Wolfgang Pietsch

WILEY-VCH

Agglomeration in Industry

Occurrence and Applications

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Preface

When this book was first planned, the idea was to combine in one volume concise descriptions of agglomeration phenomena, technologies, equipment, and systems as well as a compilation of the applications of agglomeration techniques in industry. The latter was intended to demonstrate the widespread natural, mostly undesired occurrences of the phenomena and possible ways of avoiding them as well as the old, conventional, and new, varied beneficial uses of the technologies.

However, it soon became obvious that, in its entirety, this project was too extensive and required much more time than anticipated. Therefore, it was decided to split the subject into two complementary books.

The first book, *Agglomeration Processes – Phenomena, Technologies, Equipment* (ISBN 3-527-30369-3) was published by Wiley-VCH, Weinheim, Germany, in 2002. It covers the fundamental phenomena that define agglomeration and industrial technologies and equipment for size enlargement by agglomeration. Applications are mentioned in a general way throughout this text but without going into details.

This second book is an up-to-date overview dealing with the occurrence and key applications of agglomeration, including size enlargement in pharmaceutical, food and animal feed, chemical, fertilizer and agrochemical, mineral, building material and ceramic, metal, solid fuel, and other industries. Furthermore, the book emphasizes recent developments at the level of single particles and applications of agglomeration phenomena in nanotechnologies.

Many people, institutions, and companies have contributed to the two books.

First and foremost, I wish to thank my wife Hannelore for her support and understanding, particularly during the years when I was compiling these books. They are both dedicated to her. Without my wife's active participation in preparing almost all my publications, including the first textbook entitled *Size Enlargement by Agglomeration*, which is a major reference for the current two books, and her acceptance that I was not available for many hours almost every day during much of two decades, these publications could not have been completed.

It is impossible to acknowledge all the help that was provided by a large number of individuals and companies. Chapter 15.1 is a list of vendors and other organizations, which mentions those who have, in one way or another, contributed as well as some others that might be of interest as potential contacts for the readers of these books. While I have decided not to clutter the text with references, sources have been acknowledged if figures or tables were provided by or are based on input from particular companies. The Disclaimer at the beginning of this book should be referred to when using such information.

Chapter 13 lists literature references. The earlier textbook, *Size Enlargement by Agglomeration*, contains treatments and many references relating to the developing science of the unit operation and covers the sizing of agglomeration equipment in some detail. Since the emphasis of the new books is on industrial applications, rather than theory, the earlier book should be referred to for the theoretical background. Information on the availability of reprinted copies of *Size Enlargement by Agglomeration* (Wiley, 1991) is available in Chapter 13.1 as a footnote. I have also contributed major chapters on agglomeration to two other books, portions of which are used in this book. The other books are: *Handbook of Powder Science and Technology* (Eds: M. E. Fayed, L. Otten), 1st edn, Van Nostrand Reinhold, New York (1983) and 2nd edn, Chapman & Hall, New York (1997). Full references can be found in Chapter 13.1.

Since size enlargement by agglomeration is one of the four unit operations of Mechanical Process Technology (see Chapters 1 and 2) and, for the design and construction of agglomeration systems and plants of any kind, many or all of the other unit operations are required together with the associated transport and storage technologies, often even in multiplicity, and the analytical methods are applied for process evaluation and control, the reader who is interested in the topic of this book should also learn about or have access to information on the other fields of Mechanical Process Technology (references in Chapter 13).

Finally, I wish to thank the following individuals who, as professionals and experts in their own fields, are or have been colleagues and/or partners in several continuing education courses over many years in the USA and in Europe and have agreed that their presentations and course notes can be used directly, adopted, or modified for this book. They are, in alphabetical order: T. van Doorslaer, W. E. Engelleitner, B. J. Ennis, M. E. Fayed, M. Gursch, D. C. Hicks, S. Jagnow, R. H. Leaver, R. Löbe, K. Masters, S. Mortensen, H. B. Ries, F. V. Shaw, N. Stanley-Wood, J. Storm, R. Wicke, and the late R. Zisselmar. Other major contributors were M. Karel, Y. Kawashima, the late B. Kaye, and H. Schubert.

Wolfgang Pietsch,
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7 Powder Metallurgy

Powder metallurgy (PM) is a method for manufacturing ferrous and non-ferrous industrial parts. Although relatively young, the technology is highly developed and very reliable. In accordance with its great importance for modern high-tech metal products and components, many publications are available on the subject (see Further Reading) and everywhere in the developed world scientific groups, industrial and trade organizations, and other institutions exist that promote the knowledge and applications of powder metallurgy. Many are easily accessible, for example: www.mpif.org; www.ifam.fraunhofer.de; www.PowderMetalWeb.com; www.ipmd.net.

Tab. 7.1 lists the advantages of the PM process and products. The technology is cost effective because it produces parts, simple or complex, at or very close to final dimensions. This is often called "near-net-shape" production (Section 6.7.2). As a result, only minor, if any, machining is required making it a "chipless" metal working process. Typically more than 97 % of the starting material (metal powder) is in the finished part. Because of this, powder metallurgy is a process that saves energy and raw materials.

Most PM parts are small and even larger ones weigh typically less than 2 kg, although pieces of up to 15 kg can be fabricated with conventional PM equipment.

Tab. 7.1 Advantages of the P/M process and of parts made by it (adapted from MPIF, Princeton, NJ, USA)

- Eliminates or minimizes machining (near-net-shape)
  - Eliminates or minimizes scrap losses
  - Maintains close dimensional tolerances
  - Produces good surface finishes
- Permits wide variety of alloy systems
  - Facilitates manufacture of complex or unique shapes which would be impractical or impossible with other metal working processes
  - Provides materials which may be heat treated for increased strength or increased wear resistance
  - Metallurgically immiscible materials can be combined to produce uniform structures and "exotic alloys" that are not attainable by pyrometallurgy
- Provides controlled porosity for, for example, self-lubrication or filtration
- Offers long term performance reliability
- Suited to moderate and high volume production requirements
- Cost effective

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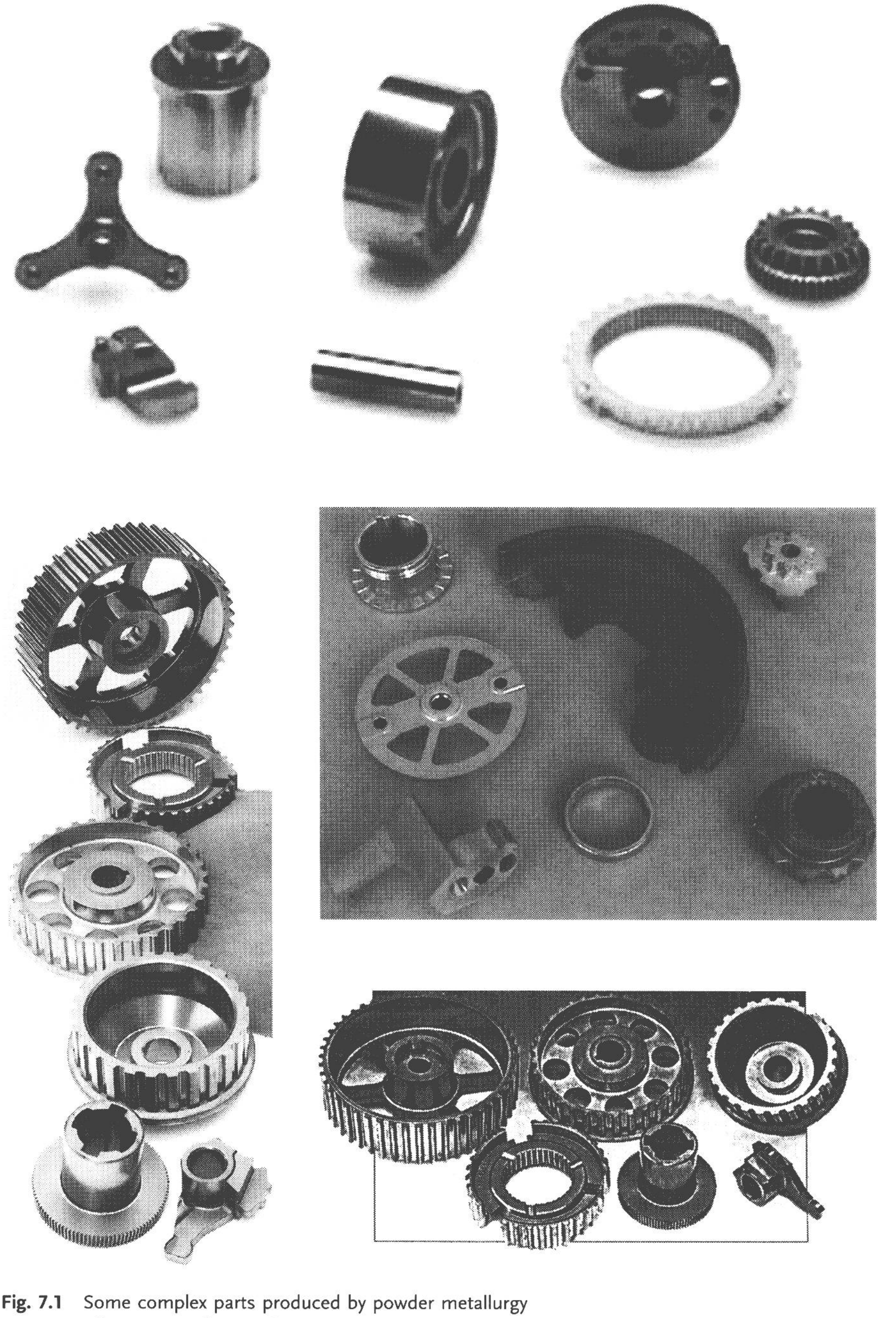

Fig. 7.1 Some complex parts produced by powder metallurgy (courtesy of Komage-Gellner, Kell am See, Germany, and Dorst, Kochel am See, Germany)

Production rates range from a few hundred or less to several thousand parts per hour. While many early powder metallurgical items, such as cutting tool tips, bushes, or bearings, had very simple shapes (cubes, rectangular blocks, discs, rings, cylinders), parts with complex contours and multiple levels are produced economically today (Fig. 7.1) [B.28, B.48, B.97]. Many gears, cams, and intricately shaped parts that would require expensive machining when produced from cast, forged, or wrought stock can be made from metal powders. Counterbores, flanges, hubs, and holes as well as keyways, keys, D-shaped bores, and other fastening devices can be an integral feature of the part and two or more parts may be combined into a single unit if product design permits.

Compared with other metallurgical manufacturing processes, PM offers the additional advantage of precise control. Powder metallurgists are able to exercise their influence over the entire production process from the pure metal to the equally pure powder, the (agglomerated) pre-form, and the finished part. By mixing metal powders, which may be of different elemental or alloy origin, size, and/or shape, various material compositions and finished products can be created.

Powder metallurgical manufacturing eliminates impurities and inclusions, avoids uneven internal stresses, and excludes poor finishes, unworkable tolerances, and many other factors that might affect the rate of production and the quality of the finished part. PM assures uniformity and optimum performance characteristics of products and offers long-term performance reliability in critical applications.

As shown in Fig. 7.2, after the formulation and blending step, shaping (forming) of the part and the development of strength are accomplished with methods of agglomeration by pressure and heat followed by a choice of post-treatment steps, if required. While powder production is accomplished by the atomization of pure molten metals or alloys [B.13d and Section 13.3, Refs. 82, 85, 87, 89, 90, 91, 93, 94], the manufacturing process for parts occurs in the solid state. Therefore, metallurgically immiscible materials can be combined to produce uniform structures and "exotic alloys" that are not attainable by melt methods. Dissimilar metals, non-metallics, and other components of widely different characteristics can be mixed, compacted, sintered, and further processed, if required, into components that exhibit unique properties. For example: ceramics can be blended with metals to make cermets (Section 6.7.2). Carbon and copper form electrical brushes with high electrical conductivity and wear resistance. Tungsten and silver are combined in the manufacture of electrical contacts and switch gear. Copper, tin, iron, lead, and graphite are compacted into heavy-duty friction material. The combination of materials through the use of PM techniques is essentially unlimited. Application for a new task only requires research and experimentation.

Since powder metallurgy is a technology in its own right, this book is not going into more detail. As far as agglomeration tools for the densification and shaping of the powders and of powder blends are concerned, Fig. 7.2 classifies the methods under hot and cold compaction. The equipment available and used for these tasks has been described in detail in an earlier book by the author [B.97]. In many respects the shaping and densification of metal powders is similar to that of high-performance ceramics and many of the presses can be used for both applications (Section 6.7.2). The same is true for sintering. Here too, some related material is included in Section 6.7.3

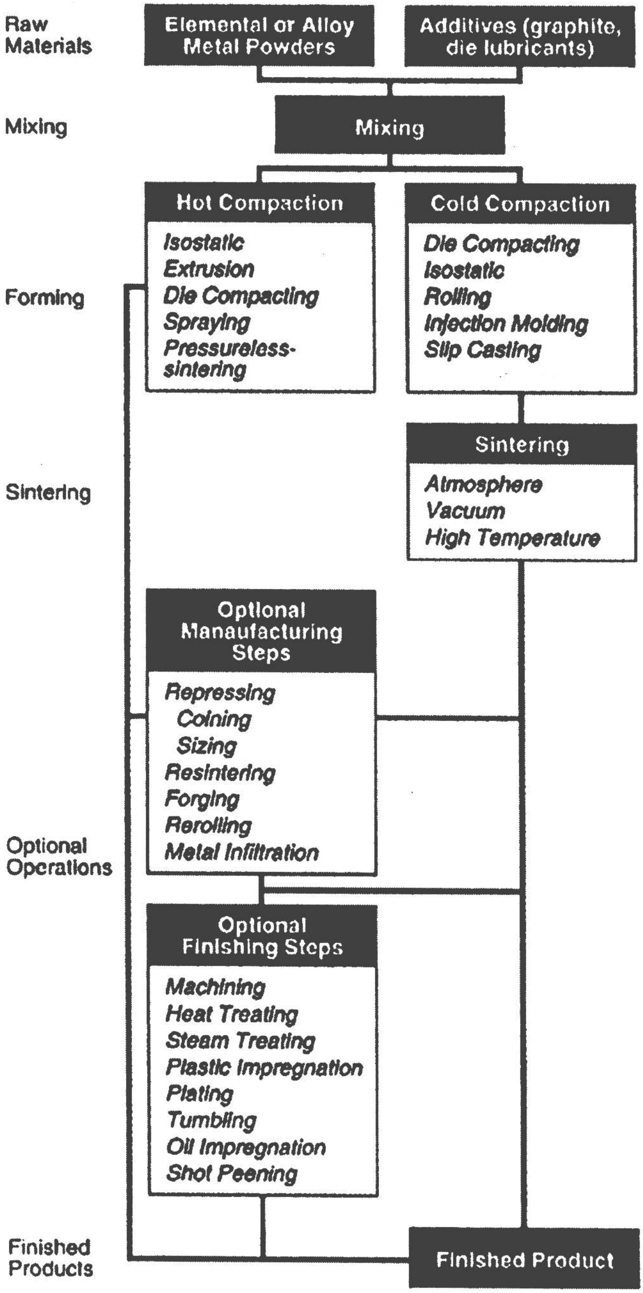

Fig. 7.2 Process diagram of powder metallurgy (courtesy of MPIF, Princeton, NJ, USA)

and the author's earlier book [B.97]. Additional information can be gleaned from the numerous websites associated with the search word "powder metallurgy" and its foreign language forms as well as from the books listed at the end of this chapter.

As can be seen from the process diagram in Fig. 7.2, hot compaction combines the steps of densifying, shaping, and sintering in one piece of equipment. For many applications it is the modern way of accomplishing the task. In most cases, after hot compaction only additional post-treatment (optional operations) is necessary if required. Isostatic pressing, either hot or cold [B.13a, B.97], results in the most uniform structure, which minimizes distortion during heat treatment (sintering) that is used either for the development of strength or the modification of density (reduction of porosity) during re-sintering (Section 6.7.2). Punch-and-die pressing is used for the mass production of simple small parts but also for complex symmetrical designs (Fig. 7.1) [B.28]. Rolling with roller presses is a relatively new process for the manufacture of sheet with special properties from powders that are often mechanically alloyed and could not be produced by traditional methods.

Further Reading

For further reading the following books are recommended: B.4, **B.13a, c, and d, B.28, B.47, B.57, B.65, B.76**, B.78, **B.79, B.84, B.85**, B.86, B.88, B.95, **B.96, B.100, B.101** (Chapter 13.1). Books mainly devoted to the subject matter are printed bold.