



Metals Handbook

Desk Edition

ASM
INTERNATIONAL



Metals Handbook Desk Edition, Second Edition was published in 1998. It was prepared under the direction of the ASM International Handbook Committee. The **Desk Edition** was edited by Joseph R. Davis.

Editorial Advisory Board

- Peter J. Blau, Oak Ridge National Laboratory
- Rodney R. Boyer, Boeing Commercial Airplane Group
- Kenneth H. Eckelmeyer, Sandia National Laboratories
- Dennis D. Huffman, The Timken Company
- Lawrence J. Korb, Rockwell International
- David V. Neff, Metallurgical Systems Company LP
- David LeRoy Olson, Colorado School of Mines
- Dennis B. O'Neil, Caterpillar Inc.
- Thomas S. Piwonka, University of Alabama
- S. Lee Semiatin, Wright Laboratory
- George F. Vander Voort, Buehler Ltd.
- Harry W. Walton, The Torrington Company

Foreword to the Print Edition

ASM International is proud to mark the 75th anniversary of ASM Handbooks. In 1923, the American Society for Steel Treating (later the American Society for Metals, now ASM International) published a small loose-leaf collection of data sheets--the first edition of what became known as **Metals Handbook**. The series has developed over the years into a multivolume collection of reference books--each volume a thorough, comprehensive, and authoritative treatise on the subject to which it is devoted. The series--now titled **ASM Handbook**--continues to evolve and expand to serve the changing needs of metallurgy professionals throughout the world. One example of this evolution is the release this year of the **ASM Handbook** on CD-ROM.

This year also marks the 50th anniversary of the classic 1948 edition of **Metals Handbook**--the last "regular" edition to be contained in one volume. The 1948 edition was the inspiration for the first **Metals Handbook Desk Edition**, published almost 15 years ago. This Second Edition is intended to serve the same function as its two predecessors: to provide an accessible, convenient, and practical single-volume first reference to all of metals technology.

It was with some trepidation that ASM International entered into the project to revise and update the **Desk Edition**. The task seemed overwhelming. The **ASM Handbook** series had grown to 20 current volumes--almost twice as many as were in existence when the first **Desk Edition** was compiled. Would it be possible to create a work that included all of the vital information from the first edition, plus the most significant knowledge and data compiled in the years since its release, and still remain within the physical limits of a single volume?

We believe that the new **Metals Handbook Desk Edition** more than meets that objective. The credit for this monumental achievement belongs to Joseph R. Davis. Joe was Handbook Editor for many years at ASM, and his extraordinary knowledge of the handbooks along with his considerable editorial skills made him uniquely qualified to oversee this project. We are grateful to Joe for his hard work and for his commitment to creating the best **Desk Edition** possible. To assist in this effort, Joe assembled an outstanding Editorial Advisory Board, made up of many longtime handbook contributors and friends of ASM, and we extend our thanks to them as well. We also wish to recognize the ASM editorial and production staff members for their dedicated efforts on this Volume.

Of course, we are especially grateful to the thousands of metallurgy professionals who have contributed to ASM Handbooks over the past 75 years. Their willingness to share their knowledge and expertise--as authors, reviewers, volume organizers, and Handbook Committee members--has made this book possible. With their ongoing support, ASM Handbooks will continue to thrive for at least another 75 years.

Alton D. Romig, Jr.
President, ASM International

Michael J. DeHaemer
Managing Director, ASM International

Preface

The **Metals Handbook Desk Edition** is intended to serve as a comprehensive single-volume reference source on the properties, selection, processing, testing, and characterization of metals and their alloys. Although the information presented in this Volume is drawn principally from the 20 volumes of the **ASM Handbook** series, it should not be considered simply an abridged version of the larger work. Instead, the **Metals Handbook Desk Edition** draws upon the complete arsenal of ASM products--both print and electronic--as well as other key sources of information originating from other publications, company literature, technical societies, and government agencies.

Volume Content

Because of the familiarity, success, and ease-of-use of the original **Desk Edition** published in 1984, it was determined from the outset of the project that the editorial approach and outline for the new edition should follow in a similar manner. The challenge in successfully revising the first edition was to determine what strategic additions (or reductions) and improvements should be made. Complicating this task was the fact that a complete edition cycle of the **ASM Handbook** (including completely new volumes on corrosion, tribology, materials characterization, and other topics) had been published since the earlier edition was produced. To ensure that the best product possible resulted from the revision/updating process, a 12-member Editorial Advisory Board representing industry, academia, and research laboratories was formed. All board members have been key contributors to the Handbook series or have been involved with other important ASM activities over the past decade. Under their guidance, an outline was established for the second edition that divided the book into five major parts: General Information; Irons, Steels, and High-Performance Alloys; Nonferrous Alloys and Special-Purpose Materials; Processing; and Testing, Inspection, and Materials Characterization.

General Information contains a glossary of more than 3000 terms, a collection of common engineering tables, and graphs comparing properties of metals and nonmetals. It also includes contributions on crystal structure, practical uses of phase diagrams, engineering design, and factors to be considered in the materials selection process.

Irons, Steels, and High-Performance Alloys. Emphasis is placed on properties and selection of ferrous alloys and heat-resistant superalloys. Important relationships between structure and properties in irons and steels are described. The effects of modern steelmaking practices on properties are examined, as is the influence of improved melting/refining methods on superalloy performance. New or expanded information is presented on austempered ductile irons, high-strength low-alloy steels, stainless steels (including duplex stainless steels), and powder metallurgy steels.

Nonferrous Alloys and Special-Purpose Materials comprises 14 major sections that describe the properties and selection of conventional (structural) nonferrous alloys and materials used for such special-purpose applications as magnetic or electrical devices, biomedical devices, and advanced aircraft/aerospace components. Metal-matrix composites and structural intermetallics--more recently developed materials not covered in the previous **Desk Edition**--are also described.

Processing. Processes extending through the entire life-cycle of a component are described, including extractive metallurgy, casting, forming, heat treatment, joining, surface cleaning, finishing and coating, and recycling. An entirely new section on powder metallurgy has also been added. The increased coverage of recycling technology reflects the response of the metals industry to environmental concerns.

Testing, Inspection, and Materials Characterization. In addition to offering information on failure analysis, fractography, nondestructive testing, mechanical testing, and metallography, a new section describes in practical terms the selection of characterization methods for bulk elemental analysis, bulk microstructural analysis, and surface analysis. New information on wear testing and tests for evaluating stress-corrosion cracking and hydrogen embrittlement is also presented.

Acknowledgments

Before acknowledging contributors to the present volume, it is important to recognize the outstanding work of the first edition's editors: Timothy L. Gall and Howard E. Boyer (sadly, Howard passed away in 1990). Tim was truly the driving force behind the original **Desk Edition**. His vision, combined with Howard's superlative technical craftsmanship, resulted in what most consider the "flagship" publication of ASM.

In order to build upon the foundation of the first edition, the present editor had to call on many old friends and colleagues. In addition to serving on the Editorial Advisory Board, the following individuals were major contributors to the second edition: Kenneth H. Eckelmeyer (Sandia National Laboratories) authored the Section "Materials Characterization" and co-authored the article "Very High Density Metals." Ken, who has contributed numerous handbook articles over the years, was also a key member of the Organizing Committee for **Materials Characterization**, Volume 10 of the **ASM Handbook**, published in 1986. George F. Vander Voort (Buehler Ltd.) revised the Section "Metallography" and contributed to the Section "Fractography." George, who is the most prolific author in the 75 year history of the **Metals/ASM Handbook**, has contributed definitive reviews on embrittlement mechanisms in irons and steel, the use of light microscopy for metallographic and fractographic analysis, and image analysis for quantitative determination of microstructural constituents. Rodney R. Boyer (Boeing Commercial Airplane Group) revised the Section "Titanium and Titanium Alloys" and helped revise other articles throughout the Handbook that deal with titanium alloys. Rod also served as the principal editor of the **Materials Properties Handbook: Titanium Alloys**, published by ASM in 1994. Thomas S. Piwonka (University of Alabama) authored the Section "Casting." Tom also served as a section chairman and contributing author for **Casting**, Volume 15 of the **ASM Handbook**, published in 1988. Peter J. Blau (Oak Ridge National Laboratory) authored the article "Wear Testing." Peter also served as volume chairman of **Friction, Lubrication, and Wear Technology**, Volume 18 of the **ASM Handbook**, published in 1992.

Other notable contributors include Hugh Baker (Consulting Editor, ASM International), who authored the Section "Structure and Properties of Metals" and reviewed the Section "Magnesium and Magnesium Alloys." Hugh, who served on the Handbook staff from 1970 to 1979, was also the editor of **Alloy Phase Diagrams**, Volume 3 of **ASM Handbook**, published in 1992. Matthew J. Donachie (Rensselaer at Hartford) and Stephen J. Donachie (Special Metals Corporation) revised the Section "Superalloys." Matt, who edited the **Superalloys Source Book** published by ASM in 1984, also authored the article "Biomaterials." Erhard Klar (OMG Americas, retired) authored the Section "Powder Metallurgy" and reviewed several other P/M-related articles. Erhard also served as volume coordinator of **Powder Metallurgy**, Volume 7 of the **ASM Handbook**, published in 1984. Brajendra Mishra (Colorado School of Mines) authored the Sections "Steelmaking Practices and Their Influence on Properties" and "Extractive Metallurgy." John C. Bittence (Welshfield Studios) revised the Section "Recycling and Life-Cycle Analysis" and assisted in editing the Sections "Forming" and "Forging."

The efforts of the ASM staff must also be acknowledged. In particular, I would like to thank veteran technical editors Steven R. Lampman and Edward J. Kubel, Jr. for their help in completing the Sections "Failure Analysis," "Nondestructive Testing," and "Mechanical, Wear, and Corrosion Testing," and Scott D. Henry, Assistant Director of Technical Publications, for his unflagging support and patience throughout the project. The kind assistance of the ASM Library is also duly noted.

As a result of the collective experience and talent of all those listed above, the rich tradition of the **Metals Handbook** continues. Whether in print form, CD-ROM format, via the Internet, or some other remarkable vehicle made possible by the computer age, it will undoubtedly continue to serve the metallurgical community well into the next millennium. The best is yet to come!

Joseph R. Davis
Davis & Associates, Chagrin Falls, Ohio

Source Acknowledgments

Major sources for the Sections in this Handbook are listed below. Additional source information is provided in the reference lists that appear in many of the articles.

Structure and Properties of Metals

Much of this Section was adapted from **Alloy Phase Diagrams**, Volume 3, **ASM Handbook**, 1992, pages 1-1 to 1-29.

Design Considerations and Materials Selection

Much of this Section was adapted from various articles appearing in *Materials Selection and Design*, Volume 20, *ASM Handbook*, 1997.

Structure/Property Relationships in Irons and Steels

Much of this Section was adapted from various articles appearing in *Materials Selection and Design*, Volume 20, *ASM Handbook*, 1997, pages 357-382.

Carbon and Alloy Steels

This Section was condensed from *Properties and Selection: Irons, Steels, and High-Performance Alloys*, Vol 1, *ASM Handbook*, 1990, pages 105 to 822. Supplemental information was also adapted from the *ASM Specialty Handbook: Carbon and Alloy Steels*, 1996, and *Fatigue and Fracture*, Vol 20, *ASM Handbook*, 1996.

Cast Irons

This Section was condensed from the *ASM Specialty Handbook: Cast Irons*, 1996, p 3 to 130.

Ferrous Powder Metallurgy Materials

This Section was condensed from *Properties and Selection: Irons, Steels, and High-Performance Alloys*, Volume 1, *ASM Handbook*, 1990, pages 800 to 821 and from *Powder Metallurgy*, Volume 7, *ASM Handbook*, 1984, pages 79 to 99.

Tool Steels

This Section was condensed from the *ASM Specialty Handbook: Tool Materials*, 1995, pages 10 to 20, 21 to 31, 119 to 153, and 383 to 395.

Stainless Steels

Much of this Section was condensed from the *ASM Specialty Handbook: Stainless Steels*, 1994. Supplemental information was also adapted from the *ASM Specialty Handbook: Heat-Resistant Materials*, 1997, pages 123 to 178.

Superalloys

For more detailed information on superalloys, the reader is referred to the *ASM Specialty Handbook: Heat-Resistant Materials* (see, in particular, pages 219 to 344).

Aluminum and Aluminum Alloys

This Section was assembled from a variety of sources, including *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2, *ASM Handbook*, 1990, pages 3 to 215; the *ASM Specialty Handbook: Aluminum and Aluminum Alloys*, 1993, pages 3 to 159; and *Corrosion*, Volume 13, *ASM Handbook*, 1987, pages 583 to 609. Updated statistical information and property data were obtained from the Aluminum Association Inc.

Copper and Copper Alloys

This Section was assembled from a variety of sources, including *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2, *ASM Handbook*, 1990, pages 216 to 427, *Corrosion*, Volume 13, *ASM Handbook*, 1987, pages 610 to 640, and *Materials Selection and Design*, Volume 20, *ASM Handbook*, 1997, pages 389 to 393. Updated statistical information and composition/property data were obtained from the Copper Development Association Inc.

Magnesium and Magnesium Alloys

This Section was condensed from *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2, *ASM Handbook*, 1990, pages 455 to 479, and from *Corrosion*, Volume 13, *ASM Handbook*, 1987, pages 740 to 754.

Titanium and Titanium Alloys

For more detailed information on titanium and titanium alloys, the reader is referred to the *Materials Properties Handbook: Titanium Alloys* published by ASM International in 1994 and to *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2 of *ASM Handbook*, 1990 (see pages 586 to 660).

Zinc and Zinc Alloys

This Section was condensed from *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2, *ASM Handbook*, 1990, pages 527 to 542, and from *Corrosion*, Volume 13, *ASM Handbook*, 1987, pages 432 to 445 and 755 to 769.

Tin and Tin Alloys

This Section was condensed from *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2, *ASM Handbook*, 1990, pages 517 to 526.

Lead and Lead Alloys

This Section was condensed from *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2, *ASM Handbook*, 1990, pages 543 to 556, and from *Corrosion*, Volume 13, *ASM Handbook*, 1987, pages 784 to 792.

Nickel and Nickel Alloys

This Section was condensed from *Corrosion*, Volume 13, *ASM Handbook*, 1987, pages 641 to 657, and *Materials Selection and Design*, Volume 20, *ASM Handbook*, 1997, pages 393 to 396.

Cobalt and Cobalt Alloys

This Section was condensed from *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2, *ASM Handbook*, 1990, pages 446 to 454.

Zirconium and Hafnium

This Section was condensed from *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2, *ASM Handbook*, 1990, pages 661 to 669, and from *Corrosion*, Volume 13, *ASM Handbook*, 1987, p 707 to 721.

Precious Metals and Alloys

This Section was condensed from *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2, *ASM Handbook*, 1990, pages 688 to 719.

Refractory Metals and Alloys

This Section was condensed from *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2, *ASM Handbook*, 1990, pages 557 to 585, and from the *ASM Specialty Handbook: Heat-Resistant Materials*, 1997, pages 361 to 382.

Cemented Carbides and Cermets

This Section was condensed from *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2, *ASM Handbook*, 1990, pages 950 to 977, and from *Friction, Lubrication, and Wear Technology*, Volume 18, *ASM Handbook*, 1992, pages 795 to 800.

Special-Purpose Materials

Portions of this Section were condensed from *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2, *ASM Handbook*, 1990, pages 761 to 1089. Supplemental information was also adapted from the *ASM Specialty Handbook: Aluminum and Aluminum Alloys*, 1993, pages 160 to 179 (aluminum-matrix composites), *ASM Specialty Handbook: Heat-Resistant Materials*, 1997, p 389 to 414 (structural intermetallics), and *Friction, Lubrication, and Wear Technology*, Volume 18, *ASM Handbook*, 1992, pages 741 to 765 (sliding bearings and hardfacing alloys).

Forming

This Section was condensed from *Forming and Forging*, Volume 14, *ASM Handbook*, 1988.

Forging

This Section was condensed from *Forming and Forging*, Volume 14, *ASM Handbook*, 1988.

Powder Metallurgy

More detailed information on powder metallurgy can be found in *Powder Metal Technologies and Applications*, Volume 7, *ASM Handbook*, 1998.

Machining

This Section was condensed from *Machining*, Volume 16, *ASM Handbook*, 1989, and the *Machining Data Handbook*, 3rd ed., published by Metcut Research Associates, Inc., Cincinnati, OH. Supplemental information was also taken from *Surface Engineering*, Volume 5, *ASM Handbook*, 1994, and the *ASM Specialty Handbook: Tool Materials*, 1995.

Heat Treating

This Section was condensed from *Heat Treating*, Volume 4, *ASM Handbook*, 1991.

Joining

This Section was condensed from *Welding, Brazing, and Soldering*, Volume 6, *ASM Handbook*, 1993.

Surface Engineering

This Section was condensed from *Surface Engineering*, Volume 5, *ASM Handbook*, 1994. Supplemental information was also taken from *Materials Selection and Design*, Volume 20, *ASM Handbook*, 1997, pages 470 to 490.

Recycling and Life-Cycle Analysis

This Section was condensed from *Properties and Selection: Irons, Steels, and High-Performance Alloys*, Volume 1, *ASM Handbook*, 1990, pages 1023 to 1033; from *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Volume 2, *ASM Handbook*, 1990, pages 1205 to 1232; and from *Materials Selection and Design*, Volume 20, *ASM Handbook*, 1997, pages 96 to 103 and 131 to 138.

Failure Analysis

This Section was condensed from *Failure Analysis and Prevention*, Volume 11, *ASM Handbook*, 1986, and *Fatigue and Fracture*, Volume 19, *ASM Handbook*, 1996, pages 371 to 380.

Fractography

Parts of this Section were condensed from *Fractography*, Volume 12, *ASM Handbook*, 1987. Updated material from the previous *Metals Handbook Desk Edition*, 1984, is also included.

Nondestructive Testing

This Section was condensed from *Nondestructive Evaluation and Quality Control*, Volume 17, *ASM Handbook*, 1989.

Mechanical, Wear, and Corrosion Testing

This Section was condensed from *Mechanical Testing*, Volume 8, *ASM Handbook*, 1985, and from *Fatigue and Fracture*, Volume 19, *ASM Handbook*, 1996.

General Information

Officers and Trustees of ASM International (1997-1998)

Officers

- Alton D. Romig, Jr., President and Trustee , Sandia National Laboratories
- Hans H. Portisch, Vice President and Trustee , Krupp VDM Austria GmbH
- Michael J. DeHaemer , Secretary and Managing Director , ASM International
- W. Raymond Cribb, Treasurer , Brush Wellman Inc.
- George Krauss, Immediate Past President , Colorado School of Mines

Trustees

- Nicholas F. Fiore, Carpenter Technology Corporation
- Gerald G. Hoefft, Caterpillar Inc.
- Jennie S. Hwang, H-Technologies Group Inc.
- Thomas F. McCardle, Kolene Corporation
- Bhakta B. Rath, U.S. Naval Research Laboratory
- C. (Ravi) Ravindran, Ryerson Polytechnic University
- Darrell W. Smith, Michigan Technological University
- Leo G. Thompson, Lindberg Corporation
- James C. Williams, GE Aircraft Engines

Members of the ASM Handbook Committee (1997-1998)

- Michelle M. Gauthier , (Chair 1997-; Member 1990-) , Raytheon Electronic Systems
- Craig V. Darragh , (Vice Chair 1997-; Member 1989-) , The Timken Company
- Bruce P. Bardes (1993-) , Materials Technology Solutions Company
- Rodney R. Boyer (1982-1985; 1995-) , Boeing Commercial Airplane Group
- Toni M. Brugger (1993-) , Carpenter Technology Corporation
- R. Chattopadhyay (1996-) , Consultant
- Rosalind P. Cheslock (1994-)
- Aicha Elshabini-Riad (1990-) , Virginia Polytechnic Institute & State University
- Henry E. Fairman (1993-) , MQS Inspection Inc.
- Michael T. Hahn (1995-) , Northrop Grumman Corporation
- Larry D. Hanke (1994-) , Materials Evaluation and Engineering Inc.
- Jeffrey A. Hawk (1997-) , U.S. Department of Energy
- Dennis D. Huffman (1982-) , The Timken Company
- S. Jim Ibarra, Jr. (1991-) , Amoco Corporation
- Dwight Janoff (1995-) , FMC Corporation
- Paul J. Kovach (1995-) , Stress Engineering Services Inc.
- Peter W. Lee (1990-) , The Timken Company
- William L. Mankins (1989-)
- Mahi Sahoo (1993-) , CANMET
- Wilbur C. Simmons (1993-) , Army Research Office

- Karl P. Staudhammer (1997-) , Los Alamos National Laboratory
- Kenneth B. Tator (1991-) , KTA-Tator Inc.
- Malcolm C. Thomas (1993-) , Allison Engine Company
- George F. Vander Voort (1997-) , Buehler Ltd.
- Jeffrey Waldman (1995-) , Drexel University
- Dan Zhao (1996-) , Essex Group Inc.

Previous Chairs of the ASM Handbook Committee

- R.J. Austin, (1992-1994) (Member 1984-)
- L.B. Case, (1931-1933) (Member 1927-1933)
- T.D. Cooper , (1984-1986) (Member 1981-1986)
- E.O. Dixon, (1952-1954) (Member 1947-1955)
- R.L. Dowdell, (1938-1939)(Member 1935-1939)
- J.P. Gill, (1937) (Member 1934-1937)
- J.D. Graham, (1966-1968) (Member 1961-1970)
- J.F. Harper , (1923-1926) (Member 1923-1926)
- C.H. Herty, Jr., (1934-1936)(Member 1930-1936)
- D.D. Huffman, (1986-1990)(Member 1982-)
- J.B. Johnson, (1948-1951)(Member 1944-1951)
- L.J. Korb, (1983) (Member 1978-1983)
- R.W.E. Leiter , (1962-1963)(Member 1955-1958, 1960-1964)
- G.V. Lueresen, (1943-1947)(Member 1942-1947)
- G.N. Maniar, (1979-1980) (Member 1974-1980)
- W.L. Mankins, (1994-1997)(Member 1989-)
- J.L. McCall, (1982) (Member 1977-1982)
- W.J. Merten, (1927-1930) (Member 1923-1933)
- D.L. Olson, (1990-1992) (Member 1982-1988, 1989-1992)
- N.E. Promisel, (1955-1961)(Member 1954-1963)
- G.J. Shubat, (1973-1975) (Member 1966-1975)
- W.A. Stadtler, (1969-1972)(Member 1962-1972)
- R. Ward, (1976-1978) (Member 1972-1978)
- M.G.H. Wells, (1981) (Member 1976-1981)
- D.J. Wright, (1964-1965) (Member 1959-1967)

Staff

ASM International staff who contributed to the development of the Volume included Scott D. Henry, Assistant Director of Reference Publications; Grace M. Davidson, Manager of Handbook Production; Bonnie R. Sanders, Manager of Copy Editing; Kathleen S. Dragolich, Production Coordinator; Erika K. Baxter and Alexandra B. Hoskins, Copy Editors; Alexandru Popaz-Pauna, Candace K. Mullet, and Jill A. Kinson, Production Assistants. Editorial assistance was provided by Denise Kelly, Heather Lampman, and Mary Jane Riddlebaugh. The Volume was prepared under the direction of William W. Scott, Jr., Director of Technical Publications.

Conversion to Electronic Files

Metals Handbook Desk Edition was converted to electronic files in 2000. The conversion was based on the first printing (1998). No substantive changes were made to the content of the Volume, but some minor corrections and clarifications were made as needed.

ASM International staff who contributed to the conversion of the Volume included Sally Fahrenholz-Mann, Bonnie Sanders, Marlene Seuffert, Gayle Kalman, Scott Henry, and Robert Braddock. The electronic version was prepared under the direction of William W. Scott, Jr., Technical Director, and Michael J. DeHaemer, Managing Director.

Copyright Information (for Print Volume)

Copyright © 1998 by ASM International®

All rights reserved

No part of this book may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the written permission of the copyright owner.

First printing, December 1998

This book is a collective effort involving hundreds of technical specialists. It brings together a wealth of information from world-wide sources to help scientists, engineers, and technicians solve current and long-range problems.

Great care is taken in the compilation and production of this Volume, but it should be made clear that NO WARRANTIES, EXPRESS OR IMPLIED, INCLUDING, WITHOUT LIMITATION, WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, ARE GIVEN IN CONNECTION WITH THIS PUBLICATION. Although this information is believed to be accurate by ASM, ASM cannot guarantee that favorable results will be obtained from the use of this publication alone. This publication is intended for use by persons having technical skill, at their sole discretion and risk. Since the conditions of product or material use are outside of ASM's control, ASM assumes no liability or obligation in connection with any use of this information. No claim of any kind, whether as to products of information in this publication, and whether or not based on negligence, shall be greater in amount than the purchase price of this product or publication in respect of which damages are claimed. THE REMEDY HEREBY PROVIDED SHALL BE THE EXCLUSIVE AND SOLE REMEDY OF BUYER, AND IN NO EVENT SHALL EITHER PARTY BE LIABLE FOR SPECIAL, INDIRECT OR CONSEQUENTIAL DAMAGES WHETHER OR NOT CAUSED BY OR RESULTING FROM THE NEGLIGENCE OF SUCH PARTY. As with any material, evaluation of the material under enduse conditions prior to specification is essential. Therefore, specific testing under actual conditions is recommended.

Nothing contained in this book shall be construed as a grant of any right of manufacture, sale, use, or reproduction, in connection with any method, process, apparatus, product, composition, or system, whether or not covered by letters patent, copyright, or trademark, and nothing contained in this book shall be construed as a defense against any alleged infringement of letters patent, copyright, or trademark, or as a defense against liability for such infringement.

Comments, criticisms, and suggestions are invited, and should be forwarded to ASM International.

Library of Congress Cataloging-in-Publication Data (for Print Volume)

Metals handbook/edited by J.R. Davis; prepared under the direction of the ASM International Handbook Committee.-- Desk ed.; 2nd ed. Includes bibliographical references and index.

I. Metals--Handbooks, manuals, etc. I. Davis, J.R.

II. ASM International. Handbook Committee.

TA459.M288 1998 620.1'6 dc21 98-45866

SAN 204-7586

ISBN 0-87170-654-7