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# Powder Materials and Their Applications

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**Abstract**—The paper considers the classification of powder materials. The main groups of technological operations required to obtain powders have been presented. The methods of obtaining powder materials and their structure have been considered. It has been shown that the metallic components of powder materials provide high thermal conductivity and run-in ability, while nonmetallic components increase the friction coefficient and reduce the tendency to seizing.

**Keywords:** powder materials, classification, process operations, powder material components
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## INTRODUCTION

Powder materials are classified as porous and compact. In porous materials, up to 30% of porosity is retained after final processing; such materials are used primarily for the production of filters and so-called "antifriction parts": bearings and bushings [1]. These products are characterized by a low friction coefficient and are suitable for intensive use, and the oil in the pores of the bearings allows for their forced lubrication to be avoided.

Compact powder materials, characterized by 2–3% porosity and obtained from carbon steel, bronze, brass and aluminum, are no less in demand in various areas of the production. In particular, they are used in the production of gears, bearing housings, and various machine parts.

In the instrument-making and electrical-engineering industries, powder alloys based on nonferrous metals are widely used; they are easily machined and have good thermal conductivity and corrosion resistance. Powder technology is generally not suitable for the manufacture of highly loaded steel parts, although this primarily applies to the powder materials with a porosity of over 3%. Based on this, powder steel is used primarily for the manufacture of lightly loaded products of the complex shape. These are materials manufactured by powder metallurgy, a technological process that covers the production of metal powders, alloys and metal-like compounds, as well as the products made from them or their mixtures with nonmetallic powders.

Powder materials are used in various fields of technology in cases in which materials with special properties are required that cannot be obtained by other production methods. Due to the manufacturing process, these materials have higher quality indicators than materials obtained using traditional technology (casting, pressure treatment).

Powder materials are classified by purpose (heat-resistant, corrosion-resistant, magnetic, antifriction, contact, friction, etc.), density (dense, porous), chemical composition (pure materials, alloys), and production technology (sintered, compacted). The following are used to obtain powder materials: solid-phase sintering, sintering in the presence of a liquid phase, impregnation, hot pressing, hot isostatic pressing. The first four methods are based on obtaining a powder mixture by mixing and pressing the components and subsequent hot sintering (or only hot pressing); in some cases, additional processing of sintered products is used (repeated pressing, etc.). This scheme is the main one for obtaining powder materials (PMs). Many products from PMs are manufactured using this technology, mainly small ones (weight is 0.5–5 kg): porous bearings, friction products, filters, hard alloys, magnets, contacts, products from refractory metals, products from heat-resistant alloys (mainly dispersion-hardened type based on nickel and aluminum), ferrites, welding electrodes, and various machine and instrument parts. However, such a scheme cannot ensure obtaining absolutely dense (nonporous) PMs [2, 3], since this requires additional deformation.

In recent years, a new technological process for obtaining aviation materials for structural purposes has been intensively developing—metallurgy of the granules of nickel, titanium and aluminum alloys. The process is based on obtaining micro-ingots of a given chemical composition, crystallizing at a high cooling rate, and their subsequent compaction by isostatic pressing. The resulting compacts (weighing up to 0.5–2 t) can be used as finished products or as blanks for

subsequent deformation. The high cooling rate during crystallization makes it possible to introduce increased quantities of alloying additives into the alloys; i.e., to create a new class of powder materials.

Highly alloyed powder materials are characterized by a uniform fine-grained structure, the absence of pores, and a high level of mechanical properties, and they are used to manufacture engine parts (nickel PM disks, etc.) and aircraft fuselages (supersonic aircraft cabin parts made of aluminum PM, etc.).

Granule metallurgy allows significant expansion of the scope of PM applications. When using pure initial powders, sintered materials can be obtained with a lower impurity content and with a more accurate match to the specified composition than conventional cast alloys. With the same composition and density, sintered materials, due to the peculiarity of their structure, in a number of cases have higher properties than fused materials—in particular, an unfavorable effect of the preferred orientation (texture), which is found in a number of cast metals (for example, beryllium), is less pronounced due to the specific conditions of melt solidification. A major drawback of some cast alloys (e.g., high-speed steels and some heat-resistant steels) is the sharp heterogeneity of the local composition caused by liquation during solidification. The dimensions and shape of the structural elements of sintered materials are easier to regulate, and, most importantly, it is possible to obtain types of mutual arrangement and shape of grains that are unattainable for molten metal. Due to these structural features, sintered metals are more heat-resistant and better withstand the effects of cyclic fluctuations in temperature and stress, as well as nuclear irradiation, which is very important for materials of new technology.

Powder metallurgy makes it possible to obtain materials that are difficult or impossible to obtain by other methods. These include some refractory metals (tungsten, tantalum) and alloys and compositions based on refractory compounds (hard alloys based on tungsten carbides, titanium, etc.): compositions and so-called "pseudo-alloys" of metals that do not mix in molten form, especially with a significant difference in melting points (for example, tungsten–copper), compositions of metals and nonmetals (copper–graphite, iron–plastic, aluminum–aluminum oxide, etc.), porous materials (for bearings, filters, seals, heat exchangers), etc.

PM allows one to save metal and significantly reduce the cost of production (for example, when manufacturing parts by casting and cutting, sometimes up to 60–80% of the metal is lost in the sprues and goes into chips).

Nanopowders are increasingly used as fillers for new materials and composites, components of many coatings, catalysts, and materials for electronics. There are many methods for producing nanopowders, but they all have two main drawbacks: first, they require expensive equipment, and, second, they are difficult to scale up to industrial-scale production. High-quality fine powders can be produced in industrial-scale production using planetary mills. Powder metallurgy includes the following main groups of process operations: production of initial metal powders and preparation of a charge (mixture) from them, compaction of powders (or their mixtures) into blanks, and sintering [4, 5].

## PRODUCTION

Powders used in powder metallurgy consist of particles sized 0.01–500 μm. Powders of metals (or their compounds) are obtained by mechanical and physicochemical methods. Mechanical methods mainly include grinding of hard metals. Solids are ground in mills with grinding bodies (rotary drum, vibration, planetary mills), impact mills (vortex, jet, centrifugal), and rotating parts (attritors, disk, cavitation, hammer, rotor). When grinding brittle materials in mills, the powder particles have a fragmentary shape, they are flaky when grinding plastic materials. The ground powders are characterized by peening (changes in structure and properties caused by plastic deformation) and are usually annealed.

Dispersion, or atomization, of liquid metals and alloys is carried out by a stream of liquid or gas. When spraying with water under high pressure, nozzles of various shapes are used. The properties of atomized powders depend on the surface tension of the melt, the spray rate, the geometry of the nozzles and other factors. Water spraying is often carried out in nitrogen or argon medium. Powders of iron, stainless steel, cast iron, and nickel and other alloys are obtained by water spraying. When spraying a jet of melt with a high-pressure gas, the particle size is affected by the gas pressure, the diameter of the metal jet, the design of the nozzle, and the nature of the alloy. Air, nitrogen, argon, and water vapor are used as atomizing gases. Metal spraying is also carried out by the plasma method or by spraying a jet of metal into water. Powders of bronze, brass, tin, silver, aluminum, and other metals and alloys are obtained by these methods.

Physicochemical methods for obtaining metal powders include reduction of metal oxides with carbon, hydrogen, or hydrocarbon-containing gases; metallothermic methods (reduction of oxides, halides or other compounds of metals by other metals); decomposition of metal carbonyls or organometallic compounds; and electrolysis of aqueous solutions and molten salts. Powders of metal-like compounds are obtained by the same methods and, in addition, by the synthesis from simple substances. Powders of Fe, Co, Ni, W, Mo, Cu, Nb, and other metals are produced by reducing metal oxides. The powder particles have a developed surface. Powders of Ni, Fe, W, and Mo with a spherical particle shape are obtained by decomposition of metal carbonyls. Electrolysis of aqueous solu-

tions of metal salts is used to prepare powders of Fe, Cu, Ni, and electrolysis of molten salts is used to obtain powders of Ti, Zr, Nb, Ta, Fe, and U.

## COMPACTION

The purpose of powder compaction is to obtain semifinished products (rods, pipes, tapes) or individual blanks that are close in shape to the final products. In all cases, after compaction, the powder from a bulk solid is transformed into a porous compact material that is strong enough to retain the shape given to it during subsequent operations. The main types of compaction are single- and double-sided pressing in rigid metal matrices, rolling, isostatic pressing with liquid or gas, die pressing, slip casting, high-speed pressing, including explosive pressing, and injection molding.

Compaction can be carried out at room (cold pressing, rolling) and high temperatures (hot pressing, extrusion, rolling). Powder compaction during pressing occurs as a result of the movement of particles relative to each other and their subsequent deformation or destruction. At relatively high pressures, powders of plastic metals are compacted mainly due to plastic deformation, and powders of brittle metals and their compounds as a result of destruction and grinding of particles. Pressed blanks from plastic metal powders are much stronger than from brittle ones. To increase the strength of the latter, a liquid binder is introduced into the powder before pressing.

## SINTERING

The final operation of powder metallurgy—sintering—consists of heat treatment of blanks at a temperature below the melting point of at least one of the components. It is carried out in order to increase the density and provide a certain set of mechanical and physicochemical properties of the product. At the initial stage of sintering, the particles slide relative to each other, contacts are formed between them, and the centers of the particles converge. At this stage, the rate of increase in density (shrinkage) is maximum, but the particles still retain their individuality. At the next stage, the porous body can be represented by a set of two mutually penetrating phases—the phase of matter and the "emptiness phase." At the final stage, the porous body contains isolated pores, and compaction occurs as a result of a decrease in their number and size [6].

Sintering of multicomponent systems is complicated by mutual diffusion. In this case, sintering can also occur with the formation of a liquid phase (liquid-phase sintering). Sintering is usually carried out in a protective (most often, inert gases) or reducing (hydrogen, hydrocarbon-containing gases) environment, as well as in a vacuum. Heating of the products is carried out in electric furnaces (vacuum, bell-type, muffle, pusher, conveyor, continuous, shaft, with walking hearth, etc.), induction furnaces, and direct current flow. Sintering and pressing can be combined in one process (sintering under pressure, hot pressing).

Materials and products obtained by powder-metallurgy methods are called "powder." These materials are conventionally divided into structural, tribotechnical, filtering, hard alloys, high-temperature, electrical, with special nuclear properties, etc. Structural powder materials are used to manufacture machine parts, mechanisms, and devices, such as gears, flanges, toothed wheels, valve seats and housings, couplings, eccentrics, cams, washers, covers, bearing housings, pump parts, various disks, bushings, etc. The main requirements for these powder materials are increased mechanical properties and cost-effectiveness. Parts made of structural powder materials are subdivided into unloaded, lightly, medium-, and heavily loaded, and by type of material, as based on iron or nonferrous metals and alloys.

Tribotechnical materials include antifriction materials and friction materials. The optimal structures of antifriction materials are a hard matrix and a soft filler. The powder-metallurgy method is the most effective for creating such a structure. The antifriction products obtained by this method have a low and stable friction coefficient, good running-in, high wear resistance, and good resistance to seizure. Products made of powder antifriction materials are self-lubricating. The solid lubricant (for example, graphite, selenides, sulfides) is contained in the pores itself. Antifriction powder materials can be used both for the production of bulk elements and as the coatings applied to substrates.

A typical example of the products made of powder antifriction materials is plain bearings. Friction powder materials are used in the units that transmit kinetic energy. Powder friction materials most often consist of metallic and nonmetallic components. In this case, metallic components provide high thermal conductivity and running-in ability, and nonmetallic ones ($SiO_2$, $Al_2O_3$, graphite, etc.) increase the friction coefficient and reduce the tendency to seize up.

Filters made of powder materials have a number of advantages over other porous products: a high degree of purification with satisfactory permeability, high heat resistance, strength, resistance to abrasive wear, thermal conductivity, etc. Filters are made by sintering loosely poured or pressed powders of bronze, stainless steel, nickel, titanium, or iron. Powder metallurgy methods make it possible to manufacture filters with variable and adjustable porosity, permeability, and degree of purification. Filters, along with porous bearings, make up the main part of porous products made of powder materials.

Powder metallurgy methods are also used to manufacture porous sealing gaskets, de-icers, flame arrestors, condensers, foam materials, and "sweating"

materials. Products made of powdered hard alloys consisting of hard refractory carbides and a plastic metallic binder are obtained by pressing powder mixtures and liquid-phase sintering. Hard alloys are divided into those containing WC (or its solid solutions with other carbides) and tungsten-free (based on TiC and other refractory compounds); they have high hardness, strength, and wear resistance. Hard alloys are used to make tools for cutting materials, stamping, pressure treatment, and drilling rocks. The properties of many hard alloy tools are significantly improved by applying thin (several micrometers thick) coatings of refractory compounds to the surface of the products.

## CONCLUSIONS

Thus, the technology for producing powder materials based on additional pressing allows the production of virtually nonporous materials.

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## CONFLICT OF INTEREST

As author of this work, I declare that I have no conflicts of interest.

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