Powder Metallurgy: Science, Technology and Materials

A. Upadhyaya and G.S. Upadhyaya
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This book is a "must" read for students, researchers, engineers, and manufacturers involved in the processing of particulate materials. It is the fifth in a series of books published with the aim of advancing knowledge of the Metallurgy and Materials Science discipline. The noble idea of publishing this series of books was initiated during the Diamond Jubilee year (2006) of the Indian Institute of Metals. The authors of this book, Anish Upadhyaya, Associate Professor, Department of Materials Science and Engineering, Indian Institute of Technology, Kanpur, India, and former Professor G.S. Upadhyaya, from the same institute, are well known in the field of powder metallurgy (PM). They have both contributed extensively to the development of PM by providing excellent academic training for young burgeoning engineers, as well as through extensive R&D. Witness that a number of ex-students of G.S. Upadhyaya are globally engaged in a variety of PM activities while Anish Upadhyaya's students are beginning to embark on their PM careers. This book is one of their major achievements and will be a valuable resource for the PM industry.

Published almost a century after Coolidge and his colleagues invented the process for ductile-tungsten lamp filament wire in 1908, this book does an excellent job of bringing together the science and technology of a relatively new field. Though the modern commercial era of PM is only a century old, it has been practiced since ancient times. A famous example of the use of this technology is the Iron Pillar of Chandragupta, built in the early 4th Century, and considered one of the world's wonders. Since the early 1900s, the technology has proliferated and PM products are now found routinely in major industry segments. One may be surprised to find that PM is used in automobiles, airplanes, the chemical industry, food and drugs, fireworks, and in the defense sector. As the technology progressed rapidly after World War II, applications often superseded development of the scientific knowledge base; this was generally left to research scientists and academe. The PM sector has been blessed with gifted individuals who have helped in our current understanding of this technology. Still, with the march of technology, new challenges are emerging. Thus, periodically, there is the need for someone to take on the responsibility of providing an up-to-date textbook that covers both the science and technology of, in this case, PM. This book does a compelling job in addressing this need.

The authors have analyzed the PM process in terms of three goals: (a) achieving a desired geometry with adequate defect control, (b) developing a microstructure to provide the desired properties and performance, and (c) optimizing the cost of production. In this book, they address each issue in detail. The book also includes a brief coverage of key areas that are not usually included in most PM textbooks, namely, powder pyrophoricity and toxicity, powder degassing, energy savings in PM, techo-economic aspects, and recycling of PM materials. There is an interesting commentary on the strategy for the PM parts business. Each chapter includes a brief summary (in bullet form), references for further reading, and exercises. The book covers the cardinal structure–property–performance relationships of PM materials and provides excellent coverage embracing conventional PM technology all the way to state-of-the-art technology and PM materials.

The book is divided into fourteen chapters. Chapter 1 provides an introduction to the overall science and technology of PM materials. This chapter will be invaluable to those who are new to PM. It lays the foundation for the following chapters. Chapter 2 covers the theory and practice of powder production in significant detail. Starting with chemical methods for producing powders, including iron, copper, nickel, cobalt, titanium, tungsten, tantalum, niobium, and alumina. The chapter then discusses other important methods of powder production; these include electrolysis, atomization, evaporation, and mechanical methods. In most cases examples of the powders produced by these processes are discussed. Chapter 3 follows a logical sequence in which, once the powders have been produced, they need to be characterized. This chapter begins with a brief note on powder sampling (often overlooked), and then discusses chemical composition and structure. The chapter covers various methods for measuring powder size, size distribution, surface topography, several types of density measurement (true, apparent, tap), flow rate, compressibility, and green strength. The chapter concludes with a brief coverage of pyrophoricity and toxicity of fine powders.

To a powder metallurgist it should be obvious that the as-produced powder is not always used in that form to make a PM part. There are often various "powder treatment" steps needed to make the powder suitable for subsequent processing; these are covered in Chapter 4 and that leads into Chapter 5, which focuses on the most common powder-forming technique, namely, powder compaction. This chapter discusses the basic fundamentals of how powders pack and form into a coherent shape through the application of pres-

sure. Common techniques such as die compaction, warm compaction, wet compaction, cold isostatic compaction, powder roll compaction, extrusion, and injection molding are included. The chapter also has a small section covering green-part handling. Chapter 6, though short, provides an excellent coverage of several pressureless powder-shaping techniques that include slip casting, tape casting, electrophoretic deposition, spray forming, and solid freeform fabrication.

Chapter 7 deals with sintering theory, recalling that the two previous chapters have taken the readers through the processes of green-shape forming. There are few occasions where the green part serves as the final component. To impart the desired strength and densification, it is mostly necessary to carry out a step known as sintering. This chapter answers the fundamental questions of "why" and "how" powders sinter with emphasis on the fundamental theory of sintering, including solid-state and liquid-phase sintering, as well as pressureless and pressure-assisted sintering. The stages of structural evolution and the relationship between processing and structure are well covered. The chapter also discusses the sintering of nanopowders. A detailed discussion on sintering technology is contained in Chapter 8, which provides a natural transition from the earlier chapter on sintering theory to sintering technology and covers various types of sintering furnaces, sintering atmospheres, rapid-sintering methods, time–temperature and sintering atmosphere effects on sintering, and the role of powder characteristics in sintering and its effect on dimensional changes. The chapter on full density consolidation (Chapter 9) provides an excellent analysis of important hot-consolidation techniques currently in use. The chapter covers dynamic powder compaction, hot pressing, hot isostatic pressing (HIPing), sinter-HIP, powder hot extrusion, powder hot forging, hot rolling, and spark sintering. These fully dense techniques are extremely important for high-performance PM products. Another key area of PM that typically receives little coverage in textbooks, namely, secondary treatments, is discussed in sufficient detail in Chapter 10. The drivers for secondary treatment of PM components are similar to those for cast or wrought products. The main drivers are improvement in properties and dimensional tolerances that are often not achieved by sintering alone. The chapter touches on a majority of secondary treatments, including sizing and coining, machining, impregnation (generally unique to PM), surface-engineering treatments, heat treatments, and joining.

Chapter 11 provides an expanded coverage of the testing and quality control of PM materials and products. Methods of measuring physical, mechanical, electrical, and thermal properties of PM materials are described. A somewhat detailed description of the structure of PM materials is included. Chapter 12, one of the largest chapters, deals with metallic and ceramic materials. This chapter does an excellent job of taking the myriad of PM materials and categorizing them into several broad groups. The coverage includes ferrous and nonferrous materials, ceramics, intermetallic compounds, metal–ceramic and ceramic–ceramic composites, nanocrystalline materials, and functionally graded materials. The last section of this chapter deals with the Metal Powder Industries Federation (MPIF) PM material designation code. The last two chapters of the book deal with applications of PM products and the techno-economics of PM processing. The chapter on applications embraces extensive coverage of PM in automotive, aerospace, ordnance, machine tools, power generation, electrical applications, magnetic application–related products, oxygen sensors, thermal management, hardfacing, metallic foams, and bio-implants. The last chapter deals with production and cost-related issues in PM processing; it should be of interest to PM parts fabricators.

Overall, this book is a reflection of the experience of both authors in teaching undergraduate and postgraduate students who have selected PM as a core or elective subject and also those who have made the decision to pursue a career in PM and are pursuing a Master or PhD degree in this area. A close interaction with students has provided the authors with the insight needed to write a book that will provide both undergraduate and postgraduate students with a clear understanding of the scientific principles and the technological drivers of the PM industry, as well as an in-depth scientific knowledge that is needed by those wishing to pursue a career in PM. There is also a wealth of information in this book for individuals who are already practitioners and who need to update their knowledge. The 500-plus pages are filled with information that will be of value to practitioners in the PM industry.

Though one can always find areas where the coverage may be considered minimal, it should be appreciated that the PM area is so large that even a lengthier book would still not provide adequate coverage of all segments. For example, the book does not include a detailed coverage of powder handling which, in a true sense, falls primarily in the area of Manufacturing Engineering. To provide a lengthy coverage of this area would have increased the size of the book unnecessarily. In summary the authors' contribution should serve as a textbook and as a reference source for all students, researchers, engineers, and practitioners engaged in PM.

For more information on this title, contact the MPIF Publications Department at 609-945-0009; E-mail: plebedz@mpif.org; www.mpif.org.

Animesh Bose, FAPMI
President
Materials Processing, Inc.
2421 Thomas Road
Haltom City, TX 76117