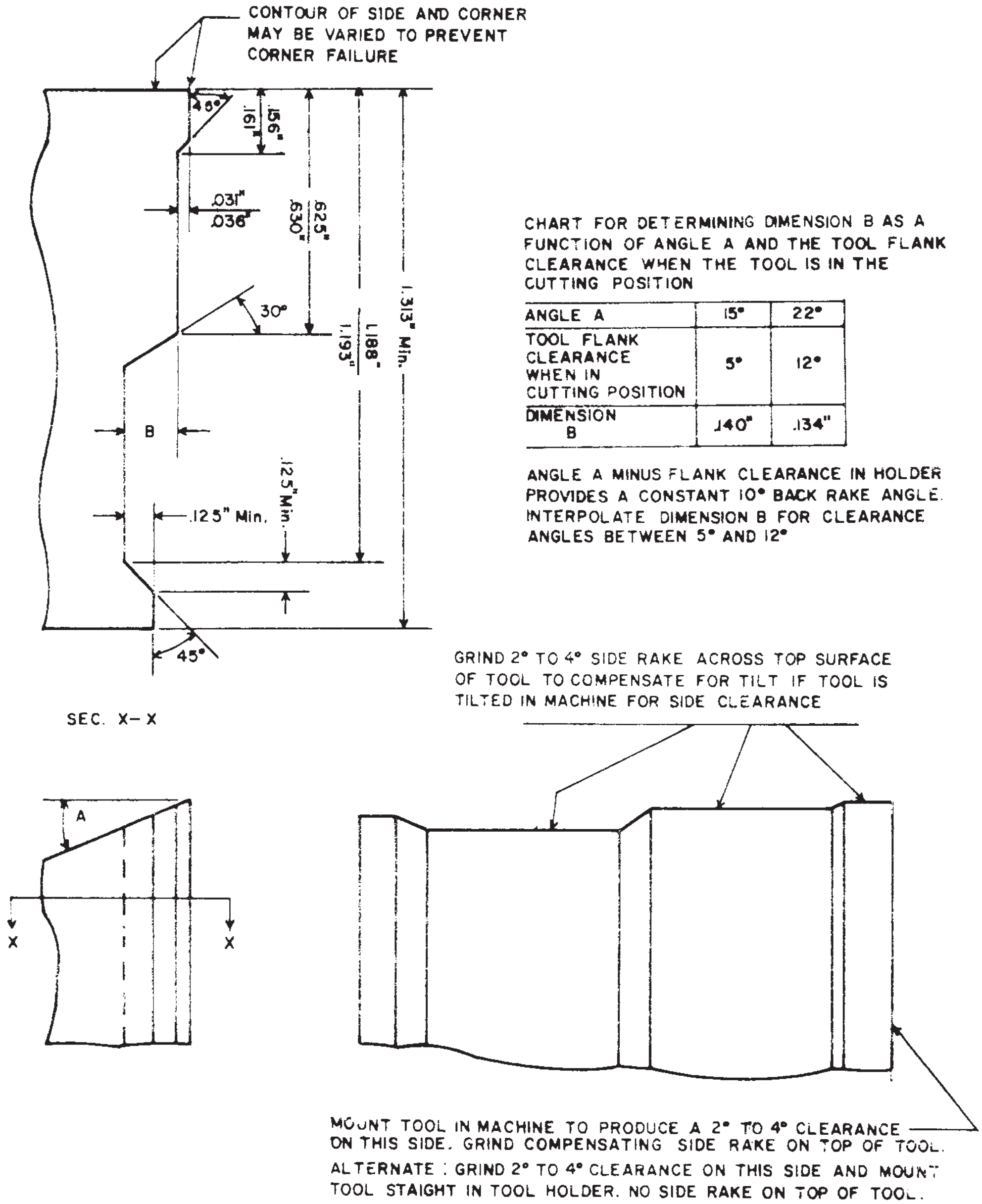


FIG. 2 Details of the Tool Edge for the ASTM Rough-Form Tool

of 5 to 12°, and, for the rough-form tool, a side-clearance angle of 2 to 4°. Note any deviation from these angles found necessary and record the reason.

8.4.4 When the side-clearance angle for the rough-form tools is obtained by a tilted tool holder, it is recommended that the rough-form tool be reground in a tool holder or fixture having an identical angle of tilt.

8.4.5 All form tools must be hardened to 63 minimum HRC.

8.5 *Cutoff Tool*—An appropriate commercial tool shall be used.

8.6 *Drills*:

8.6.1 Use solid two-flute standard length or screw-machine length high-speed steel twist drills. Note any deviation that is found necessary to conduct the test and record the reason.

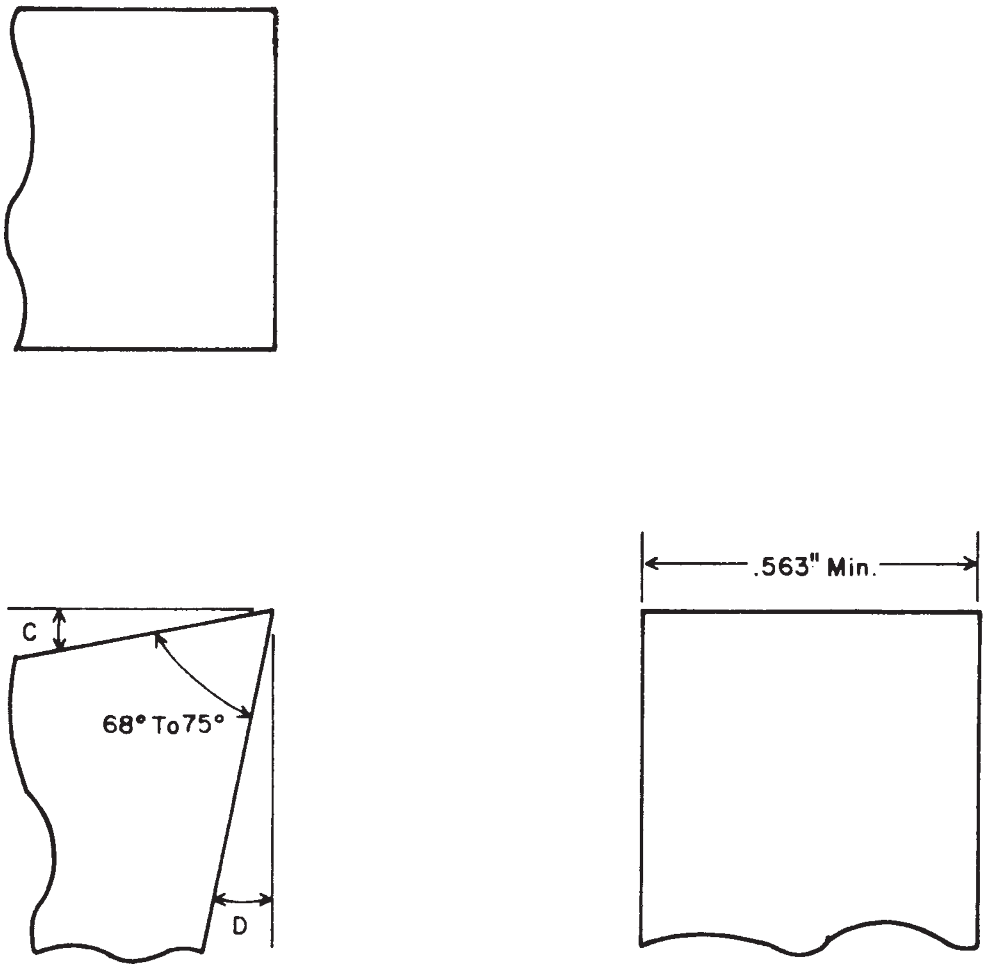
8.6.2 Included (point angles) angles shall be 118° for all metals except stainless steels and high-strength metals, when a 135° included angle shall be used.

8.6.2.1 The lip clearance angles shall be 14 ± 2° for the ⅜-in. (9.52-mm) drill(s) with 118° included angle; 12 ± 2° for the ⅝-in. (15.88-mm) drill with 118° included angle; 12 ± 2° for the ⅜-in. drill(s) with the 135° included angle; and 10 ± 2° for the ⅝-in. drill with 135° included angle.

8.6.2.2 Web thinning may be necessary when resharpening drills with 118° included angle.

8.6.2.3 Use a split point on the drills with 135° included angle.

8.6.2.4 All drills shall have the helix angle which is standard for the manufacturer of the drills.



NOTE 1—Angle C: 10° positive back-rake angle when mounted in cutting position.
NOTE 2—Angle D: 5 to 12° clearance angle when mounted in cutting position.

FIG. 3 Details of the Tool Edge for the ASTM Finish-Form Tool

8.7 Direct the coolant to flood the test pieces and the tool cutting edges during machining.

9. Test Method

9.1 Determine the reliability of machining-performance data to be expected on any given machine by running machine-capability tests prior to a test program to determine the tolerance limits within which the machine is capable of producing the test piece. A method for doing this is described in Appendix X1. Machine-capability tests should be performed each time a variance pattern of sizes develops which departs from the norm previously established.

9.1.1 If the machine is not capable of producing pieces within the limits specified in 9.7.2 before proceeding with the test program, adjust the machine to repeatedly produce the part size to less than the diameter-increase limits specified in 9.7.2.

9.2 This test method requires the determination of the maximum rate at which test pieces can be produced from a test metal consistent with an average 8-h form-tool life as defined in 5.1 and within the size and surface-roughness limits specified in 9.7.1, 9.7.2, or 9.7.3. Vary cutting speeds and tool-feed rates (and tool rake angles, if necessary) in successive test runs until that objective is attained. Start each test run with freshly ground tools at a selected cutting speed and tool-feed rate which may not be changed during that test run. Monitor the progress of a test run by measuring the size and surface roughness of test pieces in sample sets taken at regular intervals.

9.2.1 Form-tool rake angles may also be varied from those specified in 8.4.3 to obtain pieces of like quality from different materials, but only if changes of cutting speed and tool-feed rate fail to produce test pieces of like quality with respect to surface roughness and dimensional limits for comparable periods of time as specified in 5.1.2. Record the variation in rake angles in the log of test data.

9.2.2 From the nature of this test method it is clear that substantial quantities of test material will be required, varying from a few hundred pounds (or kilograms) to a few thousand pounds (or kilograms), depending upon the grades selected for test. For example, free-machining steels, which will accept high cutting speeds and tool-feed rates, may easily require 1500 to 2000 lb (700 to 900 kg) of bars for a single test run, whereas a difficult-to-machine stainless might require only 150 to 200 lb (70 to 80 kg). It is probable that three or more times these quantities will be required for tests at various conditions in order to attain the objective as specified in 9.2. Considering that these are large amounts of material for a test procedure, selection of bars to ensure randomness is not necessary.

9.3 *Test-Sample Sets*:

9.3.1 A test-sample set from a multiple-spindle automatic screw machine consists of one test piece taken at cut-off from each spindle in numbered sequence during one complete cycle (revolution) of the spindle carriage numbered and recorded in the same order. Take and record subsequent sample sets using the same spindle sequence.

9.3.2 When a single-spindle automatic screw machine is used, take six consecutive pieces as a test-sample set.

9.3.3 Take sample sets of test pieces only after the machine has produced pieces for at least 15 min, except during machine set up.

9.4 The intervals between sample sets shall be no greater than 1 h. Discard test pieces produced in the intervals between sample sets.

9.5 Make and record *(1)* surface-roughness measurements on test pieces at a minimum of four locations around the circumference produced by each form tool and *(2)* size measurements at two locations 90° apart on each circumference.

9.6 Do not make form-tool adjustments to bring pieces within size limits during the test after the tools have been set initially to produce parts of specified dimensions.

9.7 *Surface-Roughness and Size Limits*:

9.7.1 The highest recommended surface-roughness average value on a test piece in a sample set is: 150 µin. R_a on finish-formed surfaces; or 300 µin. R_a on rough-formed surfaces.

9.7.2 The maximum recommended increase in diameter from the starting size on a test piece in a sample set is: 0.003 in. (0.08 mm) for the finish-formed surface (major diameter); or 0.005 in. (0.13 mm) for the rough-formed surface (minor diameter).

9.7.3 Surface-roughness and size limits different from those specified in 9.7.1 and 9.7.2 may be used provided they are clearly stated and applied equally to all tested materials.

9.8 *Termination of Test Runs*:

9.8.1 The tool life is determined when the conditions of 5.1 are exceeded. It is suggested that the test be continued somewhat beyond that tool-life end point in order to verify as valid that point of test termination.

9.8.2 A test run may be continued beyond the point described in 9.8.1 in order to obtain information on the other form tool. Such a continued test run is subsequently terminated when all test pieces in a sample set exceed the surface-roughness or size limit specified in 9.7.1, 9.7.2, or 9.7.3 for the other form tool. Record in the test log (Fig. X1.1) the tool life of all form tools as described in 5.1.

9.8.3 A test may also be terminated for other reasons, such as excess form tool wear or tool failure. See 10.1.4.4 and 10.1.4.8.

9.9 Do not remove form tools from the tool holders or the machine for wear measurements during these test runs.

10. Recordkeeping

10.1 Record the following data for each test conducted. A suggested form is attached as Fig. X1.1.

10.1.1 *Test-Material Data*:

10.1.1.1 Grade, type, or alloy designation if applicable, and chemical composition if available.

10.1.1.2 Test material condition, that is, annealed, cold-drawn, extruded, ground, ground and polished, etc., including surface condition that is, rusty, scaled, clean, etc.,

10.1.1.3 Bar diameter, and

10.1.1.4 Mechanical properties, that is, tensile strength, yield strength (0.2 % offset), reduction of area, elongation, and hardness, if available.

10.1.2 *Machine Data*:

10.1.2.1 Machine size, make, model and number of spindles, and

10.1.2.2 Machine-indexing or high-speed time in seconds per piece for a multiple-spindle machine, or

10.1.2.3 Time when no tools are cutting, in seconds per piece for a single-spindle machine.

10.1.3 *Operating Data*:

10.1.3.1 Cam rise for each tool,

10.1.3.2 Feed rate for each tool, inches (or millimetres) per revolution,

10.1.3.3 Spindle revolutions per minute,

10.1.3.4 Surface speed, feet (or metres) per minute, calculated from original bar diameter and spindle revolutions per minute,

10.1.3.5 Machine-cycle time in seconds per piece,

10.1.3.6 Calculated and theoretical production rates described in 3.1.2 and 3.1.8, pieces per hour,

10.1.3.7 Coolant used, stating trade name and number or ASTM designation, and condition (whether new or old, clean, etc.),

10.1.3.8 Sampling frequency and sample-set size, and

10.1.3.9 Tool materials for all tools.

10.1.4 *Results*:

10.1.4.1 Maximum surface-roughness average value and size ranges produced by the rough-space and finish-form tools on test pieces at the start and at the end of tool life,

10.1.4.2 Size measurements and surface roughness range of each piece from successive sample sets in tabular form to show how rapidly any change takes place,

10.1.4.3 Total number of pieces produced during test,

10.1.4.4 Number of pieces produced by each form tool, during the life of the tool as described in 5.1, or until termination of the test for other reasons as described in 9.8.3,

10.1.4.5 Life of the form tools, in hours, calculated from the number of pieces produced by each form tool as recorded in 10.1.4.4 and the calculated hourly production rate recorded in 10.1.3.6,

10.1.4.6 Number of pieces produced by each drill during the test, and

10.1.4.7 Chip characteristics (continuous, broken, color, etc.) and any changes that occur during the test run.

10.1.4.8 If a test is terminated for any condition other than those specified in 9.7.1, 9.7.2, or 9.7.3, such as catastrophic tool failure, the reason for termination must be recorded together with the number of pieces produced and the hours of machine operation at the calculated hourly production rate.

11. Interpretation of Results

11.1 The ranges of size measurements and surface roughness of pieces produced during the test are significant indicators of machining performance.

11.2 The roughness and size limits specified in 9.7.1 and 9.7.2 are the maximum recommended values under this test method. Different limits for surface roughness or size may be used provided these are clearly stated and applied equally to all metals tested.

11.3 In general, rough-form tools will have different tool lives than finish-form tools. If one form tool produces test pieces exceeding the surface roughness or size limits specified in 9.7, the test can be continued, with that tool replaced to the point at which the other form tool produces test pieces exceeding the surface roughness or size limits specified for it in 9.7. The life of the tool replaced must be determined in accordance with 5.1 and must be recorded.

11.4 In this test method, the machining performances of metals are measured by the maximum production rates at which test pieces can be produced to specified surface roughness and size limits for specific periods of time and by the cutting speed and tool-feed rates used to attain those production rates. The range of surface roughness values, dimensional limits, and tool life achieved must be reported.

11.5 In this test method, comparisons of machining performances among metals may be made only at those production rates and operating conditions of cutting speed and tool-feed rate where test-piece quality levels defined by maximum surface roughness (9.7.1 or 9.7.3), size change (9.7.2 or 9.7.3), and tool life have been maintained substantially equivalent. Under this restriction, the results of a machining-performance test may then be expressed in terms of percent relative to the machining performance of a base metal by comparing the theoretical hourly production rate with that of a base metal or by comparing cutting speed or tool-feed rate with those of a base metal.

12. Precision

12.1 The machining performance (or, as it is sometimes called, the "machinability") of a material cannot be regarded solely as a property characteristic of that material. The principal indexes of machining performance, namely, production rates, cutting speeds, and tool-feed rates, are greatly affected by many other factors, such as the tool material, the surface-roughness and dimensional limits demanded of the product, the coolant and its properties, and the configuration of the part. These latter factors are quite independent of the work material and yet all affect its machining performance criteria. The foregoing illustrate the complexities of evaluating machining performance whether with respect to the work material or any of the other factors. Data do not now exist that will permit an evaluation of precision either for the performance of the work material alone or by comparison with the performance of other materials. It is one of the aims of this test method to provide a more uniform basis for testing and reporting machining performance and this could ultimately provide the necessary data.

APPENDIX

(Nonmandatory Information)

X1. DETERMINING MACHINE CAPABILITY

X1.1 The machine capability is the Upper Control Limit (UCLR) value on a range control chart for the dimensions of machined parts. It can also be considered as the dimensional tolerance limits within which a machine is capable of repeating, since half the machine capability is the lower limit imposed by the machine in setting plus and minus tolerance limits.

X1.2 Making a machine capability study is a simple statistical procedure, and any setup man or operator can do it with a little training. Once the machine is stabilized (warmed up) and the tools set to the middle of the tolerance or center dimension, one collects a quantity of consecutive pieces. The critical dimension of these pieces is then measured and recorded following a simple procedure.

X1.3 *Proceed as follows*:

X1.3.1 Stabilize the machine and make at least six consecutive pieces, keeping the first piece in a row with all first pieces, second pieces with second pieces, etc. Marking one spindle on a multiple-spindle machine will enable the operator to identify each piece with a specific spindle. No adjustment should be made to the machine during the sampling period.

X1.3.2 Measure and record the two critical diameters of the standard test piece.

X1.3.3 Tabulate in a table as shown in Table X1.1. Take the first six pieces and find the difference between the largest and smallest measurement for the dimensions to be measured. Do this for each group of six pieces. The resulting figure is the range (R) for each six pieces. A different range for each six pieces is to be expected.

X1.3.4 Add the ranges together. Divide by the number of groups to obtain the average range ($\bar{R}$).

X1.3.5 Multiply the average range value ($\bar{R}$) by a multiplying factor. This factor, 2.004 (D_4), is a number that, when multiplied with the average range, determines the upper control limit (UCLR) for a sample of six.[3] The resulting computation

[3] Further information on the use of this factor with other numbers of sample observations can be found in *STP 15 D, ASTM Manual on Presentation of Data and Control Chart Analysis*, 1976, Table 27, p. 134.

is the upper range control limit (UCLR) or the machine capability with which it will repeat itself 99.8 % of the time (3 Sigma).

X1.3.6 The example shown in Table X1.1 was taken from a 1-in. RAN, six-spindle National Acme, a machine made in 1965. Note that the machine's capability when machining cold drawn 12L14 was 0.0026 in.

X1.4 *ASTM Machinability Data Record*— See Fig. X1.1.

TABLE X1.1 TABULATION OF MACHINE CAPABILITY

Machine: National Acme RAN 6; Date: 9/8/75
Material: 1-in. Round 12L14
Tool: Rough Form

Piece No.	Group No.									
	1	2	3	4	5	6	7	8	9	10
1	0.6150	0.6148	0.6150	0.6153	0.6151	0.6148	0.6148	0.6153	0.6150	0.6153
2	0.6149	0.6150	0.6154	0.6150	0.6153	0.6152	0.6157	0.6152	0.6158	0.6158
3	0.6148	0.6151	0.6152	0.6152	0.6147	0.6153	0.6153	0.6151	0.6151	0.6149
4	0.6154	0.6152	0.6157	0.6157	0.6157	0.6156	0.6155	0.6166	0.6160	0.6166
5	0.6153	0.6151	0.6147	0.6152	0.6150	0.6150	0.6152	0.6151	0.6157	0.6151
6	0.6143	0.6148	0.6145	0.6147	0.6150	0.6166	0.6147	0.6144	0.6145	0.6150
Range	0.0011	0.0004	0.0012	0.0010	0.0010	0.0018	0.0010	0.0022	0.0015	0.0017

Sum of Ranges = 0.0127 in.
Average Range, $\bar{R}$ = 0.0127/10 = 0.00127 in.
Machine Capability = 2.004 $\bar{R}$ = 2.004 × 0.00127 = 0.0026 in.

Test No.

Automatic Bar Machine

Make: Model: No. of Spindles: Size:

Test Material:

Grade: Condition: Bar Diameter: (in. or mm)

Composition: (If known) __ % C __ % Mn __ % P __ % S __ % Si __ % Al
__ % N __ % Cu __ % Ni __ % Cr __ % Mo __ % Pb __ % other

Mechanical Properties: Tensile strength ____ Yield strength ____ Reduction of area, %____
Elongation, % ____ Hardness ____

Machining Conditions:

Speed: ____ rpm Index time: ____s Cycle time: ____s

Calculated Hourly Rate: pieces/h

Coolant Mfr. Trade Name and No., or ASTM Designation

Theoretical Hourly Rate: pieces/h

Tools	Cutting Speed, sfpm (sM/min)	Cam Rise, in. (mm)	Tool Feed, in./rev (mm/rev)	Tool Grade
Rough-form tool				
Finish-form tool				
Spot drill				
5/8-in. drill				
3/8-in. drill (first)				
3/8-in. drill (second)				
CO tool				

Sampling Frequency: Sample Size:

Tools	Tool Rake	Tool Relief	
		End	Side
Rough-form tool			
Finish-form tool			

FIG. X1.1 ASTM Machinability Data Record

Test Results:

Tool	Surface Roughness, µin., R_a			Average Roughness During Tool Life	Part Size Range, in.		Tool Life	
	Sample Set Range		Test Range					
	Start	End			Start	End	Pieces	h
Rough-form Finish-form								

Tool Life

Tools	No. of Pieces	h	Average per Tool
Rough-form Finish-form Large drill Small drill (first) Small drill (second)			

Types of Chips:

Departure from ASTM Procedure:

Comments:

Test Log

Test Identification

	Data
Sample Set No.	
No. of Parts Produced	

		Roughness, µin., R_a
Piece # 1	RF FF	
Piece # 2	RF FF	
Piece # 3	RF FF	
Piece # 4	RF FF	
Piece # 5	RF FF	
Piece # 6	RF FF	

		Diameter, in. (mm)
Piece # 1	RF FF	
Piece # 2	RF FF	
Piece # 3	RF FF	
Piece # 4	RF FF	
Piece # 5	RF FF	
Piece # 6	RF FF	

Test Log

Tool Changed	Reason	Tool Life	
		No. of Pieces	h

FIG. X1.1 ASTM Machinability Data Record *(continued)*