Foreword

This 2015 edition of *ASM Handbook, Volume 7, Powder Metallurgy* is a completely revised and updated work written and reviewed by the leading experts in the field. Last updated in 1998, this new Volume 7 covers conventional powder metallurgy (press and sinter) as well as an entire new section devoted to metal injection molding, including its applications, and an article on metal injection molding of microcomponents.

Based on feedback from users, the revised Volume has been reorganized for clarification. Principles and techniques of powder metallurgy are discussed first, followed by detailed divisions covering production and characterization of different metals and alloys.

ASM International is grateful for the work and dedication of volunteer editors, authors, and reviewers who devoted their time and expertise to develop a reference publication of the highest technical and editorial quality. A special note of thanks is offered to the division editors who put forth extraordinary efforts to keep this massive project focused and completed on schedule. The result is a comprehensive body of knowledge from the world’s leading innovators, researchers, and practitioners in the powder metallurgy field.

ASM International also thanks the Metal Powder Industries Federation for its cooperation and assistance with figure permissions, reviewers, and providing meeting space for editors. Figure permissions were also freely granted from *Powder Injection Moulding International*, published by Inovar Communications.

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Preface

Powder metallurgy (PM) is a versatile and multifaceted technology. Most commonly, it is used to produce complex structural components with superior dimensional accuracy and good mechanical properties in a cost-effective manner. Apart from this, it is the only way possible to produce some highly specialized material, such as cermet, hard metals, and metallic filters. It is also used to produce improved versions of high-performance alloys (tool steels, magnetic alloys, and composite materials) by ensuring superior control of microstructure and purity. In terms of tons produced, the PM industry is still considered small with only 1% by weight of all metals sold in the industry, but in terms of dollar value, due to its unique capabilities, its use is growing at a faster rate than average.

In 1984, the first ASM Handbook Volume devoted entirely to PM was published in recognition of the increasing acceptance of PM as a viable manufacturing technology. A revised edition published in 1998 captured significant advancements made in the interim. Both of these Volumes have served the PM community well. Technological advancements continue to be made in all facets of PM as more and more new applications come on board and also as the traditional applications are challenged to deliver greater performance and economy. The technology is growing both in its breadth and depth. During the planning of the current edition, it was felt that it would not be feasible to cover all facets of PM technology in one Volume. It was also felt that the practicing PM industry professional generally has different needs than researchers and academicians. In view of this, it was decided to focus this Volume primarily on the traditional press-and-sinter PM technology. The more advanced techniques and emerging technologies, such as additive manufacturing, are deferred to other potential Volumes. A notable exception to this premise is the inclusion of metal injection molding (MIM) in this Volume, which is presented as a distinct division.

Material properties achieved with PM processing can vary widely depending on the process parameters used as well as the starting raw material. To achieve optimal properties for a given application, one must have full understanding of the effects of process variables on the microstructure, and macrostructure of the component (including density), which, in turn, will influence its physical and mechanical properties. The process engineer must balance process complexity and the costs associated with it against the resulting material properties, as well as the dimensional requirements. The process-property relationships can vary to a large extent from one metal/ alloy family to another. The revised Volume’s format is aimed at simplifying the understanding of process-property relationships by treating each metal/alloy family in individual divisions.

The Volume is organized in two parts. The first part (following an introductory division on history and material standards) covers the basic principles and techniques that are common to all PM materials. These divisions include powder manufacture, powder characterization, compaction, sintering, and full density processing. The information provided in these divisions is sufficient for developing a basic understanding of the subject. For additional information, the reader is encouraged to refer to textbooks devoted to these subjects. The second part covers detailed information on PM technology as it applies to individual metal/alloy families, by presenting each metal/alloy family in a separate division. Within each material-specific division, the information presented follows the typical production steps: powder manufacture, compaction, sintering, secondary processing, as well as properties and applications. Major emphasis is placed on the material and processes as they are currently used in industry. All MIM-produced materials are covered under the division on metal injection molding, so as to avoid any confusion with property comparison with materials produced by traditional PM processing.

The Volume is designed to serve as a reference book for PM professionals—process engineers, development engineers, production managers, as well as the sales and marketing personnel. The updated material properties data presented in this Volume will also be helpful to the design engineer and assist him or her in specifying PM components in new applications. The Volume bridges the gap between standard textbooks and research papers presented at technical conferences. The presentation of information is such that it can be used as an introduction to powder metallurgy by the new workforce entering the field.

We would like to offer our sincere thanks to the contributing authors, most of whom worked on their own time to prepare the articles that make up this Volume. This extensively reorganized edition would not have been possible without the dedicated efforts of the division editors. Special thanks are due to the ASM Handbook Committee as well as Steven Lampman, Content Developer and ASM Handbook Committee Staff Liaison of ASM, for their vision and guidance. The cooperation and assistance of the Metal Powder Industries Federation and its sister organization, American Powder Metallurgy Institute, are greatly appreciated.

Much appreciation goes to Ms. Vicki Burt, Content Developer, for organizing and coordinating the entire project. Also, to the editorial staff of ASM for editing the submitted material; all of their work on this Volume was invaluable.
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 may 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 to Powder Metallurgy ........................................ 1

History of Powder Metallurgy
James P. Adams ................................................. 3
Earliest Developments ........................................ 3
Powder Metallurgy of Platinum ................................. 4
Further Developments .......................................... 5
Commercial Developments ...................................... 5
Post-War Developments ........................................ 6
Recent Developments .......................................... 7
Powder Metallurgy Literature .................................... 7
Powder Metallurgy Trade Associations ....................... 7

Powder Metallurgy Methods and Applications
W. Brian James ................................................. 9
Metal Powders .................................................. 9
Powder Processing ............................................. 10
Powder Metallurgy Material Properties ..................... 10
Processing Options to Consolidate Metal Powders .......... 11
Processing to Full Density .................................... 12
Freeform Fabrication ......................................... 14
Finishing Operations ......................................... 14

Specialty Applications of Metal Powders
Jack A. Hamill, Jr. ............................................. 20
Copier Powders .................................................. 22
Flake Pigments .................................................. 24
Fuels .................................................................. 25
Fillers ............................................................... 27
Food Enrichment ............................................... 28
Environmental Remediation .................................... 29
Material Substitution .......................................... 29
Magnetic and Electrical Applications ....................... 29
Medical ............................................................. 29

Safety and Environmental Aspects .......................... 31
Dust Generation .................................................. 31
Potential Dust Hazards ........................................ 31
Health Effects .................................................. 32
Dust Combustion/Explosions .................................. 32
Fire Triangle and Dust Explosion Pentagon ............... 33
Assessment of Dust Explosion Potential .................... 33
Prevention of Metal Dust Hazards ......................... 34
Powder Metallurgy Presses ................................... 37
Safeguarding .................................................... 37
Responsibilities ............................................... 38
Auxiliary Functions ............................................ 39
Electrical Controls ............................................. 39
Die Installation and Removal .................................. 40
Training ............................................................ 41
Changes to the New ANSI B11.16 (MPIF 47) in 2014 .... 42
Atmosphere Directionality ..................................... 43
Atmosphere Introduction ....................................... 43
Outside Influences ............................................. 44

Materials Standards and Test Method Standards for
Powder Metallurgy
W. Brian James .................................................. 45
Standards Development ........................................ 45
Materials Standards .......................................... 47

MPIF/ASTM Powder Metallurgy Materials
Designation Codes ............................................. 48
ISO Standards for Powder Metallurgy Materials .......... 49
Test Method Standards ........................................ 49

Metal Powder Production ........................................ 53

Introduction to Metal Powder Production and Characterization
Chris Schade ..................................................... 55

General Methods of Metal Powder Production
Chris Schade ..................................................... 55

Ferrous and Nonferrous Powders ................................ 55
Powder Characterization and Testing ....................... 56

Atomization
Chris Schade and John J. Dunkley ......................... 58
Process Variables ............................................. 61
Particle Size .................................................... 62
Particle Size Distribution .................................... 63
Powder Characteristics ....................................... 63
Oil Atomization ............................................... 65
Gas Atomization .............................................. 65
Process Variables ............................................. 66
Gas-Atomized Powders ....................................... 66
Rotating Electrode Process .................................. 69

Chemical and Electrolytic Methods of Powder Production
Chris Schade ..................................................... 72
Oxide Reduction ............................................... 72
Precipitation from Solution ................................... 72
Thermal Decomposition ....................................... 74
Other Chemical Methods ..................................... 74
Electrodeposition ............................................. 75

Milling of Brittle and Ductile Materials
Chris Schade ..................................................... 77
Principles of Milling—Phenomenological Description .... 77
Milling Parameters and Powder Characteristics ......... 80

Blending and Premixing of Metal Powders and Binders
Chris Schade ..................................................... 88
Blending and Premixing Variables ......................... 88
Effect of Powder Characteristics ......................... 89
Equipment for Blending and Premixing ..................... 90

Metal Powder Characterization ............................... 93

Sampling and Classification of Powders
Brian Pittenger .................................................. 95
Sampling of Powders ......................................... 95
Sampling Stored Material .................................... 96
Sampling Flowing Streams ................................... 97
Sample Reduction ............................................ 98
Evaluation of Sampling ..................................... 99
Weight of Sample Required .................................. 99
Powder Classification ....................................... 100
Basic Variables .............................................. 100
Systems for Powder Classification ....................... 100

Sieving Methods .............................................. 102
Sieve Types .................................................... 103
Process Variables ............................................ 103
Methods of Sieving ......................................... 105
Wetting Powder Clumps into the Liquid ................. 108
Breaking up Wetted Clumps ................................ 108
Preventing Flocculation of Dispersed Particles ........... 109
Selecting a Dispersing Agent ................................ 109

Bulk Properties of Powders
Sydney H. Luk ........................................... 111
Powder Morphology .................................... 111
Powder Properties ...................................... 111
Cohesive Strength ...................................... 113
Frictional Properties .................................... 114
Bulk Density ............................................ 115
Permeability and Flow Rate .............................. 119
Sliding at Impact Points .................................. 121
Segregation Tendency .................................... 121
Angle of Repose ......................................... 122
Green Strength and Springback ......................... 123
Chemical Composition ................................... 124
Conclusion .............................................. 124

Particle Image Analysis
Bo Hu .................................................. 154
Sample Preparation .................................... 154
Examples of Particle Image Analysis on Iron 145
Powder Particles ........................................ 154

Ferrous Powder Metallurgy Metallography
Thomas F. Murphy ..................................... 156
Sample Selection ....................................... 157
Cross Section Removal ................................. 158
Mounting .............................................. 160
Removal of the Deformed Metal Layer .................. 160
Grinding and Polishing .................................. 161
After Preparation ...................................... 162
Examination ............................................ 162
Etching and Interference Layer Deposition ............. 164
Optical Microscopy Techniques ......................... 165
Safety .................................................. 166

Metal Powder Compaction .............................. 169
Compressibility and Compactibility of Metal Powders
Steve Lampman .......................................... 171
Compressibility ........................................ 171
Green Strength ........................................ 175
Modeling and Simulation of Press and Sinter
Powder Metallurgy
Suk Hwan Chung, Young-Sam Kwon, Seong Jin Park and
Randall M. German ..................................... 179
Brief History ........................................... 179
Theoretical Background and Governing Equations ...... 180
Experimental Determination of Material Properties
and Simulation Verification ............................ 181

Demonstration of System Use ........................... 184
Conclusion .............................................. 186

Powder Metallurgy Presses and Tooling
Troy Robinson ......................................... 191
Compacting Press Requirements ......................... 191
Mechanical Presses ..................................... 192
Hydraulic Presses ...................................... 192
Comparison of Mechanical and Hydraulic Presses ..... 193
Part Classification ...................................... 193
Shape of Rigid Tooling ................................ 194
Powder Fill ............................................ 194
Tooling Systems ........................................ 195
Types of Presses ....................................... 196
Advanced Tool Motions ................................ 197
Tooling Design ........................................ 198
Tool Materials ........................................ 200
Tooling Clearances and Design ......................... 201

Sintering Basics ........................................ 203
Sintering Theory and Fundamentals
Mohamed N. Rahaman .................................. 205
Types of Sintering ..................................... 206
Measurement of Sintering ................................ 207
Analysis of Sintering ................................... 207
Solid-State Sintering ................................... 207
Grain Growth in Solid-State Sintering .................. 211
Processing and Microstructural Variables in
Solid-State Sintering ................................... 213
Viscous Sintering ....................................... 216
Liquid-Phase Sintering ................................ 216
Supersolidus Liquid-Phase Sintering ................... 224
Transient Liquid-Phase Sintering ....................... 227
Activated Sintering ..................................... 228
Pressure-Assisted Sintering ............................. 229

Sintering Atmospheres
Harb S. Nayar ......................................... 237
Preparation Section Atmosphere Requirements .......... 237
Sintering Section Atmosphere Requirements .......... 239
Initial Cooling Section Requirements .................. 239
Final Cooling Section Requirements ................... 239
Types of Atmospheres ................................ 239
Furnace Zoning Concept (Ref 24–29) .................... 244
Increase in Throughput and Reduction in Energy
Consumption per Pound of Sintered Parts ............... 245
Safety and Environmental Concerns in Using
Sintering Atmospheres
Thomas Philips and Harb Nayar ......................... 247
Safety Concerns ........................................ 249
Environmental Concerns ............................... 249

Full-Density Consolidation Methods ................. 251
Introduction to Full Density Powder Metallurgy
Prasan K. Samal ........................................ 253
Cold Isostatic Pressing
Peter E. Price .......................................... 255
Process Characteristics ................................ 255
Process Equipment ..................................... 256
Wet-Bag Isostatic Pressing ............................... 257
Part Size and Shape .................................... 257
Powder Properties ..................................... 258
Process Parameters ..................................... 258
Powder Metallurgy Processing by Hot Isostatic Pressing
Stephen J. Mashl ....................................... 260
History ................................................. 260
The Hot Isostatic Pressing Process ..................... 261
<table>
<thead>
<tr>
<th>Fabricating Products Using Hot Isostatic Pressing</th>
<th>263</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder Metallurgy Techniques</td>
<td>263</td>
</tr>
<tr>
<td>Microstructure and Properties</td>
<td>267</td>
</tr>
<tr>
<td>Summary</td>
<td>269</td>
</tr>
<tr>
<td>Powder Hot Pressing and Forging</td>
<td>271</td>
</tr>
<tr>
<td>Howard A. Kuhn</td>
<td>271</td>
</tr>
<tr>
<td>Powder Forging</td>
<td>271</td>
</tr>
<tr>
<td>Hot Pressing</td>
<td>275</td>
</tr>
<tr>
<td>Extrusion of Metal Powders</td>
<td>277</td>
</tr>
<tr>
<td>Mechanics of Powder Extrusion</td>
<td>278</td>
</tr>
<tr>
<td>Powder Extrusion Practice</td>
<td>281</td>
</tr>
<tr>
<td>Examples of Materials Processed by Powder Extrusion</td>
<td>281</td>
</tr>
<tr>
<td>Continuous Extrusion Process</td>
<td>284</td>
</tr>
<tr>
<td>Conclusions</td>
<td>284</td>
</tr>
<tr>
<td>Direct Powder Rolling</td>
<td>286</td>
</tr>
<tr>
<td>Prasan K. Samal</td>
<td>286</td>
</tr>
<tr>
<td>Basic Process</td>
<td>286</td>
</tr>
<tr>
<td>Practical Considerations in Direct Powder Rolling</td>
<td>287</td>
</tr>
<tr>
<td>Reasons to Use Direct Powder Rolling</td>
<td>287</td>
</tr>
<tr>
<td>Powder Metallurgy Carbon and Low-Alloy Steels</td>
<td>293</td>
</tr>
<tr>
<td>Ferrous Powder Metallurgy Materials</td>
<td>295</td>
</tr>
<tr>
<td>W. Brian James</td>
<td>295</td>
</tr>
<tr>
<td>Allloying Methods</td>
<td>296</td>
</tr>
<tr>
<td>Ferrous Powder Materials</td>
<td>301</td>
</tr>
<tr>
<td>Mechanical Properties of Ferrous Powder Metallurgy Materials</td>
<td>311</td>
</tr>
<tr>
<td>Production of Powder Metallurgy Carbon and Low-Alloy Steels</td>
<td>311</td>
</tr>
<tr>
<td>Michael L. Marucci and James A. Cutaneous</td>
<td>311</td>
</tr>
<tr>
<td>Production of Iron and Steel Powder by Water Atomization</td>
<td>312</td>
</tr>
<tr>
<td>Production of High-Porosity Iron Powders</td>
<td>314</td>
</tr>
<tr>
<td>Production of Iron Powder by Carbonyl Vapor Metallurgy</td>
<td>316</td>
</tr>
<tr>
<td>Diffusion Alloying and Bonding</td>
<td>319</td>
</tr>
<tr>
<td>Warm Compaction and Warm Die Compaction</td>
<td>322</td>
</tr>
<tr>
<td>Francis Hanejko</td>
<td>322</td>
</tr>
<tr>
<td>Pore-Free Density</td>
<td>322</td>
</tr>
<tr>
<td>Effects of Warm Die Compaction on Green and Sintered Properties</td>
<td>322</td>
</tr>
<tr>
<td>Process Considerations</td>
<td>323</td>
</tr>
<tr>
<td>Tooling Design for Warm Compaction</td>
<td>324</td>
</tr>
<tr>
<td>Mechanical Properties of Warm-Compacted and Warm-Die-Compacted Powder Metallurgy Components</td>
<td>324</td>
</tr>
<tr>
<td>Copper-Infiltrated Steels</td>
<td>326</td>
</tr>
<tr>
<td>Wayne K. Daye and Thomas W. Pelletiers II</td>
<td>326</td>
</tr>
<tr>
<td>Basic Requirements</td>
<td>326</td>
</tr>
<tr>
<td>Conventionally (Partially) Infiltrated Steels</td>
<td>327</td>
</tr>
<tr>
<td>Evaluation of Infiltrated Parts</td>
<td>329</td>
</tr>
<tr>
<td>Alloy Steels and Fully Infiltrated Steels</td>
<td>330</td>
</tr>
<tr>
<td>High-Temperature Sintering of Ferrous Powder</td>
<td>334</td>
</tr>
<tr>
<td>Metallurgy Components</td>
<td>334</td>
</tr>
<tr>
<td>Roland T. Warzel III</td>
<td>331</td>
</tr>
<tr>
<td>Sintering Stages and Effects</td>
<td>331</td>
</tr>
<tr>
<td>Improved Mechanical Properties</td>
<td>332</td>
</tr>
<tr>
<td>Improved Physical Properties</td>
<td>333</td>
</tr>
<tr>
<td>Development of a Liquid Phase</td>
<td>333</td>
</tr>
<tr>
<td>Sintering of Active Elements</td>
<td>334</td>
</tr>
<tr>
<td>Process Control Requirements</td>
<td>335</td>
</tr>
<tr>
<td>Production Sintering Practices</td>
<td>337</td>
</tr>
<tr>
<td>Roland T. Warzel III</td>
<td>337</td>
</tr>
<tr>
<td>Sintering of Ferrous Materials</td>
<td>337</td>
</tr>
<tr>
<td>Sintering Atmospheres</td>
<td>338</td>
</tr>
<tr>
<td>Iron and Iron Graphite Powder</td>
<td>339</td>
</tr>
<tr>
<td>Iron-Copper and Iron-Copper Graphite</td>
<td>341</td>
</tr>
<tr>
<td>Sintering of Alloy Steels</td>
<td>341</td>
</tr>
<tr>
<td>Sinter Hardening</td>
<td>344</td>
</tr>
<tr>
<td>High-Temperature Sintering</td>
<td>344</td>
</tr>
<tr>
<td>Powder Forged Steel</td>
<td>347</td>
</tr>
<tr>
<td>E. Ilia and W. Brian James</td>
<td>347</td>
</tr>
<tr>
<td>Material Considerations</td>
<td>347</td>
</tr>
<tr>
<td>Process Considerations</td>
<td>350</td>
</tr>
<tr>
<td>Mechanical Properties</td>
<td>355</td>
</tr>
<tr>
<td>Quality Assurance for Powder-Forced Parts</td>
<td>360</td>
</tr>
<tr>
<td>Powder Metallurgy Gears</td>
<td>362</td>
</tr>
<tr>
<td>Salvator Nigarura</td>
<td>374</td>
</tr>
<tr>
<td>Capabilities and Limitations</td>
<td>374</td>
</tr>
<tr>
<td>Gear Forms</td>
<td>375</td>
</tr>
<tr>
<td>Gear Tolerances</td>
<td>376</td>
</tr>
<tr>
<td>Gear Design and Tooling</td>
<td>376</td>
</tr>
<tr>
<td>Gear Performance</td>
<td>378</td>
</tr>
<tr>
<td>Quality Control and Inspection</td>
<td>378</td>
</tr>
<tr>
<td>Machinability of Powder Metallurgy Steels</td>
<td>384</td>
</tr>
<tr>
<td>Denis Christopherson, Jr.</td>
<td>384</td>
</tr>
<tr>
<td>The Machining Process</td>
<td>384</td>
</tr>
<tr>
<td>Machinability Measurement</td>
<td>386</td>
</tr>
<tr>
<td>Machinability Improvement</td>
<td>387</td>
</tr>
<tr>
<td>Sulfides</td>
<td>388</td>
</tr>
<tr>
<td>Metallography</td>
<td>389</td>
</tr>
<tr>
<td>Stability of Sulfides</td>
<td>390</td>
</tr>
<tr>
<td>Effects on Sintered Properties</td>
<td>390</td>
</tr>
<tr>
<td>Tool Materials</td>
<td>392</td>
</tr>
<tr>
<td>Microstructure Modification</td>
<td>393</td>
</tr>
<tr>
<td>Machining of Powder Metallurgy Materials</td>
<td>395</td>
</tr>
<tr>
<td>Denis Christopherson, Jr.</td>
<td>395</td>
</tr>
<tr>
<td>General Guidelines</td>
<td>395</td>
</tr>
<tr>
<td>Machining Guidelines</td>
<td>396</td>
</tr>
<tr>
<td>Joining Powder Metallurgy Steel Components</td>
<td>405</td>
</tr>
<tr>
<td>Peter K. Sokolowski</td>
<td>405</td>
</tr>
<tr>
<td>Fusion Methods</td>
<td>406</td>
</tr>
<tr>
<td>Solid-State Methods</td>
<td>408</td>
</tr>
<tr>
<td>Powder Metallurgy Materials for Joining</td>
<td>409</td>
</tr>
<tr>
<td>Powder Metallurgy Stainless Steels</td>
<td>411</td>
</tr>
<tr>
<td>Introduction to Powder Metallurgy Stainless Steels</td>
<td>413</td>
</tr>
<tr>
<td>Prasan K. Samal</td>
<td>413</td>
</tr>
<tr>
<td>Alloy Classification and Compositions</td>
<td>415</td>
</tr>
<tr>
<td>Prasan K. Samal</td>
<td>415</td>
</tr>
<tr>
<td>Basic Metallurgical Principles</td>
<td>415</td>
</tr>
<tr>
<td>Identification and Specifications</td>
<td>416</td>
</tr>
<tr>
<td>Characteristics and Chemical Compositions of Wrought and Powder Metallurgy Stainless Steels</td>
<td>417</td>
</tr>
<tr>
<td>Manufacture of Stainless Steel Powders</td>
<td>421</td>
</tr>
<tr>
<td>Roland T. Warzel III</td>
<td>421</td>
</tr>
<tr>
<td>Water Atomization of Stainless Steel Powders</td>
<td>421</td>
</tr>
<tr>
<td>Gas Atomization of Stainless Steel Powders</td>
<td>424</td>
</tr>
<tr>
<td>Drying, Screening, Annealing, and Lubricating</td>
<td>425</td>
</tr>
<tr>
<td>Testing for Quality Assurance</td>
<td>425</td>
</tr>
<tr>
<td>Compacting of Stainless Steel Powders</td>
<td>427</td>
</tr>
<tr>
<td>Richard R. Phillips and Prasan K. Samal</td>
<td>427</td>
</tr>
<tr>
<td>The Basic Process</td>
<td>427</td>
</tr>
<tr>
<td>Compaction Characteristics of Stainless Steel Powders</td>
<td>428</td>
</tr>
<tr>
<td>Sintering of Stainless Steels</td>
<td>433</td>
</tr>
<tr>
<td>Peter A. dePoutiloff and Prasan K. Samal</td>
<td>433</td>
</tr>
<tr>
<td>Sintering Behavior of Various Families of Stainless Steels</td>
<td>433</td>
</tr>
<tr>
<td>MPIF Material Designations</td>
<td>434</td>
</tr>
<tr>
<td>Equipment</td>
<td>434</td>
</tr>
<tr>
<td>Critical Steps in the Sintering of Stainless Steels</td>
<td>434</td>
</tr>
<tr>
<td>Atmospheres</td>
<td>436</td>
</tr>
<tr>
<td>Dimensional Change in Sintering</td>
<td>437</td>
</tr>
<tr>
<td>Secondary Operations for Powder Metallurgy Stainless Steels</td>
<td>440</td>
</tr>
</tbody>
</table>