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Goals and Contemporary Position of Powder Metallurgy in Products Manufacturing

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Additional information is available at the end of the chapter

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Abstract

This chapter is an introduction to the book on powder metallurgy (PM). It presents the basis of the selection of powder metallurgy technologies for manufacturing of products, including such applied in medicine and dentistry, and the state of the art concerning the general characteristic of powder metallurgy. The materials and products manufactured with the classical powder metallurgy methods are generally described. The last section presents the general contents of the book based on the above general information.

Keywords: products manufacturing, materials engineering, engineering design, powder metallurgy, sintered materials and products

1. The basis of the selection of powder metallurgy technologies for manufacturing of products, especially products used in medicine and dentistry

Products and other consumer goods available at the market and supplied by manufacturers dictate the standard and quality of life, exchange of information, educational standards, the quality and capabilities of medical care and other aspects of the environment we live in. Engineering designs constitute a basis for the initiated and conducted production [1]. The quality of manufacturing is closely connected with the standard of life's quality understood as how requirements are satisfied determining the level of the material and spiritual welfare of particular persons and the whole society. The needs addressed by the medical sector are higher and higher. In this sector, implants, implant-scaffolds and other devices and appropriate instruments and

apparatuses have to be used in many cases in post-operative losses of natural tissues, especially bone or dental tissues due to disease-related lesions, inflammatory conditions or injuries, especially traffic and sports injuries, and also as a result of natural ageing processes. In terms of product design, all engineering materials able to provide the required product properties are on an equal footing, and multicriteria optimisation is essential for selecting materials with the best functional and technological properties and lowest possible costs of material and product production, processing and operation. The aspects related to materials play an important role in fulfilling the tasks of the engineering environment, as a paradigm of materials engineering requires to select an engineering material which, in an appropriately selected technological process of forming a product's geometrical form and structure and engineering material properties, will ensure the suitable, required and expected usable product properties. Therefore, the issues involving materials science and materials engineering are complex and encompass the following general topics:

- an atomic and molecular structure of materials;
- dependence between the structure and properties of materials;
- formation of the structure and properties of materials;
- technologies of materials processes;
- investigations into a structure and properties of materials;
- examination of properties of products fabricated from materials in operating conditions; and
- predicting the properties of products, also in operating conditions.

This chapter concerns the detailed and selected aspects of synthesis and technologies of materials processing as an important part of manufacturing, understood as the making of products using raw materials in various processes, with various machines and in operations managed in line with a well-elaborated plan. Product designing—after the phase of industrial design, where product functions are generally described and a product concept is generally developed, including its external form, colour and potential general ideas as to how to assemble the key components—is composed of engineering design and subsequent production preparation. Engineering designing, in which product shape and product components are defined, materials are selected from which they are to be made and appropriate technological processes are selected, enables to design and produce products meeting their expected usable functions, as well as requirements concerning the shape, economic and reliability aspects. Material properties can be changed by changing a technological process, and some combinations of the product shape and material may be infeasible using certain technological processes. Materials design provides a material with the most advantageous set of functional properties ensured by appropriate chemical composition and the material's technological process. Engineering design combines, therefore, the three equally important and inseparable components:

- materials design to guarantee the required durability of a product or product components made of engineering materials with the required physiochemical and technological properties;
- structural design whose purpose is to develop a shape and geometrical features of a product satisfying human needs; and
- technological process design enabling to achieve the required geometrical features and properties for particular product elements and also their correct interaction after assembly considering the volume of production, level of automation and computer aid, while ensuring also the lowest possible product costs.

An engineering design process is influenced by the selected technological process and by a possibility of using certain technologies. Such factors dictate material selection and a sequence of technological operations, as well as dimensions, dimensional tolerances, the joining of elements and other constructional aspects. Numerous factors linked to a technological process have to be taken into account in a design process by designing in consideration of:

- production and assembly;
- casting;
- plastic working;
- powder metallurgy (PM);
- machining;
- joining;
- heat and surface treatment;
- processes applied for ceramic materials;
- processes applied for polymer materials; and
- manufacture of composite materials.

Producibility should also be considered in a design process.

2. General characteristic of powder metallurgy

Powder metallurgy (PM) plays an important role in technologies of materials processes and in the formation of product forms and properties of engineering materials. PM is a field of technology covering the manufacturing methods of powders of materials and metallic materials or their mixtures with non-metallic powders and the manufacturing of semi-products and products from such powders without having to melt the main component [1–7]. At present, in about 80% the parts fabricated by powder metallurgy methods are employed in the automotive industry, mainly for economic reasons. Moreover, powder metallurgy methods

are utilised in other industries, among others in aviation, energy and household sector, and for producing certain complex parts applied in medicine and dentistry, especially for bone and dental implants and implant-scaffolds and epitheses. The history of powder metallurgy dates back 3000 years before Christ, because ancient Egyptians were making parts with this technology, and ancient Incas were making valuable items of gold and noble metals, although mass production began at the end of the twentieth century. Initially, small particles were extracted from sponge iron, which were then melted or sintered. Metal powders were started to be produced later, and then they were initially formed and sintered. Generally speaking, the following operations can be distinguished in a classical technological process of products fabricated by the powder metallurgy method:

- metal powder or a mixture of different metals is produced;
- powder is prepared and mixed with lubricating and slipping agents;
- cold-powder moulding and compactions;
- sintering; and
- finishing.

Figure 1 shows a sequence of technological operations suitable for the powder metallurgy process.

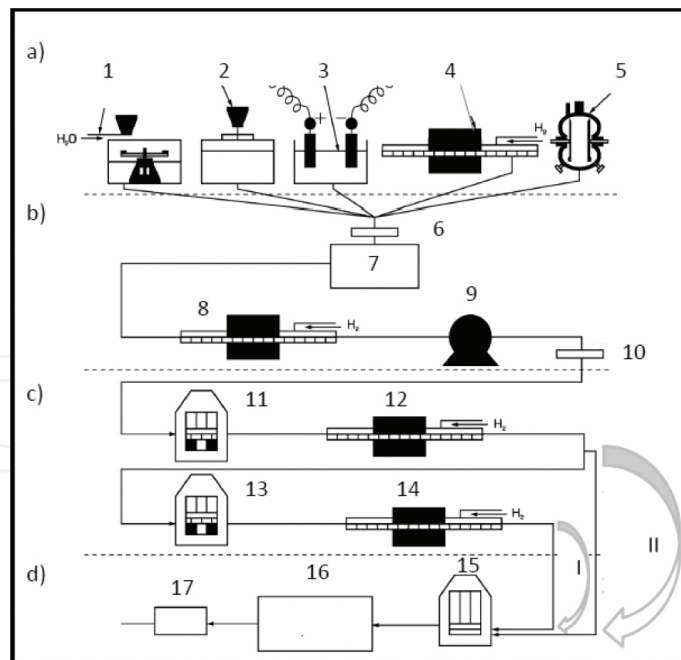


Figure 1. Simplified diagram of mass production of powders from iron and steel powders: (a) powder production, (b) powder preparation, (c) preliminary moulding and sintering, (d) finishing; 1, DPG sputtering; 2, sputtering; 3, electrolysis; 4, reduction; 5, crushing in Hametag mill; 6, screen; 7, tank; 8, preliminary reduction; 9, mill; 10, screen; 11, I pressing; 12, I sintering; 13, II pressing; 14, II sintering; 15, calibration; 16, heat treatment (hardening, quenching and tempering, surface treatment); 17, final control; I, double cycle; II, single cycle.

The phenomena taking place during preliminary moulding and then sintering are the essence of powder metallurgy. Cold compaction of material can take place only to a certain limit value of space filling, which, in the case of typical actual systems of powders, according to the percolation theory, is 0.6. This is related to the fact that although the grains of metallic raw materials may be subject to plastic deformation, and the grains of raw materials used in ceramics are rigid, at room temperature they cannot be deformed plastically under the influence of mechanical forces. Further compaction of the system is connected with increasing the level of space filling, that is, consolidation can take place only in sintering as a result of thermal activation. Grain regrouping takes place subsequently, the driving force of which is excessive energy collected on their grain surface, and then the number of inter-grain contacts is rising. The process is thermodynamically advantageous as the unit surface energy of the separation boundary solid body/solid body is lower than the unit energy of the separation boundary solid body/gas, thus the formation processes of the solid body/solid body boundary can take place by themselves. Activation energy connected with temperature rise is needed to initiate such processes. Under the influence of the energy supplied, atomic (ionic) vibrations are activated, particularly on the surface of grains. This has an effect on an increased number of bonds and durable inter-grain necks are created. Their surface is increasing, preventing the relative movement of grains and is leading to the transport of the mass in the grain area. Consequently, it leads to changes in the shape of grains and higher and higher elimination of pores.

Sintering usually takes place below a melting point of the main component. It can also occur in the solid phase. In the first phase of sintering in the solid phase, powder grains are bonding due to adhesion caused mainly by moulding. The diffusion of atoms occurs on the surface after heating, taking place in the entire volume of powder as time passes. Grains are joined permanently as a result of such phenomena and sinter porosity is lowered. Excess surface energy of the system of powder grains is the basic driving force in sintering in the solid phase. The system being sintered, while striving for energy minimisation, is reducing the area of free surfaces by creating inter-grain necks, by smoothing the surface, by spheroidisation and by elimination of pores. Sintering in the solid phase occurs at a temperature lower than a material melting point, as a result of which the liquid phase is not being formed even temporarily, and the sinter reaches its high properties owing to various mechanisms of matter transportation, including slipping at the grain boundaries, diffusion and evaporation and condensation. In the case where sintering is done together with moulding, the external forces cause additional plastic deformation of metal powder grains, which—due to high temperature—is usually accompanied by recovery and recrystallisation processes—either static or dynamic.

Material sintering with the liquid phase takes place when at least two components are present in a mixture of powders, and sintering occurs above a melting point of the lowest melting component. An important characteristic of the liquid phase present in sintering is the ability of wetting the solid insoluble particles. The wetting ability of the liquid phase, depending on surface energy, may be modified by using alloy additives with high surface activity and by the growth of system temperature, thus increasing the intensity of sintering. Sintering with the liquid phase is usually suitable for multicomponent powders, and low-melting eutectics

created by particular components are melted. A liquid filling the pores between powder grains is created in the first stage of sintering with the liquid phase, facilitating the regrouping and compact arrangement of grains. The liquids of certain small grains are being solved and crystals with large grains are precipitated from the liquid. The solid particles finally adhere to each other and are sintered. The excessive content of the liquid phase may, however, lead to losing the shape of the element being sintered, when maximum wetting takes place, and the liquid phase completely separates solid particles. Solid particles are being regrouped due to the presence of the liquid phase with high wetting ability, penetrating boundaries between the solid particles, and the element being sintered shrinks. The sinters achieved by sintering with the liquid phase are characterised by a structure composed of evenly arranged solid-phase particles in the solidified liquid.

Apart from sintering in the solid phase or with participation of the liquid phase, the third type of supersolidus sintering is distinguished, which is a variant of sintering in the liquid phase and is distinct for high-carbon steels, high-speed steels and nickel-based superalloys. Supersolidus sintering is accompanied by preformed shrinkage and increased physical and mechanical properties. In some cases, when double-component mixtures of powders A and B are sintered, and where a diffusion rate of components A to B is many times higher than diffusion from B to A, the sinters are swelling, and their high porosity, called diffusive porosity, can be useful in a production process of porous preforms.

<div>Process</div> <div>Characteristic</div>	Dimension	Shape complexity	Density	Dimen- sional tolerances	Production yield	Cost
Conventional	◐	◐	◑	○	○	○
Powder Injection Moulding	◑	○	◐	◐	◐	◐
Hot Isostatic Pressing	○	◐	○	●	●	●
Powder Forging	◐	◐	○	◐	○	◐
Symbols: ○ very high, ◐ high, ◑ medium, ◒ small, ● very small.						

Table 1. Comparison of powder metallurgy processes.

At present, parts with a complicated shape, tight-dimensional tolerances, controlled density and properties can be manufactured by powder metallurgy methods. A technological process of powder metallurgy ensures high flexibility in the selection of physiochemical properties and other requirements, including:

- production of structural parts with complex shapes;

- controlled porosity;
- controlled properties;
- high mechanical strength and resistance to vibrations;
- high hardness and wear resistance;
- high manufacturing precision and good surface quality; and
- large number of production series while ensuring tight-dimensional tolerances.

Table 1 compares the basic characteristics of different powder metallurgy processes.

Powder metallurgy is becoming an unrivalled manufacturing process in the following cases:

- product porosity is the desired property, for example, in special filters;
- a porous structure is required to store lubricants as for self-lubricating bearings; and
- a structure is obtained composed by infiltration of the sintered porous skeleton from one metal with another liquid metal with a lower melting point, as in the case of tungsten-silver electric contacts or steel contact infiltrated with copper to improve conductivity and strength.

Elements made of some materials, for example, had melting metals and sintered carbides, may only be fabricated with powder metallurgy methods.

The following usually conditions the application of powder metallurgy for product manufacturing:

- costs reduction versus other manufacturing processes and
- unique properties provided only by powder metallurgy.

Powder metallurgy process	Range of density, g/cm ³	Relative selling price in agreed, units/kg
Pressing and sintering	6–7.1	5.4–6
Pressing, sintering, dimensional moulding	6–7.1	6.4–7.1
Saturation with copper	7.3–7.5	7.8–7.9
Hot moulding	7.2–7.4	6.9–7.3
Double pressing and sintering	7.2–7.4	8.9–9.1
Powder injection moulding	7.5–7.6	100–155.6
Hot powder forging	7.8	11.1–12.2
Double pressing and sintering + Hot isostatic pressing	7.87	13.3–15.6

The values given are averaged; small parts are more costly than large parts.

Table 2. Comparison of indicative prices of elements fabricated by different powder metallurgy methods from iron or steel powders.

Powder metallurgy can be competitive in relation to other production processes, for example, casting, plastic working and machining, by complementing or replacing such techniques. It is usually substantiated for a large scale of production, not smaller than 1000–10,000 pieces, when investment expenses are depreciated for tooling and accessories. **Table 2** presents indicative prices of parts manufactured by various powder metallurgy methods.

The following benefits of powder metallurgy can be quantified: maximum usage of charge materials (over 95%), minimised proper energy required for producing 1 kg of ready elements and some of them cannot be fabricated by other methods (approx. 43%), reduced number of technological operations vis-à-vis plastic working or machining and lower temperatures than in conventional metallurgy. The cons of the powder metallurgy method are associated with the production of materials with high porosity and hence with relatively low strength, and with difficulties in obtaining products with a complex shape due to uneven distribution of pressure in the powder volume in pressing. Product porosity can be used, for example, in filters and porous (self-lubricating) bearings. Powder metallurgy and ceramic materials technologies are often similar, and hence the selected sintered materials and ceramic materials are sometimes discussed together.

3. General presentation of materials and products manufactured with the classical powder metallurgy methods

Powder metallurgy methods have found applications in the mass production of numerous elements produced from iron, carbide steels and alloy steels. Work intensity can be significantly reduced with them, machines can be relieved, raw materials saved and wastes reduced. Sintered elements of machines are used in the machine and car industry. Toothed gears, rollers, washers, nuts, pawls, parts of shock absorbers, valve seats, bearings, building joinery, parts of reinforcement, office machines and sewing machines are fabricated from sintered powders.

Products sintered from low-carbon steel have the tensile strength of approx. 220 MPa, hardness of 50 HBW and elongation of up to 20%. Strength as well as corrosion and abrasion resistance can be enhanced by applying products from steel powders, in particular with the chemical composition corresponding to special steels. Such products can be achieved by various methods, namely by:

- sintering steel powders with chemical composition corresponding to a ready sinter;
- mixing, at a suitably chosen ratio, iron powders with powdered carbon and powders of other alloy components and then sintering;
- mixing iron powders with cast iron powders or ferroalloys and then sintering; and
- carburising the products achieved by iron powder sintering.

Products sintered from copper and copper alloys are widely used. They are fabricated from a mixture of Cu, Sn or Zn powders or alloy powders, for example, Cu-Pb or Cu-Zn. Copper and

bronze or brass are used for the manufacture of sintered parts of equipment and machinery, building joinery and in production of medals.

Powder metallurgy methods allow producing products which cannot be manufactured by other methods. Such products include, among others,

- solid bearings;
- porous bearings; and
- sintered filters.

Sintered slide bearings possess good mechanical properties. They are usually made by hot pressing or skeleton infiltration from the skeleton of hard-melting metals having a lower melting point. They are used at an elevated and reduced temperature and with high loads and such conditions exclude lubrication with oils.

Sintered solid bearings with the appropriate fraction of graphite or soft low-melting metals are self-lubricating. They are usually produced from ferrographite or copper graphite. Iron can be partially replaced by Cu, Pb, Sn or Zn, and copper by Sn, Zn or Pb. Lead bronze with a concentration of 10–40% Pb can also be used. Depending on working conditions, slide bearings may also contain 0–60% of Cu, 0–70% of Ni, 0–70% of Co, 0–30% of Cr, 0–10% of Al, 0–10% of Mo, up to 50% of graphite and 0–40% of carbides and metal borides.

Self-lubricating bearings are produced as porous from metal powders, usually from iron or copper alloys, in particular from copper alloys with tin, to which non-metal powders, for example, graphite, may be added. The pores existing in the material can be joined, forming capillary channels. The volume of pores reaches up to 50% of the total volume of bearings. Such bearings are generally produced as thin-walled sleeves with jackets, and also as barrels. Porous tapes are also made, which are placed onto steel washers and rolled into half-sleeves. Porous bearings are saturated with special oil lubricating a shaft or an axle in work. Sintered porous bearings are used in systems where additional lubrication cannot be provided.

Sintered products with a porosity of up to 50% include filters having good mechanical properties, including tensile strength, bending strength, and also high resistance to impact loads and high temperature. They are used in arms, aviation, automotive, chemical and lathe machinery industry. Depending on working conditions, mainly temperature, they are made of powders of tin bronze, chromium or austenite steels resistant to corrosion or nickel brass, and also powders of other metals. Metal fibres can also be sintered. Porous sintered filters allow to clean particles with the diameter of 10^{-3} – 10^{-4} mm. Gases are cleaned of mechanical contaminants, and also to some extent dried. Gas pressure can also be regulated to some extent with porous filters. Liquids are cleaned from mechanical contaminants mainly.

Stainless steels fabricated by powder metallurgy methods, for example, **ASEA-STORA process (ASP)** method or by sintering Fe, Cr and Ni powders, have enjoyed technical importance considering sintered materials. Such methods allow producing steels with a very small concentration of carbon, which are hard to achieve by a conventional method.

Powder metallurgy methods allow producing pristine hard-melting metals, for example, Ta, Nb, Ti, resistant to corrosion, or W or Mo used at high temperatures, especially in electrical and electronic engineering. Hard-melting sintered metals are subjected to hot plastic working, for example, peening, wire drawing, forging or rolling.

Ceramic-metallic composites represent a large group of heat-resistant and high-temperature creep-resisting sinters, as one of important groups of composite materials manufactured by this technology. Oxides, carbides, silicides or borides are the ceramic materials in cermet composites. They increase resistance to high temperature and the insensitivity of strength properties to temperature changes, heat resistance, high hardness and abrasion resistance at high temperature. Sintered carbides and sintered oxides can be used as heat-resistant materials.

The discussed group of materials also includes metals reinforced through dispersion by an external hard and heat-resistant phase, for example, tungsten sintered with a small additive of sodium oxide, calcium or aluminium, silicon dioxide or thorium dioxide, preventing excess growth of grains and tungsten creepage. This is similar to sintered chromium with added yttrium oxide. The **sintering aluminium powder (SAP)** method is employed in the production of $\text{Al} + \text{Al}_2\text{O}_3$ sinters. The fraction of oxides in such sinters is up to 15%, usually 5–11%. Today, apart from aluminium, especially $\text{U} + \text{UO}_2$, $\text{Fe} + \text{Al}_2\text{O}_3$, $\text{Fe-Cr} + \text{Al}_2\text{O}_3$, $\text{Fe} + \text{Fe}_2\text{O}_3$ and $\text{Ni} + \text{Al}_2\text{O}_3$ sinters are manufactured by this method.

It should be stressed that conventional and especially special powder metallurgy methods allow, in many cases, to fabricate implants, implant-scaffolds, scaffolds, very often made of titanium and its alloys, as well as parts of instruments, for example, surgical instruments or other parts of devices applied directly or indirectly in medicine or dentistry, which are also manufactured from stainless steels or other special alloys.

Powder metallurgy has found broad applications in the production of sintered tool materials such as sintered metal carbides, carbide steels, high-speed steels with a high concentration of carbon and alloy elements, and also cermets and ceramic sinters, which cannot be produced otherwise. Powder metallurgy enables to achieve such materials as, for example, high-speed steels with better technological properties than those of materials fabricated by traditional metallurgical methods. Carbide segregation and banding were managed to be eliminated almost completely in such steels, even in products with larger section. Tools can be made from high-speed steels or carbide steels directly by pressing and sintering or large blocks can be made with dimensions similar to conventional ingots (not used these days usually as continuous casting processes are common), which can then be subjected to plastic working, as in ASP process or its latest variants, for example, STAMP or MICROCLEAN. Advanced sintered tool materials are witnessing constant advancements connected with fast progress in materials engineering. The properties and intended use of the finished products made of sintered tool materials are diverse depending on the phase composition, the content of hard-phase particles in sintered tool materials (whether they are present or not), the chemical composition of a binding material, as well as on the material's thermal workability. In general—in the group of sintered tool materials—one can distinguish the following:

- steels and cermetals based on carbides of transition metals and cermetals based on nitrides or mixtures of nitrides and carbides of transition metals;
- ceramic materials containing mostly $\alpha\text{-Al}_2\text{O}_3$ and/or Si_3N_4 , possibly with the addition of oxides of other elements;
- mixed materials—ceramic-carbide materials—containing $\alpha\text{-Al}_2\text{O}_3$ and (or) Si_3N_4 , as well as carbides of transition metals with potential addition of oxides or nitrides of other elements; and
- super hard-sintered materials—including polycrystalline synthetic diamond and boron nitride (BN) with a regular special network, called borazon—deposited on sinter carbide plates.

A group of sintered tool materials based on carbides of transition metals, due to a volume fraction of carbides in the structure, can be split into:

- sintered high-speed steels;
- sintered carbide steels; and
- sintered carbides.

Powder metallurgy allows fabricating sintered **tool-gradient materials (TGMs)** with a continuous or discrete-graded structure within the entire volume.

4. Overview of the selected research problems

The second chapter—on the basis of general information concerning the fundamentals of selection of the powder metallurgy technology and the general description of the technology, supplemented by a general review of materials and products fabricated by this technology covered in the first chapter—presents the state of the art of classical powder metallurgy technologies and a general description of new variants and special and hybrid technologies used in powder metallurgy, also for fabrication of products finding their applications in medicine and dentistry. Such descriptions, prepared according to a thorough review of extensive literature in this field, set a basis, especially for students, PhD students and engineering staff less experienced in this technical field, for scrutinising over a dozen case studies provided in the following chapters, comprehensively describing author's accomplishments of numerous teams from different countries across the world in advanced research areas relating to powder metallurgy and to special and hybrid technologies.

The first of the chapters is devoted to the sintering of prealloyed Fe-Ni-Cu-Mo powders modified by boron based on thermodynamic investigations. Prealloyed diffusion powder of such a type is applied for structural parts in the automotive industry. One of the methods to reduce porosity and increase mechanical properties of sintered materials is to apply activated sintering by introducing boron powder. The sintering process elaborated was very detailed, based on a thermodynamic analysis and microstructure investigations. It was stated that the

sintering process is impacting changes in the morphology of porosity and the increase of density, as well as the mechanical properties of the sintered alloys.

On the other hand, the direct current-assisted sintering of metal parts was presented as a promising and relatively new research and development field of powder metallurgy. Attention was then drawn to the physicochemical aspects of the plasma environment, basic knowledge of plasma heating and surface-related phenomena during the direct current plasma sintering of parts. All these aspects are approached considering the main techniques of the direct current plasma-assisted-sintering process applied to powder metallurgy. Finally, some results on direct current plasma heating and surface modification are presented.

The next chapter presents the outcomes of own investigations into four alternative manufacturing technologies of sintered porous skeletons by powder metallurgy methods, being the reinforcement of aluminium alloy matrix composite materials fabricated by infiltration. Porous skeletons were manufactured from Al_2O_3 aluminium powders by reactive sintering using blowing agents or by ceramic injection moulding, from mullite $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ by sintering a mixture of halloysite nanotubes with agents forming an open structure of pores and from titanium by selective laser sintering. The structure and basic mechanical properties were also presented of such composite materials with small density ensured by an aluminium alloys matrix, and their broad application possibilities, in particular for medical and dental purposes.

The next chapter describes the structure, as well as mechanical properties of aluminium alloy matrix nanocomposites reinforced with multiwalled carbon nanotubes and halloysite nanotubes fabricated using powder metallurgy techniques, including mechanical alloying and hot extrusion. The powder of aluminium alloy AlMg1SiCu was used as a nanocomposite matrix. The investigation's results show that the technology of nanocomposite materials manufacturing can find the practical application in the production of new light-metal-matrix nanocomposites.

An important part of the book is devoted to the potential applications of powder metallurgy technologies for medical and dental uses. One of the chapters discusses how porous scaffolds are produced with the method of selective laser melting from Ti/Ti6Al4V powders in line with the make-to-order concept according to individual needs of each patient. The material is additionally subjected to surface treatment consisting of the deposition of atomic layers of titanium dioxide with nanometric thickness. The clinical data acquired from a patient during computer tomography, nuclear magnetic resonance or using traditional plaster casts are converted by a computer into a virtual solid model of a patient's loss.

The numerous technological applications of powders of different materials, also metals and their alloys, include additive manufacturing processes of metallic parts. Another chapter presents the latest overview of developments in the field of additive manufacturing of metallic components. Input materials and specific requirements for input materials are briefly mentioned. An overview of the technological process is described and the selective laser-melting technology as well as beam-melting technologies. Some examples of applications for this technology and its influence on the properties of the so-manufactured materials are described.

Another example is the use of powder metallurgy methods for the fabrication of vacuum-sintered duplex stainless steels. The structure of sintered stainless steels in terms of sintering atmospheres, including vacuum sintering, the influence of sintering parameters on microstructural changes of the single phase and duplex microstructure, was described. A relationship between sintering and corrosion resistance was presented by focusing on the effect of sintering density on corrosion resistance. The mechanical, magnetic and physical properties of sintered stainless steel were also discussed. The main sectors, and examples of applications of sintered stainless components, were presented.

An important part of the book, covering a few chapters, is devoted to tool materials manufactured by powder metallurgy methods and to the potential extension of service life of the so-manufactured tools through integrated surface treatment. First of the chapters presents essential information concerning sintered tool materials containing carbides and characterises graded materials whose properties change gradually according to their volume. The results of investigations are presented into the structure and properties of newly developed sintered-graded tool materials produced by the conventional metallurgy method from a mixture of high-speed HS6-5-2 steel powder and WC carbides. Manufacturing, composition, properties and applications of sintered hard metals are also presented. The general idea when using hard metals is to exploit their excellent properties in terms of hardness, toughness, wear resistance and chemical stability. Due to such characteristics, hard metals are excellent for cutting tools and this is the main field of their applications. An overview of the actual scenario concerning different tool materials is presented, including a short history and description of state-of-the-art techniques as regards their composition, manufacturing routes and key properties. This part will present some results of the authors' own research in this field, carried out over the recent years. Such research is continued in the next chapter devoted to the properties and testing of cemented carbides. The chapter comprises three main parts concerning degradation processes associated with the grinding of cemented carbides, the origin of residual stresses and their impact on cemented carbide properties and finally on the corrosion of cemented carbides in various environments. Nevertheless, little attention continues to be attached to the damages of cemented carbide cutting tools and such a phenomenon tends to be ascribed to various other factors such as the coatings applied, cutting process conditions, and the work-piece material. This part ends with a chapter providing a general description of the selected sintered tool materials, including injection-moulded ceramic-metallic tool materials and treatment technologies of their surface, especially physical and chemical vapour deposition (PVD) and (CVD) in view of the results of own investigations with technology foresight methods. The outcomes of multifaceted research, carried out with advanced materials engineering methods, into the structure and properties of multicomponent, graded and multilayer coatings on the investigated materials, are also presented.

Another chapter depicts coatings having an effect on the increased abrasive wear using powder eutectic materials of Fe-Mn-C-B system. The structural state and physical-mechanical properties of eutectic powder alloys and coatings correspond to composite dispersion-strengthened materials. The formation of a hardened layer with the eutectic structure on metal surface corresponds to the creation of a new material with certain mechanical properties.

The last one chapter of the book presents the production of a novel Cu-based composite frictional train-brake material by powder metallurgy methods. The tribological behaviour of these materials is analysed by pad-on-disk tests without lubrication, and the coefficient of friction, wear rate and wear value were studied in order to identify the effects of the sintering temperature on the base materials composition. Generally, the material obtained demonstrated excellent brake performance and wear resistance.

The editor, publisher and the whole team of authors, by making this book available to the readers, deeply believe that the detailed information collected in the book, largely deriving from own and original research and R&D works pursued by the authors, will be beneficial for the readers to develop their knowledge and harmonise specific information concerning these topics, and will convince the manufacturers about the advantages of using the powder metallurgy technology in many branches of industry, which – on one hand – makes it possible to gain improvements in economical manufacturing, on the other hand will enhance the functional properties of multiple products in their service conditions.

5. Additional information

The investigations were made mainly in the framework of the Project ‘BIOLASIN—Investigations of structure and properties of newly created porous biomimetic materials fabricated by selective laser sintering’ funded by the DEC-2013/08/M/ST8/00818 of the Polish National Science Centre in the framework of the ‘Harmony 4’ competitions, headed by Prof. Leszek A. Dobrzański.

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