ASM Handbook®

Volume 15
Casting

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Dedicated to the memory of
JOSEPH R. DAVIS
(1954–2007)
Editor, Metals Handbook, 1982–1991

Foreword

In this revision of *ASM Handbook*® Volume 15 on casting, ASM International is indebted to the volunteer efforts of the Volume 15 Editorial Committee and over 150 participants who helped as authors or reviewers. Their professional commitment and efforts represent a continuing devotion to the practice of metalcasting and the publication of peer consensus information on it.

Special thanks are extended to Srinath Viswanathan, University of Alabama, for recruiting an outstanding Editorial Committee with Diran Apelian, Worcester Polytechnic Institute; Babu DasGupta, National Science Foundation, Raymond J. Donahue, Mercury Marine; Michael Gywn, ATI Inc.; John L. Jorstad, J.L.J. Technologies, Inc.; Raymond W. Monroe, Steel Founders' Society of America; Thomas E. Prucha, American Foundry Society; Kumar Sadayappan and Mahi Sahoo, CANMET Materials Technology Laboratory; Edward S. Szekeres, Casting Consultants Incorporated; and Daniel Twarog, North American Die Casting Association. We thank them and the other contributors for this publication.

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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 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 IEE/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

From the preceding Volume 5 (1970) of the 8th Edition *Metals Handbook* and the 9th Edition *Metals Handbook* Volume 15 (1988) on casting, this Handbook provides an update on the continuing advances in casting technologies and applications. Casting, as both a science and practical tool in art and technology, is enormously varied in scope. It is impossible to capture the full scope of casting technology in one volume.

The main focus of this Volume is on the products and processes of foundry (shape) casting, although primary (ingot or continuous casting) of steel and aluminum are also covered. In addition, continuous casting of copper is described in an article, as copper continuous casting was a precursor to steel and aluminum continuous casting in some respects. Some of the articles on melt processing, such as the articles on "Electric Arc Furnace Melting" and "Steel Melt Processing," also briefly describe primary production of cast metal.

Shape casting of metal is dominated by cast iron, which constitutes just over 70% of the worldwide production of castings on a tonnage basis (See Table 2 in the first article "History and Trends of Metal Casting"). This is followed by steel, copper-alloy, and aluminum-alloy castings, which make up about 25% on the worldwide tonnage of casting production. Magnesium and zinc are on the order of 1% or less. The dominance of just a few alloys in shape casting is due to the fact that successful and economic shape casting typically involves alloy compositions near a eutectic. The lower melting points and narrower freezing range of near-eutectic compositions promote better castability.

Since the 1988 edition of Volume15, several developments have occurred (see Table 5 in the first article "History and Trends of Metal Casting"). Of these developments, computer technology continues to shorten development time and help simulate the casting process. Automation and robotic technology also has improved the productivity and process control of casting. In terms of processes, semisolid processing, squeeze casting, lost-foam, vacuum molding, and various dies casting technologies continue to improve and finds new applications. These important topics are updated in this Volume. For nonferrous alloys, high-pressure die casting of aluminum is a major area of expansion and update in this volume.

In addition, coverage on sand casting is expanded and consolidated in this Volume with major articles on "Green Sand Molding," No-Bake Sand Molding," and "Shell Molding and Shell Coremaking." Bonded sand mold casting, although well-established for many years, is the most widely used method of casting on a tonnage basis. Improvement in methods and materials continue to provide better yields, productivity, and product quality. The sand system is also a major factor in the economics of large-volume, production casting. Coverage on sand casting is expanded relative to the previous edition with the intention of providing a reference that may be helpful as a communication tool between product designers and metalcasters in developing successful and economical products.

This Volume consists of 18 sections. The first section introduces the historical development of metal casting, as well as to the advantages of castings over parts produced by other manufacturing processes, their applications, and the current market size of the industry. This includes an article on "Metalcasting Technology and the Purchasing Process" written by Al Spada and the technical staff of the American Foundry Society. Then, the principles and practice of melt processing are described in the next three sections followed by a section on principles of solidification including nucleation kinetics, fundamentals of growth, transformation behavior, and microstructure development. Solid-state processing of casting, such as heat treat treatment and hot isostatic pressing, are also introduced. This is followed by a section on the "Modeling and Analysis of Casting Processes."

Like the previous edition, traditional subjects such as patterns, molding and casting processes, foundry equipment, and processing considerations are extensively covered in the next sections. As noted, coverage on sand casting has been consolidated and expanded. For example, the major method of shell molding is described in an article—based on an update of a still largely valid 1970 handbook (Volume 5) article. New updates are also provided on processes growing in use, such as squeeze casting, lost-foam casting, semisolid metal forming, and low-pressure casting. The latter is particularly important in producing quality products, as described by John Campbell in the article "Filling and Feeding Concepts."

Finally, the last five sections describe the major types of cast alloys in term of processing and the properties and characteristics of cast ferrous and nonferrous alloys. Emphasis is placed on cast iron, cast steel, aluminum, copper, and zinc. The last section covers the quality aspects of cast products and the processing of castings.

It is hoped that this Handbook is a useful work of peer-consensus reference information for the producers, designers, and buyers of castings. Many thanks are extended to all the contributors and the editors who worked on this Volume. This publication would not have been possible without their commitment and effort.

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