

ASM Handbook®

Volume 1A Cast Iron Science and Technology

Prepared under the direction of the
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First printing, September 2017

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Library of Congress Cataloging-in-Publication Data

ASM International

ASM Handbook

Includes bibliographical references and indexes

Contents: v.1. Properties and selection—irons, steels, and high-performance alloys—v.2. Properties and selection—nonferrous alloys and special-purpose materials—[etc.]—v.23. Materials for medical devices

1. Metals—Handbooks, manuals, etc. 2. Metal-work—Handbooks, manuals, etc. I. ASM International. Handbook Committee. II. Metals Handbook.

TA459.M43 1990 620.1'6 90-115

SAN: 204-7586

EISBN: 978-1-62708-134-4

ISBN-13: 978-1-62708-133-7

ISBN-10: 1-62708-133-X

ASM International®
Materials Park, OH 44073-0002
www.asminternational.org

Printed in the United States of America

Foreword

In this year of renewal at ASM International, it is especially fitting to release *Cast Iron Science and Technology*, Volume 1A of the *ASM Handbook* series. Its focus on improving materials performance is a key value that ASM International strives to offer its members and those who research, develop, process, make, and buy cast irons. Volume 1A covers the processing and applications of cast irons, which differentiates it from, and supplements, *Properties and Selection: Irons, Steels, and High-Performance Alloys*, Volume 1, *ASM Handbook*.

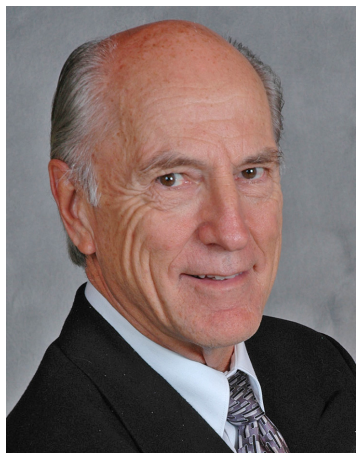
Coverage in this Volume includes fundamentals, primary processing, fabrication, effects of processing on properties, process and product design, and the engineering properties of specific grades, types, and product forms of iron castings.

ASM International is grateful for the work and dedication of volunteer editors, authors, and reviewers. They devoted their time and expertise to develop a reference work that reflects the continuing commitment of ASM International to present a publication of the highest technical and editorial quality. The result is a comprehensive body of knowledge from the world's leading innovators, researchers, and practitioners in the cast iron field that gives readers the tools to solve problems. ASM International is indebted to Volume Editor Doru M. Stefanescu, a world-renowned expert who worked tirelessly to oversee this undertaking.

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Preface



Professor Doru Michael Stefanescu
Volume Editor

“Research isn’t practical.” Neither are babies. They are costly, dirty and have no practical value. They net no return on the investment for 20 years, and even then they may be a liability rather than an asset. There are many reasons for not having babies and for not doing research. The result of yielding to those superficial reasons is the same in both cases—a dim and declining future climaxed by extinction.

H.W. Lownie (foundryman), 1961

Cast iron is probably the most complex alloy used by human civilization. It includes in its chemical composition more elements than superalloys, that is, base elements (C, Si, Mn, P, S), alloying elements (Cu, Sn, Ni, Cr, Mo, V, Al), and minor elements (As, B, Bi, Cd, Pb, Sb, Se, Te, Ti, Zr). Depending on composition and cooling rate, it solidifies with either stable or metastable eutectic and with the carbon-rich phase, graphite, in a variety of morphologies, from flake/lamellar to nodular/spheroidal. Cast iron is the first man-made metal-matrix composite, combining crystalline iron and crystalline graphite. It has a wide range of properties, including higher specific properties (property/density) than many of its competing materials. For example, cast iron has higher specific fatigue strength and higher specific tensile strength at temperatures above 100 °C than aluminum, and all this at a much lower price. This explains why iron castings represent approximately 70% of the total tonnage of castings worldwide. Thus, collecting the available information on the history, science, and technology of cast iron in a single volume is a worthwhile endeavor. As, at the beginning of human civilization, iron processing was considered magic, which then evolved into an art, then technology, and finally science, culminating today with virtual cast iron, this endeavor is not just worthwhile but also challenging.

Yet, this book intends to be more than a technical compendium. It aspires to also acknowledge the history of cast iron, an important

attribute if we care to consider the fast pace of knowledge development. The Renaissance genius Sir Francis Bacon was thought to be the last person who knew everything a person could know, at least in a European nation, in 1600. Until 1900, human knowledge doubled every century. By 1945, knowledge was doubling every 25 years. Today, different types of knowledge have different rates of growth: Nanotechnology knowledge doubles every 2 years, but clinical knowledge doubles every 18 months. On average, human knowledge doubles every 13 months. According to IBM, the building of the “internet of things” will lead to the doubling of knowledge every 12 hours.

But what is knowledge? According to Aristotle (384–322 B.C.E.), considered to be the father of science and the scientific method and the inventor of the language of science, knowledge includes theoretical (*episteme*—knowing and understanding), practical (*praxis*—doing), and technical (*technē*—making, production). It is one of the ambitions of this Volume to include aspects of all these types of knowledge on cast iron. And, as Plato (428–347 B.C.E.), considered to be the founder of Western spirituality, stated, “where there is number there is order; where there is no number there is nothing but disorder,” this Volume also stresses the mathematical, quantitative aspects of the science of cast iron. This is a logical objective, as many of the processes used in iron casting are still empirical in nature, but many others are deeply rooted in mathematics. The knowledge ladder includes generation of knowledge, transfer of knowledge, and implementation of knowledge. Thus, knowledge is not merely the possession of information but rather its implementation and use, which brings us to the main goal of this Volume—to package and transfer knowledge in a form that can facilitate its implementation in praxis. Because this is a monumental, almost impossible task, its completion necessitated the involvement of the top iron casting engineers and scientists in the international community. Their collective effort was successful in assembling what I believe to be the most complete text on cast iron available in the English language today.

This Volume is structured in eleven sections, starting with an introduction that covers the history of cast iron and a detailed classification and discussion of the basic types of cast iron. The following section is a rather academic treatment of the fundamentals of the metallurgy of cast irons, including thermodynamics principles specific to cast iron, microstructure evolution and volumetric changes during solidification and solid-state transformation, and prediction of solidification microstructure through computational modeling, which was dubbed earlier in this preface as “virtual cast iron.” Next, an extensive discussion of the many facets of the science and engineering of processing of cast iron is provided, with particular emphasis on liquid metal preparation, casting processes, and heat treatment. The section on secondary processing addresses issues such as machining, inspection, and quality control. The properties of various types of iron and the effects of processing are treated in a section that concludes with another “virtual cast iron” subject, computer-aided prediction of mechanical properties. The specifications, selection criteria, microstructure, and production particularities of the main classes of cast iron—gray iron, ductile iron, compacted graphite iron, high-alloy iron, and malleable iron—are then

discussed in great detail in separate sections. Attention is given to more recent developments, such as thin-wall iron and heavy-section ductile iron castings. Most articles include a large number of references that serve a dual purpose: to give credit where credit is due, and to direct the reader to additional information on the subject, if the reader is interested.

This Volume is the product of the combined efforts of an international team of top scientists and metal casting specialists from no less than 12 countries (Argentina, Brazil, China, Denmark, France, Norway, Poland, Romania, Spain, Sweden, the United Kingdom, and the

United States of America) and of the outstanding diligence of the ASM International technical and support personnel, to whom the Editor is deeply grateful. The Editor would like to extend his personal appreciation to the leaders of the ASM International team, Mr. Steve Lampman, Senior Content Developer, and Ms. Vicki Burt, Content Developer, for their remarkable efforts in coordinating this gargantuan task and their personal contributions to the text. It required many, many days. We—the authors, the ASM International team, and the Editor—do hope that the readers will find in this Volume answers to most of the questions that they may have on cast iron for many years to come.

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 ($\text{kg} \times 10^3$) 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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