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Volume 22B
Metals Process Simulation

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Foreword

Publication of Volume 22B, *Metals Process Simulation*, completes an ambitious undertaking begun in 2007 to compile an all-new, comprehensive reference resource on modeling as it applies to metals processing. The first part, Volume 22A, *Fundamentals of Modeling for Metals Processing*, was published in 2009.

Many of the sections in this Volume will be familiar to *ASM Handbook* users, as they have been covered extensively across the *ASM Handbook* series: phase diagrams, casting and solidification, forming, machining, powder metallurgy, joining, heat treatment, and design. This Volume interprets these subjects in the interdisciplinary context of modeling, simulation, and computational engineering.

The high cost of capital investment in manufacturing can be mitigated by modeling and simulating the options. The effects of processing on materials can be tested and understood through modeling. This Volume and its companion, Volume 22A, provide materials engineers and scientists with the information they need to understand the potential and advantages of modeling and simulation and to provide them with the tools they need to work with the modeling experts.

When the first *ASM Handbook* was published in 1923 by ASM International's predecessor, the American Society for Steel Treaters, the computational tools of choice were a slide rule, paper, pencil, and data tables—all conveniently sized to slip into a lab coat pocket. Today, computational tools are almost entirely software based, although some handheld electronics are also conveniently sized to slip into a lab coat pocket. Many of the basic concerns between then and now are the same: how to control properties during processing, how to minimize waste, how to maintain quality, and so on. Additional contemporary concerns include automated manufacturing, new alloys, new applications such as aerospace and medical devices, environmental responsibility, tracking, and so on.

ASM International is indebted to co-editors David Furrer and S. Lee Semiatin for their vision and leadership in bringing Volumes 22A and 22B to completion. The many authors and reviewers who worked on these Volumes shared that vision. Unlike the subjects about which they wrote, a technical article cannot be modeled or simulated; it must take tangible form as text and images, and this Volume is the direct result of the contributors' generosity in sharing their time and expertise.

That first *ASM Handbook* was published as a loose-leaf collection of data sheets assembled in a leather-bound binder. Today's *ASM Handbooks* are available online, in hardcover, or as DVDs. Times have changed, and ASM International continues to provide the quality information that materials science professionals need to chart the course of the future for their industries.

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Preface

Computer-aided engineering and design have substantially changed the way new products are developed and defined. The pencil and drafting table have long since been replaced by the mouse and computer monitor. To date, much of this engineering transformation has been limited to geometric design, or the *form* and *fit* of a component. Efforts are now ongoing to develop computer-based tools to assess the *function* of components under the intended final application conditions (i.e., temperature, environment, stress, and time).

There have been substantial efforts over the past 25 years to develop and implement computer-based models to simulate manufacturing processes and the evolution of microstructure and accompanying mechanical properties within component materials. The rate of change within this area of engineering has continued to increase with increasing industrial application benefits from the use of such engineering tools, accompanied by the reduced cost and increased speed of computing systems required to perform increasingly complex simulations.

Volumes 22A and 22B of the *ASM Handbook* series summarize models that describe the behavior of metallic materials under processing conditions and describe the development and application of simulation methods for a wide range of materials and manufacturing processes. Such information allows the sharing of best practices among diverse scientific, engineering, and manufacturing disciplines. Background information on fundamental modeling methods detailed in Volume 22A provides the user with a solid foundation of the underlying physics that support many industrial simulation software packages. The present Volume provides an overview of a number of specific metals processing simulation tools applicable in the metals manufacturing industry for a wide range of engineering materials.

All simulation tools require a variety of inputs. For example, details regarding material and process boundary conditions are critical to the success of any computer-based simulation. Thus, this Handbook also provides information regarding material and process boundary conditions that are applicable to manufacturing methods. Additionally, this Volume provides guidance regarding how to develop and assess required thermophysical material data for materials that have not been previously characterized, so practitioners of simulation software packages can effectively generate required material and manufacturing process databases to enable successful predictions for metals processing methods.

The benefits provided by integrated computational materials engineering include reduced component development time, enhanced optimization of component design (design for performance, design for manufacturing, and design for cost), and increased right-the-first-time manufacturing. These benefits have led to an overwhelming pull for materials and manufacturing process simulation integration with early stages of component design.

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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.

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