Superalloys Developed by SPS Technologies for Aerospace Fasteners

SPS TECHNOLOGIES
Aerospace Fasteners Group

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SPS Technologies Superalloys...An Overview

Superalloys used for aerospace fasteners require a combination of mechanical strength, notch toughness, elevated temperature capability and corrosion/oxidation resistance.

Typical superalloy requirements

Mechanical strength requirements might include tensile, shear, fatigue, creep and/or stress rupture strengths, depending on the application demands. Strength requirements have increased as new developments in engine design and other technologies have arisen.

The continual need for greater thrust output and better fuel efficiency has resulted in faster-spinning, hotter-running gas turbine engines. This, in turn, has created the need for alloys that can withstand higher stresses and temperatures, a trend that is expected to continue. Below is a chart that shows the strength/operating temperature niche occupied by many of the alloys used at SPS.

Another critical material property is the ability to resist corrosion at ambient and elevated temperatures, including general corrosion, crevice corrosion, stress corrosion, oxidation and sulfidation. The positions the SPS alloys occupy in the Galvanic series shown on this page confirm their outstanding corrosion resistance. For joints exposed to potentially corrosive environments, the fastener should be galvanically compatible with the joint. That is, the materials used should be relatively close on the galvanic series. If this is not practical, platings or coatings can be applied to the "noble" corrosion resistant fasteners to promote galvanic compatibility with structures assembled from more "active" materials, such as aluminum alloys.

It is important to understand that the properties of a superalloy are not merely the result of its composition. Material processing and fastener manufacturing play roles in achieving the desired combination of properties. Cold working, thermal treatments and the sequence of critical manufacturing operations significantly enhance performance.

SPS Fastener Alloys for Elevated Temperatures

Room Temperature Tensile Strength, ksi	Maximum Use Temperature, °F: 700	800	900	1000	1100	1200	1300	1350	1400
260	*MP35N*		H-11		*MP159*				
240									
220			CW 718 or H-11					*AEREX 350*	
200			CW A-286 or AMS 6304						
180				AMS 6304		STA 718			
160									Waspaloy
140						STA A-286			
120		CW 304 S/S							

Key: STA = Solution Treated and Aged CW = Cold-Worked and Aged

This chart identifies the strength/maximum operating temperature niche for many of the fastener alloys used by SPS.

Galvanic Series of Metals and Alloys Ladder

Noble

- Graphite
- Platinum
- Gold
- Titanium
- MP35N®
- MP159®
- AEREX™ 350
- Ni-Base Superalloys
- Silver
- A-286
- Stainless Steel - Passive
- Copper
- Nickel-Copper Alloys
- Bronzes
- Brass
- Nickel
- Lead
- Tin
- Stainless Steel - Active
- Carbon & Alloy Steel
- Cadmium
- Aluminum
- Zinc
- Magnesium

Active

The galvanic series is a list of metals and alloys arranged according to their relative corrosion potentials.

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SPS superalloys

Over the years, SPS Technologies has developed three proprietary superalloys to satisfy the increasing demands among high technology fastener users for the performance advantages described here.

MP35N was the first fastener superalloy developed by SPS Technologies. It provided the unique combination of high strength and outstanding corrosion resistance, with a 750°F temperature capability.

To meet the higher operating demands of turbine engine manufacturers, SPS Technologies developed MP159, which added an 1100°F operating temperature capability to the high strength and corrosion resistance advantages of MP35N.

AEREX 350, the newest superalloy offering from SPS, pushes the operating temperature envelope to 1350°F, while retaining excellent strength and corrosion resistance. No other fastener alloy can match this combination of properties.

Where SPS superalloys are used

Marine, space and medical applications are just a few of the environments that challenge the superalloys made by SPS. Other applications are...

- Space Shuttle Orbiter & Solid Rocket Motors
- Aircraft Structure & Landing Gears
- Aircraft Gas Turbine Engines
- Gas Turbine Engines for Power Generation
- High-Performance Automotive Engines
- Marine—Ships, Submarines, Naval Aircraft
- Petrochemical Equipment
- Chemical Processing Equipment
- Medical X-Ray Imaging Equipment
- Cryogenic Uses

Metallographic sample preparation and examination of optical microscopy verifies proper material processing and fastener manufacturing.

Developmental Support

Cannon-Muskegon Corp., a subsidiary of SPS Technologies, provided significant support in the development of AEREX 350, the newest member of the SPS superalloy family. Cannon-Muskegon specializes in superalloy R&D, design and manufacturing for a range of medical, aerospace, petrochemical, marine and other components where strength, corrosion resistance and high-temperature performance are critical.

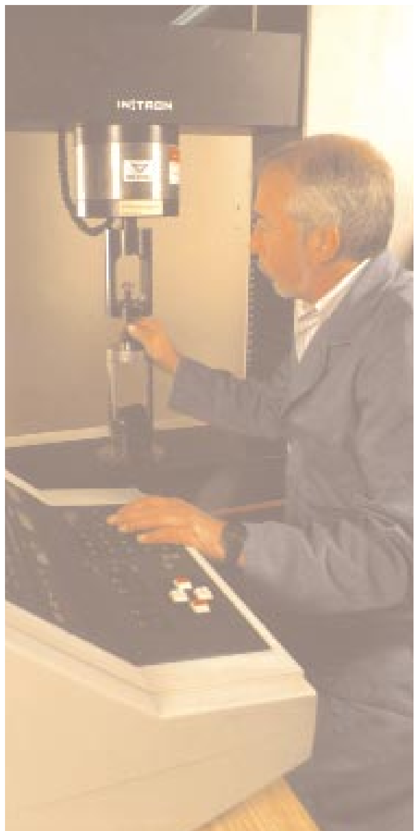
Cannon Muskegon's support continues today with the firm's analytical laboratory providing alloy composition and metallurgical purity testing. Research and development into new and better fastener alloys is on-going at Cannon-Muskegon, as well.

Future Superalloys

SPS Technologies is continuing its search for next generation superalloys to meet the anticipated fastener requirements of OEM's. The company has made significant investments in facilities and on-going R&D to stay ahead of the demand curve for superalloys that can perform in hotter, colder, more corrosion-resistant, more stressful environments.

Chemical Compositions (weight percent)

Element	MP35N	MP159	AEREX 350	Function
Ni	35	BAL	BAL	Matrix strengtheners by solid solution and cold-work induced phase transformation (fcc → hcp)
Co	BAL	36	25	
Cr	20	19	17	
Mo	10	7	3	
Ti	1 max	2.9	2.2	Gamma prime strengtheners
Al	—	0.2	1.1	
Nb	—	0.5	1.1	
Ta	—	—	4	Matrix and gamma prime strengtheners
W	—	—	2	
Fe	1 max	9	—	Reduces mix cost and provides sigma phase control
C	0.025 max	0.04 max	0.025 max	Grain boundary strengtheners
B	0.01 max	0.03 max	0.025 max	



SPS utilizes sophisticated testing machines to measure material and fastener property levels.

MP35N® SUPERALLOY

MP35N Basics

MP35N, the first in the line of high performance SPS superalloys, helped SPS Technologies establish itself as the leading supplier of fasteners for the Space Shuttle. The alloy's combination of high strength, outstanding corrosion resistance and excellent cryogenic properties meet the requirements for airframe and other Shuttle fastener applications.

Since its development, MP35N has been successfully used in applications outside of the aerospace industry. For instance, it is the highest strength material approved for structural components in aggressive, sour well environments (NACE specification MR0175 Sulfide Stress Cracking Resistant Metallic Materials for Oil Equipment).

MP35N material used for the manufacture of SPS fasteners conforms to the requirements of the aerospace material specification AMS 5844.

Nominal Composition

Nickel	35%
Cobalt	35%
Chromium	20%
Molybdenum	10%

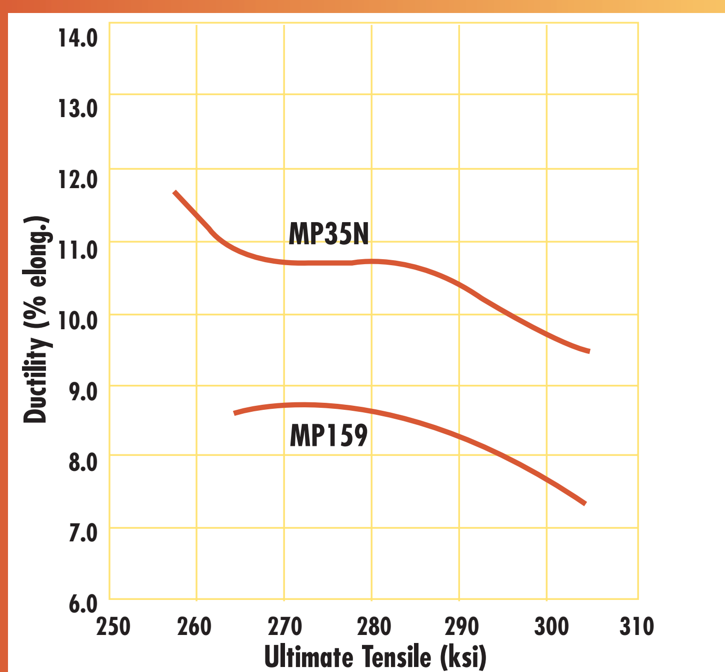
Metallurgical Strengthening Mechanisms

The prime strengthening mechanism in this alloy is the solid state phase transformation of part of the matrix from a face-centered cubic (fcc) crystal structure to a hexagonal close-packed (hcp) structure by cold working. This transformation occurs because of the high cobalt content in the alloy, and has been termed "the MULTIPHASE reaction." The presence of two distinct crystal structures poses a barrier to the motion of dislocations and leads to pronounced strengthening. Subsequent age hardening acts to stabilize these two phases through the process of solute partitioning, which contributes to further strengthening.

MP35N Properties Profile

- High strength coupled with excellent ductility and toughness
- Most corrosion resistant fastener alloy available...resists general corrosion, stress-corrosion cracking and crevice corrosion
- Maximum operating temperature of 750°F
- Highest fatigue strength of corrosion resistant fastener materials
- Shear strength of 145 ksi minimum has been the highest of the corrosion resistant fastener materials for many years

Ultimate Tensile vs. Elongation



This graph details the high levels of ductility exhibited by MP35N and MP159 over their typical strength range. The combination of high strength and toughness is an important factor for fastener design.

MP35N Corrosion Resistance

MP35N is often selected as a fastener alloy for its ability to resist stress corrosion cracking.

In laboratory tests, MP35N alloy samples were loaded to 90% of their proportional limit and alternately immersion tested in 3% salt solution for 10 minutes and in moving air for 50 minutes. After 2500 hours, no evidence of general corrosion or cracking appeared.

The table below compares the corrosion rate, in mils per year, of MP35N and three other corrosion resistant alloys in an accelerated corrosion test at 120°F. For all three chloride containing environments, the MP35N specimens exhibited no discernible surface or crevice corrosion.

Crevice corrosion tests were performed on MP35N, MP159, 13-8Mo and Custom 455 alloy bolts in a 10% ferric chloride solution. Several bands of electroplater's tape were applied to the bolts to promote the conditions necessary for crevice corrosion. Following 6 hours of exposure to the solution, Multiphase alloy bolts exhibited no visible evidence of corrosion while the other alloy bolts experienced extensive attack.

Corrosion of Alloys in Chloride Solutions at 120°F (mils/yr.)

Alloy	Condition	10% HCl + 1% $FeCl_3$	10% NaCl + HCl (pH=2)	10% $FeCl_3$
MP35N	Surface	0.0	0.0	0.0
	Crevice	No attack	No attack	No attack
Hastelloy C	Surface	0.7	0.1	0.0
	Crevice	No attack	No attack	No attack
Hastelloy F	Surface	13.0	0.1	0.0
	Crevice	No attack	No attack	No attack
316 S/S	Surface	50	5.0	>50.0
	Crevice	Attacked	Attacked	Attacked

Connecting rod application.

For more corrosion test data ask for SPS Product Report No. 5817, "Multiphase Alloy Environmental Resistance."

MP35N Fastener Applications

- Airframes
- Space Shuttle structure
- Tie rods
- Petrochemical equipment
- Cryogenic uses
- Marine equipment
- Submersibles
- Racing engine connecting rod bolts

Bolts crevice corrosion tested in 10% ferric chloride solution. The MP35N and MP159 alloy bolts show no visible evidence of attack, in sharp contrast to the other two high strength fastener alloys.

MP159® SUPERALLOY

MP159 Basics

MP159 was developed in response to the need for a fastener alloy that could perform under the higher operating temperatures developed by turbine engines and other high performance motors. MP159 has advantages similar to MP35N, but can perform in applications up to 1100°F, and is suitable for short term use at even higher temperatures. This capability makes MP159 alloy fasteners desirable for use in jet engines, rocket motors and other applications.

MP159 alloy's unique attributes led to its use for high strength landing gear bolts on commercial aircraft and to secure the Space Shuttle aboard its Boeing 747 ferry plane, as well as applications in the solid rocket boosters.

MP159 also exhibits excellent forgeability, superior to that of MP35N, which allows the manufacture of tension rated, 260 ksi tensile strength bolts above 0.75 inch diameter.

Nominal Composition

Cobalt	36%
Nickel	25%
Chromium	19%
Iron	9%
Molybdenum	7%
Titanium	3%
Columbium	0.6%
Aluminum	0.2%

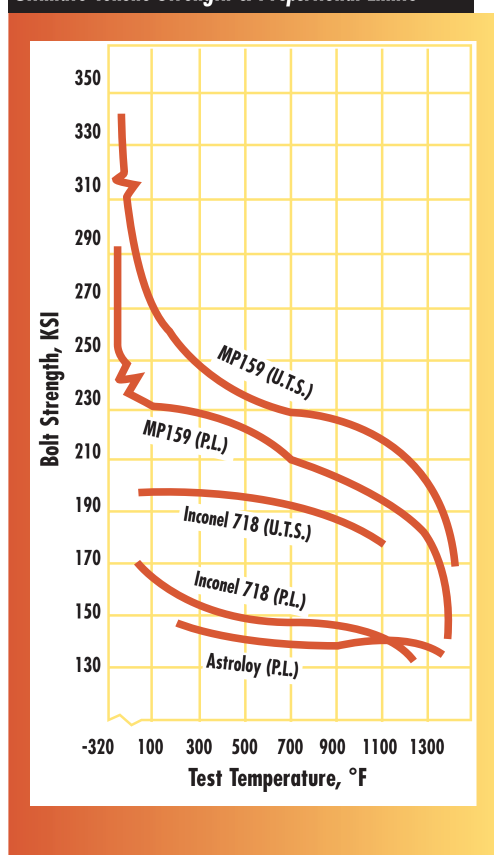
Metallurgical Strengthening Mechanisms

Like MP35N, this alloy undergoes the MULTIPHASE reaction, but also benefits from a second strengthening mechanism. Elements have also been added to the chemical composition to cause the precipitation of the gamma prime (γ') phase during age hardening. The gamma prime phase, which forms in many conventional nickel-base superalloys, is responsible for high-temperature strength.

MP159 Properties Profile

- High strength coupled with excellent ductility and toughness as illustrated in the graph on page 6
- Higher operating temperature than MP35N: 1100°F
- High creep strength at 1100°F
- Highly resistant to stress relaxation at operating temperatures; clamping load is maintained
- Capable of being forged and manufactured into complex configurations
- Corrosion resistance equivalent to that of MP35N
- Excellent fatigue resistance

Ultimate Tensile Strength & Proportional Limits



MP159 provides high yield and ultimate tensile strengths from cryogenic temperatures up to 1100°F.

MP159 Corrosion Resistance

Extensive laboratory testing of MP159 bolts has verified the alloy's excellent resistance to crevice corrosion, stress corrosion cracking and hydrogen embrittlement:

Resistance to crevice corrosion was demonstrated in a 10% ferric chloride solution test, reported in the MP35N section of this literature.

Stress corrosion cracking resistance was evaluated by loading MP159 alloy bolts to 75% of the minimum ultimate tensile strength and alternately immersing the loaded bolts in a 3.5% NaCl solution for 10 minutes and air drying for 50 minutes in accordance with MIL-STD-1312, test no. 9 procedures. After 5000 hours of testing, the bolts were sound, free of cracks and any visible corrosion.

Salt swab tests were performed on MP159 alloy bolts loaded to 75% of the minimum ultimate tensile strength in aluminum alloy cylinders. A salt solution was applied to the bolts every 100 hours. These conditions promote the cathodic generation of hydrogen on the bolt surface. After 1000 hours of this severe test, no bolt failures occurred, indicating exceptional resistance of MP159 to galvanically induced hydrogen embrittlement.

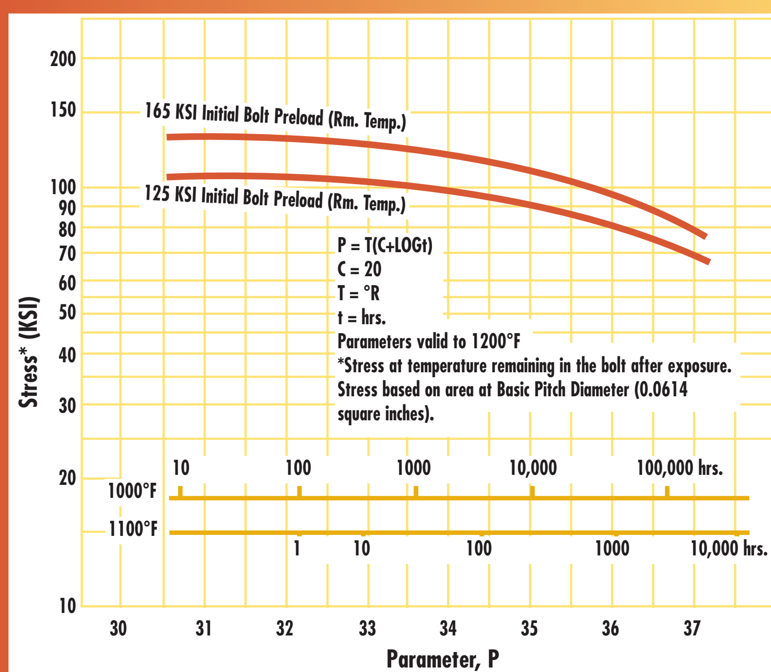
For further information on MP159 properties, ask for SPS Product Report No. 5533, "The Evaluation of a 260 KSI High Temperature, High Strength, Corrosion Resistant Tension Fastener Made from Multiphase Alloy MP159."

MP159 Applications

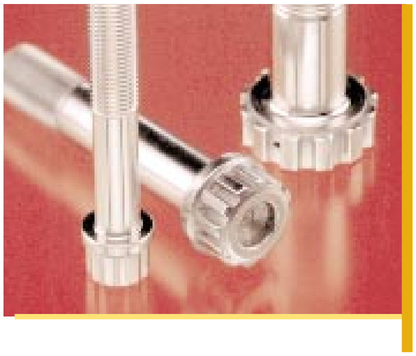
- Gas turbine engines
- Airframes
- Shuttle propulsion system
- Aircraft landing gear
- Marine equipment
- Chemical processing apparatus
- Petrochemical refineries
- Pulp and paper processing plants
- Power generation equipment

600 ton press used for forging large diameter MP159 alloy bolts.

Stress Relaxation



Retention of bolt preload (clamping load) following exposure to elevated temperature service is essential for maintaining joint integrity. The change in bolt preload over time at various temperatures can be estimated from relaxation tests conducted in accordance with MIL-STD-1312, test no. 17. The above curves plotted on a Larson-Miller parameter scale were generated from .312-24 UNJF size MP159 bolts preloaded in Waspaloy cylinders and nuts to the indicated initial stresses. Relaxation is also influenced by joint and nut materials, but the curves can be used to determine the approximate loss of preload in a bolt as a function of preload, temperature and time.



AEREX 350® SUPERALLOY

AEREX 350 Basics

As gas turbine engine technology and materials technology advanced hand-in-hand, new alloys were developed for blades, vanes, disks and other engine components. Many of these alloys were evaluated as potential fastener materials, but most lacked the unique blend of characteristics required. AEREX 350 became the first alloy in many years developed primarily for fasteners; and, counter to the typical trend, may eventually be used for turbine disk applications.

AEREX 350 has the highest temperature limit of the three SPS superalloys. This high-strength, corrosion-resistant nickel-based superalloy is suitable for demanding applications up to 1350°F.

Thermal expansion is also a critical factor in elevated-temperature fastener applications, as all the materials used in the "hot zones" must expand and contract at the same rate to maintain joint reliability. AEREX 350 exhibits a thermal expansion rate comparable to many engine component materials, as shown in the adjoining graph.

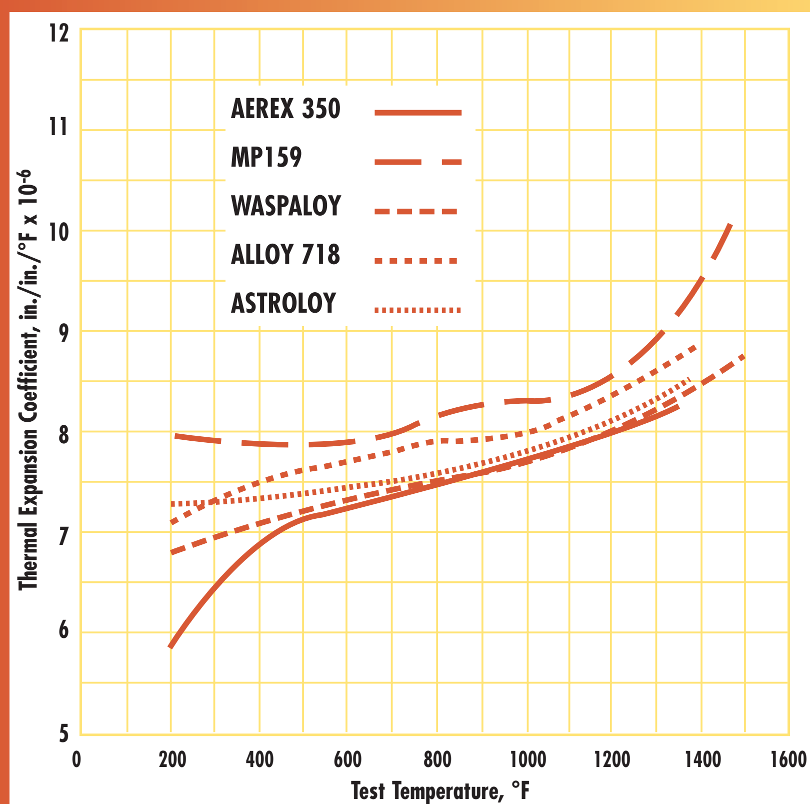
Nominal Composition

Nickel	45%
Cobalt	25%
Chromium	17%
Molybdenum	3%
Titanium	2.2%
Columbium	1.1%
Aluminum	1.1%
Tantalum	4%
Tungsten	2%

Metallurgical Strengthening Mechanisms

Like MP35N and MP159, this alloy undergoes the MULTIPHASE reaction, but also benefits from two additional strengthening mechanisms. Elements are also added to the chemical composition to cause precipitation of the gamma prime (γ') phase with higher temperature capability than MP159. Because this alloy is used at even higher temperatures than MP159, elements were added to the chemical composition to also cause the precipitation of eta (η) phase during thermal treatments. This phase contributes to notch toughness at elevated temperatures.

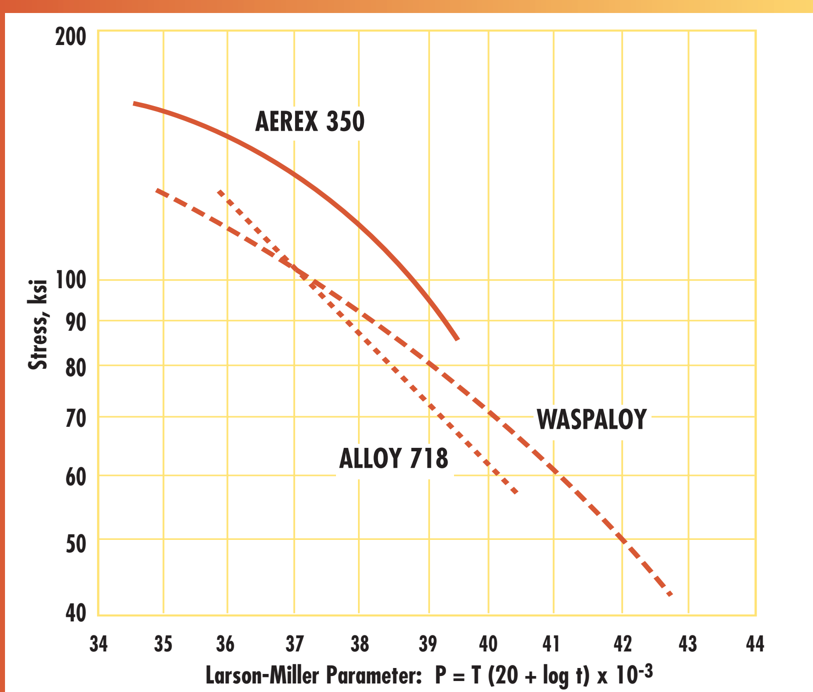
AEREX 350 ALLOY THERMAL EXPANSION



AEREX 350 Properties Profile

- Provides excellent stress rupture performance. Below is a graph that shows the rupture life advantage AEREX 350 enjoys over competing alloys.
- Capable of being forged and manufactured into complex configurations. Some representative parts made to date are displayed in the photograph on this page.
- Combines ambient temperature corrosion resistance with elevated temperature oxidation/sulfidation resistance
- Offers a coefficient of thermal expansion equivalent to that of other nickel-based alloys
- Displays excellent notch toughness and thermal stability
- Can be alternatively-processed to 150 KSI minimum shear strength for ambient temperature applications.
- Coupled with its inherent forgeability, AEREX 350 superalloy is capable of providing the largest diameter, highest shear-strength, corrosion resistant fasteners

STRESS RUPTURE STRENGTH OF BOLTING ALLOYS



Stress rupture data are typically plotted in a Larson-Miller format, which allows the three parameters of stress, temperature and time to be evaluated. The curves presented plot the combination of these three variables necessary to produce rupture in specimens. Stress rupture resistance increases towards the upper right quadrant.

AEREX 350 alloy's forgeability permits the complex head configurations seen on these small diameter bolts.

AEREX 350 Corrosion Resistance

AEREX 350 corrosion resistance is comparable to the MP159 alloy. Oxidation, sulfidation and hot salt corrosion resistance are comparable to that of Waspaloy. Contact SPS Technologies for more information.

AEREX 350 Applications

- Aerospace gas turbines
- Power generating gas turbines
- Aircraft landing gear
- Airframe

Mechanical and Physical Properties

Material Mechanical Properties

Minimum Tensile Property Requirements

	MP35N	MP159		AEREX 350	
	RT	RT	1100°F	RT	1350°F
UTS, ksi	260	260	205	220	155
0.2% YS, ksi	230	250	190	180	135
Elong., %	8	6	5	8	8
RA, %	35	22	15	20	20

Elevated Temperature Stress Rupture Requirements

	MP35N	MP159	AEREX 350
Temp./Stress/Time	None	1200°F/140 ksi/23 hrs. min.	1350°F/90 ksi/23 hrs. min.

Fastener Mechanical Properties

Minimum Tensile Property Requirements

	MP35N	MP159		AEREX 350	
	RT	RT	1100°F	RT	1350°F
UTS, ksi	260	260	205	220	155

Room Temperature Shear Strength Requirements

	MP35N	MP159	AEREX 350*
SS, ksi	145 min.	132 min.	130 min.

* Higher values are attainable with special processing. Call for details.

Elevated Temperature Stress Rupture Requirements

	MP35N	MP159	AEREX 350
Temp./Stress/Time	None	1200°F/140 ksi/23 hrs. min.	1350°F/90 ksi/23 hrs. min.

Physical Properties

	MP35N	MP159	AEREX 350
Density	0.304 lb./in.^{3} 8.43 g/cm^3	0.302 lb./in.^{3} 8.37 g/cm^3	0.311 lb./in.^{3} 8.62 g/cm^3
Melting Range	2400 to 2625°F 1315 to 1440°C	2300 to 2525°F 1260 to 1385°C	2360 to 2487°F 1293 to 1364°C

Coefficient of Thermal Expansion

MP35N

Temperature		Coefficient	
		in./in./°F	mm/mm/°C
70°F to	21°C to	x 10^{-6}	x 10^{-6}
200	93	7.1	12.8
400	204	7.6	13.7
600	316	8.2	14.8
800	427	8.3	14.9
1000	538	8.7	15.7

MP159

Temperature		Coefficient	
		in./in./°F	mm/mm/°C
70°F to	21°C to	x 10^{-6}	x 10^{-6}
212	100	7.95	14.3
392	200	7.90	14.2
572	300	7.88	14.2
752	400	8.09	14.6
932	500	8.29	14.9
1112	600	8.39	15.1
1292	700	8.90	16.0
1472	800	10.13	18.2

AEREX 350

Temperature		Coefficient	
		in./in./°F	mm/mm/°C
70°F to	21°C to	x 10^{-6}	x 10^{-6}
800	425	7.5	13.5
1000	540	7.7	13.9
1200	650	8.0	14.4
1300	705	8.2	14.8

Elastic and Shear Moduli

MP35N
Elastic Modulus

Temperature		psi x 10^6 (Mpa x 10^3)	
°F	°C	Annealed	Cold Worked and Aged
78	26	33.76 (232.8)	34.05 (234.8)
450	232	31.33 (216.0)	31.76 (219.0)
900	482	29.15 (201.0)	29.19 (201.3)

Shear Modulus

Temperature		psi x 10^6 (Mpa x 10^3)	
°F	°C	Annealed	Cold Worked and Aged
78	26	12.09 (83.36)	11.74 (60.95)
450	232	11.29 (77.84)	10.84 (74.74)
900	482	10.24 (70.60)	9.83 (67.78)

MP159
Elastic Modulus

Temperature		psi x 10^6 (Mpa x 10^3)	
°F	°C	Annealed	Cold Worked and Aged
78	26	32.2 (222)	35.3 (243)
450	232	30.2 (211)	32.8 (226)
900	482	27.1 (187)	29.3 (202)

Shear Modulus

Temperature		psi x 10^6 (Mpa x 10^3)	
°F	°C	Annealed	Cold Worked and Aged
78	26	11.7 (81)	11.3 (78)
450	232	11..0 (76)	10.5 (72)
900	482	9.9 (68)	9.4 (65)

AEREX 350
Elastic Modulus

Temperature	Msi (Gpa)	
°F	°C	Cold Worked and Aged
72	22	31.3 (216)
437	225	29.8 (206)
613	323	27.9 (192)
892	478	26.9 (185)
1011	544	25.4 (175)
1359	737	22.1 (152)

Shear Modulus

Temperature	Msi (Gpa)	
°F	°C	Cold Worked and Aged
72	22	12.2 (83.8)
437	225	11.5 (79.6)
613	323	10.7 (73.4)
892	478	10.3 (70.9)
1011	544	9.72 (67.0)
1359	737	8.25 (56.9)

Only basic properties were included here in the interest of space. Please contact SPS Technologies for information on specific properties not included. A full range of test results for both alloy materials and fasteners is also available.

Specifications

	Material	Bolt
MP35N	AMS 5844	AS 7468
MP159	AMS 5842	AS 7475
AEREX 350	Pending	Pending

Comprehensive Technical Support Available

SPS Technologies maintains advanced production facilities and capabilities for the design and manufacture of high technology, precision fasteners and mission-critical components. Tell us what the design specifications are for your superalloy bolts and our applications engineers will work with you to produce a product that meets and exceeds your requirements. We can also design and manufacturer matching nuts in the specific configuration that meets your joint design needs.

MP35N, MP159 and AEREX 350 are registered trademarks of SPS Technologies. Waspaloy is a registered trademark of United Technologies Corporation.

SPS TECHNOLOGIES
Aerospace Fasteners Group

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