Handbook of
POWDER METALLURGY

Second Edition

by

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Foreword to Second Edition

In metallurgical production and the creation of new types of metallic materials, powder metallurgy has steadily gained importance. P/M research and development has placed the powder techniques in competition with more conventional techniques. Powder metallurgy has succeeded in the fabrication of alloys which cannot be produced by melting and casting methods. Powder metallurgy further has succeeded in the development of high strength material by distribution of fibers into a metal matrix. Titanium carbide alloys with larger amounts of carbon made by powder metallurgy proved to have exceptional strength properties.

The first edition of Hausner's HANDBOOK OF POWDER METALLURGY is internationally known. However, it is not up-to-date and not available anymore. This second edition of the HANDBOOK is considerably revised and brought up-to-date by H.H. Hausner and M. Kumar Mal, both highly recognized by the international community of powder metallurgists.

In the first edition, most of the data were presented in English units; this second edition contains all the data also in the metric system. This should make the book more valuable for the international readership. More detailed information is given on powder production by atomization, on isostatic pressing, forging, carbide tool production, cost calculations, etc. All this will be welcomed by the readership.

This second edition of the HANDBOOK will definitely contribute to a better understanding and further development and advancement of powder metallurgy.

Prof. Dr. Waether Dawihl
University of Saarland

Foreword to First Edition

Powder metallurgy has long since grown beyond the stage of being used primarily for the processing of refractory and other special materials, and has become serious competition for classical forming methods. Today, for economic reasons, all sorts of nonferrous metals and alloys, as well as steels, are increasingly being processed by powder metallurgical means. Engineering and scientific viewpoints interact directly with one another in this field to a degree that is only rarely found in other technologies.

Powder metallurgy has grown to be such a comprehensive field today, at first glance, one might think it impossible for a single person to describe it completely. But this view is quickly dispelled by Dr. H. H. Hausner's HANDBOOK OF POWDER METALLURGY. It covers the entire field, with its various branches and refinements, while at the same time remaining within the bounds of manageable size and readability. By avoiding unnecessary descriptive text and concentrating instead on graphical presentations which explain basic relationships, and on tables which put forth a variety of data, Dr. Hausner has achieved a concise presentation. It shows him to be an expert whose experience has guided him in presenting all the essentials of his field.

We are convinced that this handbook will meet with great success and will soon become indispensable to all powder metallurgists, the scientists as well as the practitioners of the art. We congratulate Dr. Hausner on the completion of this excellent work which will bring him both respect and gratitude of the powder metallurgical profession.

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Introduction

This Handbook was originally compiled as a teaching device to be used in powder metallurgy courses, and as a supplement to the existing text books. All the information given therein is in the form of tables and graphs, which deal with the principles and technology of powder metallurgy. Hundreds of examples are given for the changes in properties of P/M products as affected by the processing variables. This Handbook will therefore be valuable not only for students and teachers, but also for the practical powder metallurgists involved in research, development and production, and for those who design parts fabricated from metal powders.

The book is divided into 21 chapters. Chapters 1 to 11 deal with the characteristics of powders and the principles and characteristics of powder metallurgy processes; chapters 12 to 21 with special materials and properties. The Appendix deals with powder statistics, prices and costs, physical and chemical data on metals, and the terminology of powder metallurgy.

In the first chapter, an attempt was made to cover the fundamentals of powder metallurgy in diagrams and tables showing the basic variables in powder metallurgy processing. The method of presenting the fundamentals in form of principle graphs has its merits, and was found to be useful as a first introduction.

Chapters 2 to 4 concern powder production and characteristics, the principles of powder comminution and of powder mixing. The basic commercial methods of powder production, and the advantages and disadvantages of each method are listed. Many examples are given for the characterization of powdered materials. Various types of milling and mixing equipment are listed, and an evaluation of the degree of mixing is presented.

Compaction of powders, unidirectional pressing and other methods are presented in Chapter 5. The important problems of friction during powder compaction are shown in Chapter 6, and the types and applications of various lubricants for decreasing friction are discussed.

Chapter 7 deals with the principles of sintering, the theories as well as the technological aspects. Sintering furnaces, sintering atmospheres, and data on the effect of atmospheres are discussed in Chapter 8.

One of the great advantages of powder metallurgy is the formation of alloys in the solid state of their constituents. This data, including diffusion data, are given in Chapter 9. In chapter 10 will be found information on hot pressing, the combination of compacting and sintering and the effect of hot pressing conditions on the properties of P/M parts. Information on the forging of P/M preforms, which represents the latest development in powder metallurgy, is given in Chapter 11.

Chapters 12 to 21 deal with powder metallurgy products of different materials or special properties.

Chapter 12, the most extensive in this Handbook, concerns iron powder metallurgy. It is divided into six subjects: iron powders, sintering of iron, iron-nickel alloys, iron-copper alloys, other iron alloys and steels, and various treatments of ferrous P/M parts. Although the tables and graphs of this chapter are not complete, they represent an extensive and worthwhile review of this most important part of powder metallurgy production. Information on copper, bronze and brass, and other copper alloys, is given in Chapter 13. Emphasis therein is on prealloyed powders.

The powder metallurgy of light metals includes information on aluminum and titanium, and their alloys, representing the latest development in powder metallurgy, while also offering interesting production aspects for the future. Data given include beryllium and magnesium. Chapter 14 is on light metals and offers interesting new insights into the powder metallurgy of these metals.

Tungsten plays an important role in the history of powder metallurgy. It was one of the first commercial products produced from metal powders. Chapter 15 deals with the powder metallurgy of tungsten, molybdenum and other refractory metals and alloys, and data is given in the many tables and graphs. Soon after the development of powder metallurgy, tungsten refractory compounds such as tungsten carbides were produced from powders and revolutionized the tool industry.

Chapter 16 deals with refractory compounds and cemented carbides, and the latest developments in this field. During the last few years, the main emphasis was on refractory compounds for the space industry.

Electric contact materials are also early products in the history of powder metallurgy. Chapter 17 reviews the P/M materials for electrical applications. Chapter 18 deals with porous materials. The changes in porosity during powder metallurgy processing and special filter materials are described in the tables. Friction and anti-friction materials (bearings) are discussed in Chapter 19. Dispersion strengthened materials reinforced by particles or fibers are the subject of Chapter 20. Chapter 21 refers briefly to non-destructive testing of powder metallurgy produced.

This second revised and extended edition of the Handbook was a necessity. Since the publication of the first edition in 1973, powder metallurgy has grown in many new directions and in tonnage production. It was therefore necessary to add new material and increase the number of pages from 482 to approximately 600. In the first edition practically all the data was presented in the English system: this second edition contains all the data also in metric, SI-System to facilitate the use of the book for the international readership. Another good reason for issuing the second edition is the fact that the first edition is completely sold out and that many orders for the book still come from all parts of the world. Under these circumstances the second edition was a necessity. The re-editing of the book was not simple but all the reasons for re-editing were stimulating for the authors. It was our intention to present a maximum of information in con-

centrated form to the practical powder metallurgist and to stimulate many new problems for the theoretically oriented metallurgist.

The presentation of the P/M fundamentals in the form of principle graphs which was offered in the first edition was definitely a success. During the last ten years these graphs were frequently used in P/M lectures and courses. We have tried our best to present the variables in the various types of P/M processing in the form of tables in order to call the attention of the readers to the facts and circumstances which may cause deviations from the basic principles shown in the graphs. Many graphs and tables were added in this second edition.

Additional information in this edition was given with respect to atomization, porosity characteristics, forging, and hot isostatic pressing. The P/M statistics were updated and an appendix was added that includes the computerized unit cost calculation in P/M parts production.

We have compiled a handbook consisting of graphs and tables practically without text. Nevertheless the first edition of the book was frequently used as a textbook in many P/M courses and lectures because data in the graphs and tables provided valuable "practical examples."

Henry H. Hausner
M. Kumar Mal

chapter 1

Principles of Powder Metallurgy

The following 65 principle diagrams show some of the important fundamental correlations between powder characteristics and processing variables in powder metallurgy and the effect of these variables on some properties of compacted and sintered metal powders. Needless to say, this collection of diagrams is not complete. They were used by the author to introduce the principles of powder metallurgy to his students, and the graphic presentation was selected because simple curves are easier to remember than words.

These principle curves show just the trends in the correlation of the variables. The reasons for these correlations are to be explained by the teacher and examples with precise data, based on experimental work, should be added.

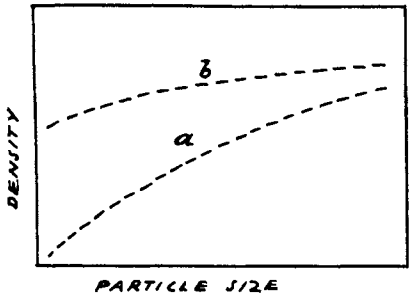


Fig. 1.1. Effect of powder particle size on the density of the loose powder
a) apparent density
b) tap density

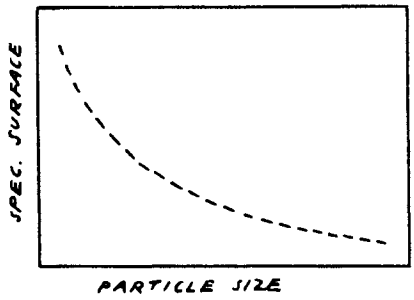


Fig. 1.2. Specific surface of the powder mass as a function of particle size

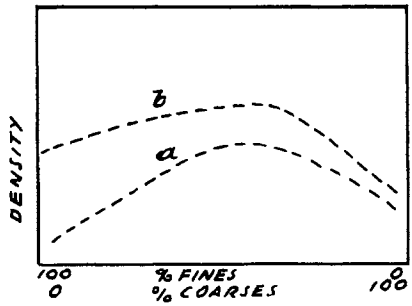


Fig. 1.3. Effect of mixing of coarse and fine powders on the density of a loose powder mass
a) apparent density
b) tap density

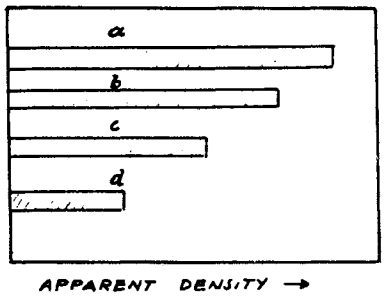


Fig. 1.4. Apparent density of a powder as affected by particle shape
a) spherical
b) round
c) irregular
d) dendritic

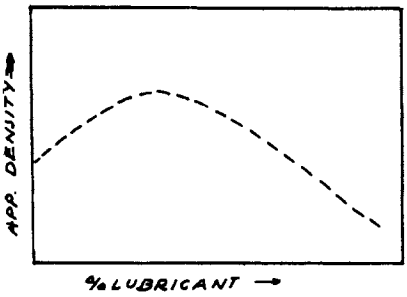


Fig. 1.5. Effect of the amount of lubricant added on the apparent density of a powder

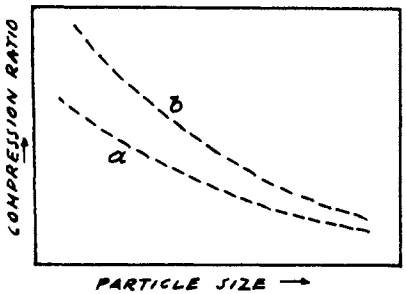
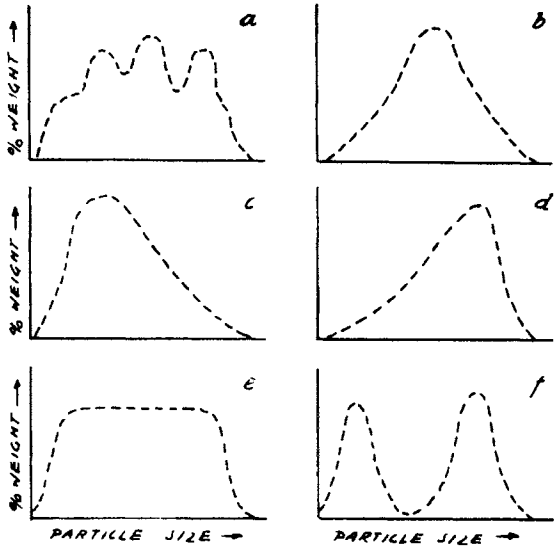


Fig. 1.6. Effect of powder particle size and oxidation on the compression ratio:
a) metallic particle surface
b) oxidized particle ssurface

Fig. 1.7. Various types of powder particle size distribution



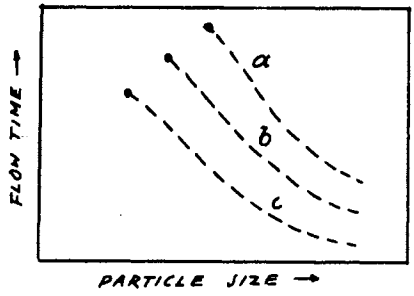


Fig. 1.8. Effect of particle size and opening diameters of the flow device on the flow of powders
a) small opening dia.
b) medium opening dia.
c) large opening dia.

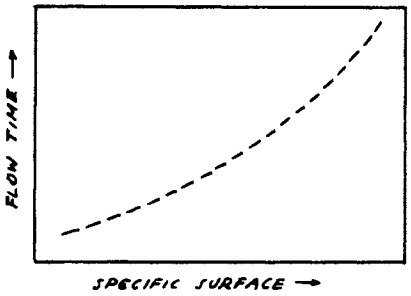


Fig. 1.9. Flow time as affected by the specific surface of the powder

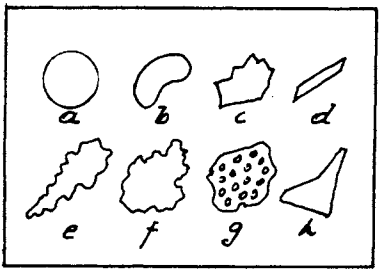


Fig. 1.10. Various shapes of metal powders
a) spherical
b) rounded
c) angular
d) acicular
e) dendritic
f) irregular
g) porous
h) fragmented

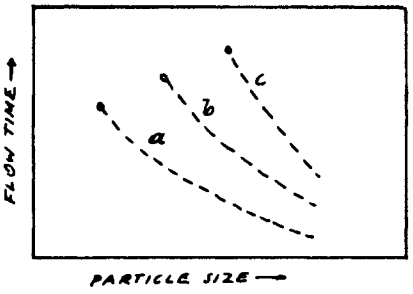


Fig. 1.11. Effect of powder particle shape on the flow time
a) spherical shape
b) irregular shape
c) dendritic shape

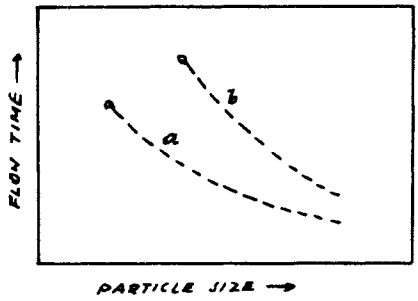


Fig. 1.12. Effect of particle size and oxidation on the flow of metal powder
a) oxidized particle surface
b) metallic particle surface

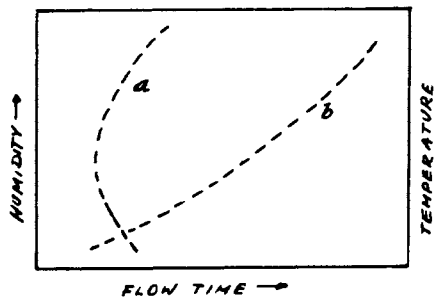


Fig. 1.13. Flow time of metal powders as affected by humidity (a) and temperature (b)

Mixing of Powders

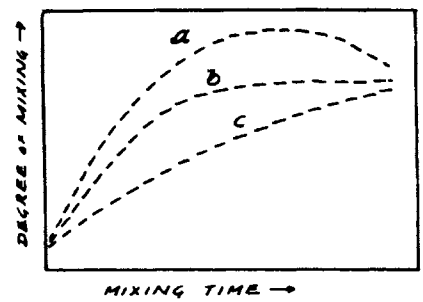


Fig. 1.14. Effect of mixing time on the degree of mixing for 3 different types of mixers

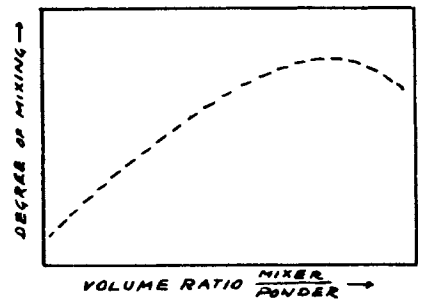


Fig. 1.15. Degree of powder mixing as affected by the ratio of the mixer volume to the volume of the powder

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