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.

William E. Frazier  
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"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, Sh, 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 (techne—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 irons 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 particulars 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 (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/cm³ rather than kg/m³ 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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Contents

Introduction ............................... 1

A History of Cast Iron

Doru M. Stefanescu, The Ohio State University and The University of Alabama ............ 3

The Beginnings of Metal Casting and of the Iron Age .................. 3

Early Cast Iron in Mesopotamia and China ....................... 4

Cast Iron in Europe in the Medieval Ages .................. 5

Early Modern Period (16th to Mid-18th Century) ........... 5

Late Modern Period ....................... 6

Cast Iron—A High-Tech, Economical, Modern Material ................. 8

Classification and Basic Types of Cast Iron

Revised and updated by Doru M. Stefanescu, The Ohio State University and The University of Alabama ............ 12

Classification ................................ 13

Principles of the Metallurgy of Cast Iron .................. 15

Gray Iron (Flake or Lamellar Graphite Iron) .................. 18

Ductile Iron (Spheroidal Graphite Iron) ....................... 21

Compacted (Vermicular) Graphite Irons .................. 22

Malleable Irons ................................ 24

Special Cast Irons ................................ 26

Fundamentals of the Metallurgy of Cast Iron .......... 29

Thermodynamics Principles as Applied to Cast Iron

Doru M. Stefanescu, The Ohio State University and The University of Alabama ............ 31

Thermodynamics of Binary Fe-X Systems .................. 31

Thermodynamics of Ternary Fe-C-X Systems .................. 35

Thermodynamics of Multicomponent Iron-Carbon Systems .................. 41

Composition Control of Iron-Carbon Melts .................. 42

The Liquid/Solid Transformation (Solidification)

The Liquid State and Principles of Solidification of Cast Iron

Doru M. Stefanescu, The Ohio State University and The University of Alabama ............ 46

Rosana Rusanda, Emerson Climate Technologies .................. 46

Fundamentals of Solidification of Cast Iron .................. 46

Length Scale of Solidification Structures .................. 46

Undercooling ................................ 47

Nucleation ................................ 49

Growth and Interface Stability .................. 49

Solidification Structures of Solid Solutions .................. 51

Solidification Structures of Eutectics .................. 54

Solidification Structures of Peritectics .................. 56

Microstructure Evolution during the Liquid/Solid Transformation in Cast Iron

Doru M. Stefanescu, The Ohio State University and The University of Alabama ............ 59

Nucleation and Growth of Austenite Dendrites .................. 59

Nucleation of Graphite .................. 60

Nucleation of Austenite-Iron Carbide Eutectic .................. 63

Growth of Graphite ................................ 64

Eutectic Solidification of Cast Iron .................. 70

Principles of Thermal Analysis

Hasse, Fredriksson, KTH Stockholm

Doru M. Stefanescu, The Ohio State University and The University of Alabama ............ 81

Basics of Cooling Curves .................. 81

Solidification Temperature and Chemical Composition .................. 82

The Gray-to-White Transition .................. 83

Cooling Curves and Graphite Shape .................. 85

Nonequilibrium Solidification .................. 86

Conclusions ................................ 86

Volumetric Changes during the Solidification of Cast Iron

Atila Diószegi and Peter Svádlov, Tönköping

University, Sweden .................. 88

Methods to Measure Volume Changes .................. 88

Direct Measurements of Volume Changes .................. 88

Indirect Measurement of Volume Changes .................. 89

Dilatometer Measurements .................. 89

Problems Associated with Volume-Change Measurements .................. 90

Anisotropic Displacement .................. 91

Kinetic of Graphite Expansion .................. 92

Computational Models for Prediction of Solidification Microstructure

A.V. Catalina, Caterpillar Inc. USA

A.A. Barbelko and W. Kapturkiewicz, AGH University of Science and Technology, Krakow, Poland

M. Zha, School of Materials Science and Engineering, Southeast University, China .................. 94

Macroscopic Transport Equations .................. 94

Analytical Microscopic Models for Solidification .................. 95

Macro-Microscopic Modeling of Cast Iron Solidification Microstructure .................. 96

Cellular Automaton Modeling .................. 101

The Solid/Solid Transformation

The Austenite-to-Pearlite/Ferrite Transformation

Jacques Lacaze, Université de Toulouse .................. 106

Stable and Metastable Three-Phase Fields .................. 106

The Austenite Decomposition .................. 107

Austenite Decomposition to Ferrite and Pearlite in Spheroidal Graphite Irons .................. 108

Austenite Decomposition to Ferrite and Pearlite in Lamellar and Compact Graphite Irons .................. 110

Modelling Austenite Decomposition to Ferrite and Pearlite .................. 111

The Austenite-to-Austferrite Transformation

Robert Boeri, UNMdP-INTEMA .................. 114

General Features of the Decomposition of Austenite into Bainite .................. 114

Heat Treatment Cycle and Microstructure .................. 116

Factors Affecting the Transformation of Austenite during Austempering of Free-Graphite Cast Irons .................. 117
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modification and Inoculation of Cast Iron</td>
<td>119</td>
</tr>
<tr>
<td>Liquid Metal Preparation</td>
<td></td>
</tr>
<tr>
<td>Cast Iron Melting Furnaces</td>
<td>121</td>
</tr>
<tr>
<td>Cupola Furnaces</td>
<td>122</td>
</tr>
<tr>
<td>Refractory Linings</td>
<td>123</td>
</tr>
<tr>
<td>Water-Cooled Cupolas</td>
<td>124</td>
</tr>
<tr>
<td>Emission-Control Systems</td>
<td>125</td>
</tr>
<tr>
<td>Cupola Control Principles</td>
<td>125</td>
</tr>
<tr>
<td>Specialized Cupolas</td>
<td>127</td>
</tr>
<tr>
<td>Electric Melting Furnaces</td>
<td>128</td>
</tr>
<tr>
<td>Holding Furnaces</td>
<td>129</td>
</tr>
<tr>
<td>Electric Arc Furnaces</td>
<td>130</td>
</tr>
<tr>
<td>Induction Crucible Furnaces</td>
<td>131</td>
</tr>
<tr>
<td>Coil and Transformer Yokes</td>
<td>133</td>
</tr>
<tr>
<td>Refractory Linings</td>
<td>134</td>
</tr>
<tr>
<td>Refractory Technology</td>
<td>136</td>
</tr>
<tr>
<td>Refractory Behavior</td>
<td>137</td>
</tr>
<tr>
<td>Crucible Monitoring</td>
<td>139</td>
</tr>
<tr>
<td>Duplex Mode</td>
<td>140</td>
</tr>
<tr>
<td>Pouring Furnaces</td>
<td>140</td>
</tr>
<tr>
<td>Pressure-Actuated Pouring Furnaces</td>
<td>140</td>
</tr>
<tr>
<td>Pouring Magnesium-Treated Melts</td>
<td>142</td>
</tr>
<tr>
<td>Other Pouring Technologies</td>
<td>143</td>
</tr>
<tr>
<td>Cast Iron Melt Quality Control</td>
<td>146</td>
</tr>
<tr>
<td>Graphitization</td>
<td>147</td>
</tr>
<tr>
<td>Structural Diagrams</td>
<td>147</td>
</tr>
<tr>
<td>Cooling Curve (Thermal) Analysis</td>
<td></td>
</tr>
<tr>
<td>Ramón Sudrez and P. Lapranaga, Maristas Azterlan Engineering</td>
<td></td>
</tr>
<tr>
<td>Adrián Udou, Metallurgical Quality Assistant</td>
<td>149</td>
</tr>
<tr>
<td>Evaluation of Carbon-Silicon Contents</td>
<td>149</td>
</tr>
<tr>
<td>Evaluation of Graphite Shape</td>
<td>151</td>
</tr>
<tr>
<td>Evaluation of Graphite Nucleation</td>
<td>152</td>
</tr>
<tr>
<td>Chill Depth Prediction</td>
<td>153</td>
</tr>
<tr>
<td>Amount of Primary Phase</td>
<td>153</td>
</tr>
<tr>
<td>Evaluation of Contraction-Expansion Balance</td>
<td>153</td>
</tr>
<tr>
<td>Graphite Distribution Type in Gray Iron</td>
<td>154</td>
</tr>
<tr>
<td>Tensile Strength and Hardness in Gray Iron</td>
<td>155</td>
</tr>
<tr>
<td>Prediction of Nodule Count</td>
<td>155</td>
</tr>
<tr>
<td>Magnesium Control</td>
<td>156</td>
</tr>
<tr>
<td>Control of Compacted Graphite Iron (CGI)</td>
<td>157</td>
</tr>
<tr>
<td>Ferrite/Pearlite in Ductile Iron</td>
<td>158</td>
</tr>
<tr>
<td>Modification and Inoculation of Cast Iron</td>
<td></td>
</tr>
<tr>
<td>Iulian Riposan, Politehnica, University of Bucharest</td>
<td></td>
</tr>
<tr>
<td>Torbjørn Skaland, ELKEM Foundry Products</td>
<td>160</td>
</tr>
<tr>
<td>Inoculation of Gray Cast Iron</td>
<td>162</td>
</tr>
<tr>
<td>Modification and Inoculation of Ductile Cast Iron</td>
<td>166</td>
</tr>
<tr>
<td>Modification and Inoculation of Compacted Graphite</td>
<td>171</td>
</tr>
<tr>
<td>Trace (Minor) Elements in Cast Irons</td>
<td>177</td>
</tr>
<tr>
<td>Robert Voigt, Pennsylvania State University</td>
<td>177</td>
</tr>
<tr>
<td>Effects of Minor Elements on Microstructure and Properties</td>
<td>177</td>
</tr>
<tr>
<td>Trace Element Testing and Control</td>
<td>178</td>
</tr>
<tr>
<td>Allowable Levels of Trace and Tramp Elements</td>
<td>178</td>
</tr>
<tr>
<td>Casting Processes</td>
<td></td>
</tr>
<tr>
<td>Filling and Feeding Systems for Cast Iron</td>
<td>182</td>
</tr>
<tr>
<td>John Campbell, University of Birmingham</td>
<td>182</td>
</tr>
<tr>
<td>Filling of Iron Castings</td>
<td>182</td>
</tr>
<tr>
<td>Feeding of Ductile Iron</td>
<td>188</td>
</tr>
<tr>
<td>Molding and Casting Processes</td>
<td></td>
</tr>
<tr>
<td>John Campbell, University of Birmingham</td>
<td>189</td>
</tr>
<tr>
<td>József Tamás Svádor and Judit Svádor, Jonköping University</td>
<td>189</td>
</tr>
<tr>
<td>Aggregate Molding Materials</td>
<td>189</td>
</tr>
<tr>
<td>Binder Systems</td>
<td>191</td>
</tr>
<tr>
<td>Sand Reclamation Techniques</td>
<td>197</td>
</tr>
<tr>
<td>Casting and Molding Processes</td>
<td>199</td>
</tr>
<tr>
<td>Surface Quality and Mold-Metal Interface Interaction</td>
<td></td>
</tr>
<tr>
<td>Doru M. Stefanescu, The Ohio State University and The University of Alabama</td>
<td>207</td>
</tr>
<tr>
<td>Physics and Chemistry of Mold-Metal Interaction in Iron Alloys</td>
<td>207</td>
</tr>
<tr>
<td>The Casting Skin</td>
<td>208</td>
</tr>
<tr>
<td>Metal Penetration in Sand Molds</td>
<td>212</td>
</tr>
<tr>
<td>Computational Modeling of Gas Evolution in Sand Molds</td>
<td>218</td>
</tr>
<tr>
<td>Laurentiu Nastac, The University of Alabama</td>
<td>218</td>
</tr>
<tr>
<td>Heat Treatment</td>
<td></td>
</tr>
<tr>
<td>Introduction to Cast Iron Heat Treatment</td>
<td>220</td>
</tr>
<tr>
<td>J.L. Dossett, Consultant</td>
<td>228</td>
</tr>
<tr>
<td>General Considerations</td>
<td>229</td>
</tr>
<tr>
<td>Stress Relief</td>
<td>231</td>
</tr>
<tr>
<td>Annealing</td>
<td>232</td>
</tr>
<tr>
<td>Normalizing</td>
<td>233</td>
</tr>
<tr>
<td>Through Hardening and Tempering</td>
<td>234</td>
</tr>
<tr>
<td>Surface Hardening of Cast Irons</td>
<td>236</td>
</tr>
<tr>
<td>Heat Treating of Gray Irons</td>
<td>240</td>
</tr>
<tr>
<td>Introduction</td>
<td>240</td>
</tr>
<tr>
<td>Classes of Gray Iron</td>
<td>240</td>
</tr>
<tr>
<td>Stress Relief</td>
<td>241</td>
</tr>
<tr>
<td>Examples of Stress Relief</td>
<td>242</td>
</tr>
<tr>
<td>Annealing</td>
<td>243</td>
</tr>
<tr>
<td>Normalizing</td>
<td>244</td>
</tr>
<tr>
<td>Transformation Hardening</td>
<td>245</td>
</tr>
<tr>
<td>Hardenability</td>
<td>246</td>
</tr>
<tr>
<td>Austenitizing</td>
<td>247</td>
</tr>
<tr>
<td>Quenching</td>
<td>249</td>
</tr>
<tr>
<td>Quenched and Tempered Properties</td>
<td>249</td>
</tr>
<tr>
<td>Austempering</td>
<td>251</td>
</tr>
<tr>
<td>Martempering</td>
<td>252</td>
</tr>
<tr>
<td>Flame Hardening</td>
<td>253</td>
</tr>
<tr>
<td>Induction Hardening</td>
<td>255</td>
</tr>
<tr>
<td>Other Surface-Hardening Methods</td>
<td>255</td>
</tr>
<tr>
<td>Heat Treatment of Ductile Iron</td>
<td></td>
</tr>
<tr>
<td>Revised by K. Hayrynen, Applied Process Inc.</td>
<td>256</td>
</tr>
<tr>
<td>Standards for Heat Treatment of Ductile Iron</td>
<td>256</td>
</tr>
<tr>
<td>General Characteristics</td>
<td>257</td>
</tr>
<tr>
<td>Austenitizing Ductile Cast Iron</td>
<td>258</td>
</tr>
<tr>
<td>Atmospheres for Heat Treatment of Ductile Iron</td>
<td>259</td>
</tr>
<tr>
<td>Annealing Ductile Iron</td>
<td>260</td>
</tr>
<tr>
<td>Hardenability of Ductile Cast Iron</td>
<td>261</td>
</tr>
<tr>
<td>Normalizing Ductile Iron</td>
<td>261</td>
</tr>
<tr>
<td>Quenching and Tempering Ductile Iron</td>
<td>263</td>
</tr>
<tr>
<td>Marquenching (Martempering) Ductile Iron</td>
<td>263</td>
</tr>
<tr>
<td>Austempering Ductile Iron</td>
<td>264</td>
</tr>
<tr>
<td>Surface Hardening of Ductile Iron</td>
<td>265</td>
</tr>
<tr>
<td>Stress Relieving of Ductile Iron</td>
<td>268</td>
</tr>
<tr>
<td>Effect of Heat Treatment on Fatigue Strength</td>
<td>268</td>
</tr>
<tr>
<td>Heat Treatment of Malleable Irons</td>
<td></td>
</tr>
<tr>
<td>Edited by J.R. Keough and K.L. Hayrynen, Applied Process Inc.</td>
<td>270</td>
</tr>
<tr>
<td>Malleabilizing</td>
<td>270</td>
</tr>
<tr>
<td>Hardenening and Tempering</td>
<td>271</td>
</tr>
<tr>
<td>Surface Hardening of Pearlitic Malleable Iron</td>
<td>273</td>
</tr>
<tr>
<td>Heat Treatment of High-Alloy White Cast Irons</td>
<td></td>
</tr>
<tr>
<td>Revised by J.R. Keough and K.L. Hayrynen, Applied Process Inc.</td>
<td>275</td>
</tr>
</tbody>
</table>
Alloy Types and Properties ........................................ 275
Nickel-Chromium White Irons ..................................... 275
High-Chromium White Irons ....................................... 277

Secondary Processing of Cast Iron ................................. 285

Welding of Cast Irons
Reviewed by Charles White, Kettering University ................. 287
Fusion Welds ..................................................... 287
Weldability ...................................................... 289
Welding Procedures ............................................ 290
Base-Metal Preparation .......................................... 293
Repair Welding .................................................. 295
Shielded Metal Arc Welding .................................... 296
Gas Metal Arc Welding ......................................... 300
Flux Cored Arc Welding ....................................... 301
Gas Tungsten Arc Welding ................................... 302
Submerged Arc Welding ...................................... 302
Oxyfuel (Gas) Welding ........................................ 303
Flame Spraying ................................................ 306
Braze Welding .................................................. 307
Other Fusion Welding Methods ................................... 308
Solid-State Welding Methods .................................... 308
Surfacng and Overlaying ........................................ 308

Brazing and Soldering of Cast Irons
Reviewed by Charles White, Kettering University ................. 310
Soldering of Cast Irons ........................................ 311
Brazing of Cast Irons ........................................... 311
Brazing Filler Metal Selection ................................ 311
Cleaning ......................................................... 313
Fixturing ........................................................ 314
Brazing Procedures ............................................. 314
Heating Methods for Brazing ................................... 316
Application Examples .......................................... 316

Machining
Simon N. Lekakh, Missouri University of Science and Technology
Dika Handayani, Pennsylvania State University
Michael E. Finn, Finn Metalworking and Cutting Solutions .... 319
Cutting Cast Irons ................................................ 319
Machinability Test Methods .................................... 320
Effect of As-Cast Surface Integrity ................................... 322
Effect of Microstructure on Machinability ....................... 323
Spheroidal Graphite Iron Machinability ......................... 325
Machining Austempered Ductile Irons ............................... 326
Cutting Tool for Machining Gray Irons ......................... 327
Machining Parameters .......................................... 333
Cutting Lubrication (Coolants) .................................. 333
Dry Machining .................................................... 333
Cleaning and Coating of Cast Irons ............................... 335
General Cleaning of Castings .................................. 335
Mechanical Cleaning and Finishing .............................. 335
Nonmechanical Cleaning ........................................ 337
Cast Iron Organic Coatings
Jayson L. Helsel and Kenneth B. Tator, KTA-Tator, Inc. ......... 338
General Surface Preparation .................................... 339
Coatings for Atmospheric Exposure ............................... 341
Architectural Cast Iron Protection ................................ 342
Exterior Coatings for Underground Service ....................... 343
Interior Coatings for Underground Service ....................... 344
Repairs/Replacement of Deteriorated Pipe ......................... 345
Cast Iron Inorganic Coatings ................................... 347
Electroplating and Electroless Plating ............................ 347
Hot Dip Coatings ............................................... 350
Hardfacing and Weld Cladding .................................. 351
Thermal Spraying ............................................... 351
Conversion Coatings .......................................... 352
Porcelain Enameling ............................................ 352

Inspection and Quality Control
Casting Defects .................................................. 355
Common Defects in Ductile Cast Irons ............................ 361
Defects in Gray Iron Castings .................................. 363
Surface Defects in Compacted Graphite Iron: Casting Skin .......................... 367
Examples of Defects in Cast Irons ................................ 372
Nondestructive Inspection of Cast Irons
John A. Griffin, The University of Alabama ......................... 373
The Role of Nondestructive Inspection ........................... 373
Surface/Near-Surface Inspection Methods ......................... 373
Volumetric Inspection Methods ................................... 376

Metallography and Microstructures of Cast Iron
Janina M. Radzikowska, The Foundry Research Institute (retired), Kraków, Poland
George Vander Voort, Straus Inc. (Consultant) ...................... 379
Sampling and Specimen Preparation ................................ 379
Grinding and Polishing ............................................ 381
Etching ........................................................ 384
Illumination Techniques ........................................... 393
Examples ......................................................... 395

Fracture Analysis
Diego O. Fernandino and Roberto E. Boeri, National University of Mar del Plata ........................................... 399
Fracture Modes .................................................... 399
Special Cases of Environmentally Assisted Fracture ............... 407
Identifying Crack Propagation Direction Using Fractographic Features ........................................... 408

Properties of Cast Irons and Effects of Processing .................... 411

Physical Properties of Cast Irons
Doru M. Stefanescu, The Ohio State University and The University of Alabama .................. 413
Density ........................................................ 413
Properties of Liquid Iron ........................................... 414
Thermal Properties ............................................... 417
Conductive Properties .......................................... 420
Magnetic Properties ............................................. 425
Acoustic Properties .............................................. 427
Mechanical Properties of Gray Irons ............................... 430
Classification of Gray Irons ...................................... 431
Test Bars ........................................................ 431
Hardness ........................................................ 432
Elasticity and Deformation ....................................... 434
Strength and Ductility .......................................... 436
Fatigue Properties ............................................... 438
Stress-Life (High-Cycle) Fatigue .................................... 439
Strain-Life (Low-Cycle) Fatigue ................................... 446
Fatigue Crack Propagation ........................................... 448
Toughness ......................................................... 449
High-Temperature Strength ........................................ 451

Mechanical Properties of Ductile Irons ........................... 456
Classes and Grades of Ductile Iron ................................ 456
Factors Affecting Mechanical Properties ......................... 457
Hardness Properties ............................................. 459
Tensile Properties ............................................... 460
Shear and Torsional Properties ................................... 462
Damping Capacity ............................................... 462
Compressive Properties ......................................... 462
Fatigue Properties ............................................... 463
Fracture Toughness .............................................. 465
Impact Tests ....................................................... 467
Austempered Ductile Iron ........................................... 469
Mechanical Properties of Compacted Graphite Iron ............... 472
Tensile Properties and Hardness ...................................... 472
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Castability, Product Design, and Production of Compacted Graphite Irons</td>
<td>612</td>
</tr>
<tr>
<td>Speciﬁcation, Selection, and Applications of Compact Graphite Irons</td>
<td>612</td>
</tr>
<tr>
<td>Properties</td>
<td>613</td>
</tr>
<tr>
<td>Microstructure and Characterization of Compact Graphite Iron</td>
<td>615</td>
</tr>
<tr>
<td>Thin-Wall Ductile Iron Castings</td>
<td>616</td>
</tr>
<tr>
<td>Compacted Graphite (CG) Iron Castings</td>
<td>617</td>
</tr>
<tr>
<td>Production and Applications of Thin-Wall Ductile Iron Castings</td>
<td>624</td>
</tr>
<tr>
<td>Heavy-Section Ductile Iron Castings</td>
<td>626</td>
</tr>
<tr>
<td>Metallography and Microstructures of Ductile Irons</td>
<td>630</td>
</tr>
<tr>
<td>Production of Austempered Ductile Iron</td>
<td>632</td>
</tr>
<tr>
<td>Microstructure and Characterization of High-Alloy Cast Irons</td>
<td>634</td>
</tr>
<tr>
<td>Quality Index</td>
<td>638</td>
</tr>
<tr>
<td>Castability, Product Design, and Production of High-Alloy Iron Castings</td>
<td>639</td>
</tr>
<tr>
<td>Speciﬁcation, Selection, and Applications of High-Alloy Iron Castings</td>
<td>639</td>
</tr>
<tr>
<td>Properties</td>
<td>643</td>
</tr>
<tr>
<td>Microstructure and Characterization of High-Alloy Cast Irons</td>
<td>645</td>
</tr>
<tr>
<td>Castability, Product Design, and Production of High-Alloy Iron Castings</td>
<td>645</td>
</tr>
<tr>
<td>Malleable Iron Castings</td>
<td>647</td>
</tr>
<tr>
<td>Microstructure and Characterization of Malleable Irons</td>
<td>649</td>
</tr>
<tr>
<td>Castability, Product Design, and Production of Malleable Irons</td>
<td>650</td>
</tr>
<tr>
<td>Pearlitic and Martensitic Malleable Iron</td>
<td>653</td>
</tr>
<tr>
<td>Hardness and Compressive Properties</td>
<td>678</td>
</tr>
<tr>
<td>Fatigue and Fracture</td>
<td>679</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>683</td>
</tr>
<tr>
<td>High-Alloy Iron Castings</td>
<td>687</td>
</tr>
<tr>
<td>Pearlitic and Martensitic Malleable Iron</td>
<td>702</td>
</tr>
<tr>
<td>High-Alloy White Iron</td>
<td>704</td>
</tr>
<tr>
<td>Machining and Finishing High-Alloy Iron Castings</td>
<td>717</td>
</tr>
<tr>
<td>Malleable Iron Castings</td>
<td>733</td>
</tr>
<tr>
<td>Malleable Iron Castings</td>
<td>735</td>
</tr>
<tr>
<td>Melting Practices</td>
<td>735</td>
</tr>
<tr>
<td>Microstructure</td>
<td>736</td>
</tr>
<tr>
<td>Current Production Technologies</td>
<td>738</td>
</tr>
<tr>
<td>Applications</td>
<td>739</td>
</tr>
<tr>
<td>Ferritic Malleable Iron</td>
<td>739</td>
</tr>
<tr>
<td>Pearlitic and Martensitic Malleable Iron</td>
<td>741</td>
</tr>
<tr>
<td>Reference Information</td>
<td>747</td>
</tr>
<tr>
<td>Abbreviations and Symbols</td>
<td>749</td>
</tr>
<tr>
<td>Index</td>
<td>753</td>
</tr>
</tbody>
</table>