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Foreword

ASM International is pleased to publish a new edition of *Metallography and Microstructures*, Volume 9 of the *ASM Handbook* series. Metallography is a longstanding core interest of ASM International members, and this new Volume 9 reflects the continuing importance of metallography in metallurgical analyses for production quality control, research, engineering, and educational training. Since the 1985 edition of Volume 9, substantial changes have occurred in automation, equipment, preparation methodology, alloys, manufacturing technologies, and digital imaging. The new Volume 9 addresses these and other developments, as described in the Preface.

We commend the Volume Editor, George Vander Voort, for his vision and direction in revising *Metallography and Microstructures*. His familiarity with past and present volumes of the Handbook series has been instrumental in this project. His worldwide acquaintances with members of the metallographic community also have made this Volume an international effort with important contributions from authors around the world. Moreover, many thanks are extended to the devoted volunteers and ASM members, who have contributed their time and expertise as authors and reviewers. This Volume would not have been possible without their commitment. The sharing of their knowledge and experience is the basis for ASM International as their professional society.

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Policy on Units of Measure

By a resolution of its Board of Trustees, ASM International has adopted the practice of publishing data in both metric and customary U.S. units of measure. In preparing this Handbook, the editors have attempted to present data in metric units based primarily on Système International d'Unités (SI), with secondary mention of the corresponding values in customary U.S. units. The decision to use SI as the primary system of units was based on the aforementioned resolution of the Board of Trustees and the widespread use of metric units throughout the world.

For the most part, numerical engineering data in the text and in tables are presented in SI-based units with the customary U.S. equivalents in parentheses (text) or adjoining columns (tables). For example, pressure, stress, and strength are shown both in SI units, which are pascals (Pa) with a suitable prefix, and in customary U.S. units, which are pounds per square inch (psi). To save space, large values of psi have been converted to kips per square inch (ksi), where 1 ksi = 1000 psi. The metric tonne (kg $\times$ 10^3) has sometimes been shown in megagrams (Mg). Some strictly scientific data are presented in SI units only.

To clarify some illustrations, only one set of units is presented on artwork. References in the accompanying text to data in the illustrations are presented in both SI-based and customary U.S. units. On graphs and charts, grids corresponding to SI-based units usually appear along the left and bottom edges. Where appropriate, corresponding customary U.S. units appear along the top and right edges.

Data pertaining to a specification published by a specification-writing group may be given in only the units used in that specification or in dual units, depending on the nature of the data. For example, the typical yield strength of steel sheet made to a specification written in customary U.S. units would be presented in dual units, but the sheet thickness specified in that specification might be presented only in inches.

Data obtained according to standardized test methods for which the standard recommends a particular system of units are presented in the units of that system. Wherever feasible, equivalent units are also presented. Some statistical data may also be presented in only the original units used in the analysis.

Conversions and rounding have been done in accordance with IEEE/ASTM SI-10, with attention given to the number of significant digits in the original data. For example, an annealing temperature of 1570 °F contains three significant digits. In this case, the equivalent temperature would be given as 855 °C; the exact conversion to 854.44 °C would not be appropriate. For an invariant physical phenomenon that occurs at a precise temperature (such as the melting of pure silver), it would be appropriate to report the temperature as 961.93 °C or 1763.5 °F. In some instances (especially in tables and data compilations), temperature values in °C and °F are alternatives rather than conversions.

The policy of units of measure in this Handbook contains several exceptions to strict conformance to IEEE/ASTM SI-10; in each instance, the exception has been made in an effort to improve the clarity of the Handbook. The most notable exception is the use of g/cm^3 rather than kg/m^3 as the unit of measure for density (mass per unit volume).

SI practice requires that only one virgule (diagonal) appear in units formed by combination of several basic units. Therefore, all of the units preceding the virgule are in the numerator and all units following the virgule are in the denominator of the expression; no parentheses are required to prevent ambiguity.

Preface

This new edition of *Metallography and Microstructures,* Volume 9 of the *ASM Handbook* series, is quite different from the 1985 edition in several ways. One difference is that the citations of micrographs are integrated within the textual discussions on the metallography and microstructures of materials. This is distinctly different from the previous edition, in which the end of each article contained an atlas of many micrographs without citation in text. The atlas method in the previous edition was effective at that time, as micrograph collections are useful in making visual comparisons for different materials conditions and/or specimen preparation techniques. However, with the development of electronic publication, a new approach is possible, where a large collection of micrographs can be stored and searched electronically. This is the underlying concept of the newly released Micrograph Center as part of the ASM International Materials Information Online. This electronic archive provides a collection of the previously published micrograph atlases in the 8th and the 9th Editions *Metals Handbook.* As such, one objective of the new Volume 9 is to complement more closely the electronic archive of the Micrograph Center by moving away from an atlas format and by focusing more on representative micrographs that are visual tools in assisting experienced and new practitioners in the preparation and interpretation of micrographs.

The new Volume 9 also places more emphasis on the underlying physical metallurgy of alloys, as an important part in the interpretation and understanding of microstructural development. In this regard, formation of phase constituents is described in more detail in terms of the general concepts in physical metallurgy and key compositional categories of important alloy systems. Some coverage on phase diagrams is included, although binary phase diagrams are not collected to the same extent as in the 8th Edition *Metals Handbook,* Volume 8, *Metallography, Structures, and Phases Diagrams* (1973). This is because binary phase diagrams are covered extensively in other publications such as *ASM Handbook,* Volume 3, *Alloy Phase Diagrams,* and the *Desk Handbook: Phase Diagrams for Binary Alloys,* ASM International, 2000. In this volume, the key emphasis is on the concepts for using phase diagrams as a tool in metallographic interpretation and on the presentation of important binary-phase regions or the quasi-binary and pseudo-binary diagrams of key compositional components.

The new Volume 9 edition also provides important updates and new information reflecting the substantial changes in automation, equipment, consumable products, and preparation methodology, as well as new metals, alloys, and manufacturing technologies that have emerged since 1985. Expanded and new coverage includes:

- New articles on field metallography, digital imaging, and quantitative image analysis, quantitative metallography, and color metallography
- All-new articles on the metallography and microstructural interpretation of cast irons, coated steel, carbon and low-alloy steels, aluminum alloys, precious-metal alloys, titanium alloys, ceramics, and thermal spray coatings
- Substantially revised articles on metallography and microstructural interpretation of tool steels, stainless steels, copper alloys, P/M alloys, and cemented carbides
- New micrographs throughout
- More integrated in-text citation of micrograph images with respect to discussions on preparation techniques and alloy metallurgy
- Updated coverage on specimen-preparation techniques for both manual methods and semi-automatic machines
- Practical coverage on sectioning and specimen extraction
- Laboratory safety guide
- New expanded color section

The titles of new articles on metallurgical topics include:

- Metallography: An Introduction
- Physical Metallurgy Concepts in Interpretation of Microstructure
- Fundamentals of Solidification
- Solidification Structures of Steels and Cast Iron
- Solidification Structures of Aluminum Alloys
- Solidification Structures of Titanium Alloys
- Inter-Diffusion Structures
- Plastic Deformation Structures
- Textured Structures

Titles of all-new articles on metallography include:

- Metallographic Sectioning and Specimen Extraction
- Light and Electron Microscopy
- Digital Imaging
- Quantitative Image Analysis
- Quantitative Characterization and Representation of Global Microstructural Geometry
- Three-Dimensional Microscopy
- Metallography of Archaeological Alloys
- Field Metallography Techniques
- Color Metallography
- Selected Color Images
- Laboratory Safety in Metallography

In addition, this edition of Volume 9 has all-new articles on the metallography and microstructures of the following materials:

- Cast Iron
- Carbon and Low-Alloy Steels
- Aluminum and Its Alloys
- Cobalt and Its Alloys
- Precious Metals and Their Alloys
- Titanium and Its Alloys
- Biomedical Orthopedic Alloys
- Semisolid Formed Alloys
- Thermal Spray Coatings
- Ceramics

With this extensive revision of Volume 9, *Metallography and Microstructures* continues to be a comprehensive and indispensable reference work for anyone who specifies, performs, monitors, evaluates, or uses metallurgical analyses for production quality control, research, or educational training.

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