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Manufacturing Methods of Complex-shaped Powder Components

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Main directions of the manufacture of powder articles of complex configurations are considered. Results of investigations in which complex-shaped articles were prepared by pressing on hydraulic presses, magnetic pulse compaction, joint sintering of several powder components, infiltration, and brazing are presented.

In order to increase the strength and density of joints, the method of infiltration of powder components with copper melt was used. Factors influencing the infiltration process and properties of articles are analyzed. Examples of applications of components consisting of several elements are presented.

Keywords: powders, sintering, complex-shaped component infiltration, joining of powder details.

1. INTRODUCTION

In the last decade, the trend to manufacturing powder components of more and more complex shape, increasing their masses, and improving their physico-mechanical properties are observed.

The powder metallurgy industry surpasses many other industries producing metallic articles in the rate of increase of production. The main cause of this is that, in powder components, better properties can be obtained, whereas their cost is smaller. The powder metallurgy method appears to be competitive in the production of composite components in large numbers [1, 2].

The development of parts of complex configuration from powder materials is often limited by the necessity of mechanical processing. For instance, components with undercuts, slots, and holes located perpendicularly to the processing direction are complex to press. The modern powder metallurgy technology makes it possible to produce highly complex parts by joining powder compacts with one another, with a part prepared by cutting, or with a wrought component.

2. DEVELOPMENT OF POWDER METALLURGY

Powder metallurgy is defined as a technology or a method of commercial manufacture of complex-shaped components from metallic powders [3].

In the present work, the field of powder metallurgy connected with iron and low-alloy steels is considered, but principles under consideration are analogous to those used in some other fields of powder metallurgy. In the production of articles, two types of iron powders are mainly used, namely sponge and atomized powder [4].

At the beginning of the 21st century, the total volume of iron and steel powders intended for the production of powder components reached 1 million tones. The largest world-famous producers of iron powders are Höganäs AB (Sweden), QMP (Canada), and Pometon (Italy). The USA Various interlayers, in the form of foils or coatings, consumes 45 % of these powders (Fig. 1).

Another component of materials used in the production of many components is copper powder. The copper content in powder articles ranges from 1.0 to 30 %. Among the largest producers of powder copper, Uraleletromed (Russia), [5], Chang Sung Corporation (Korea), and Eckart-Werke (Germany) should be mentioned.

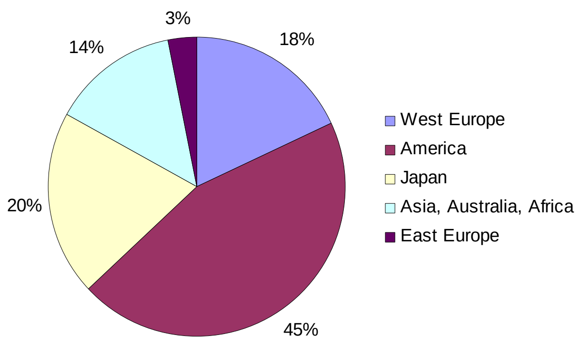

Fig. 1. Production and sale of iron powders [5]

3. PRESSING OF COMPLEX-SHAPED COMPONENTS

In pressing, under pressure applied to powder, the plastic deformation of powder particles, their cold welding, the blocking of neighboring particles, and the filling of pores with the material forced into them occur. When the compacted powder is removed from the die, regions of cold welding and blocking hold particles together. This makes it possible to transport compacts to a sintering furnace. To obtain more homogeneous densities and provide the easy removal of the compacted components from a die, lubricants are used [3, 7].

Presses used in commercial production of powder articles are modern equipment and often have several punches, which makes it possible to press complex-shaped components [3, 6]. Nevertheless, there exist a number of limitations:

1) the insufficiency compacting pressure for the attainment of a required density in the case of increased dimensions of components;
2) the impossibility to manufacture components of large length (1/d ≤ 10);

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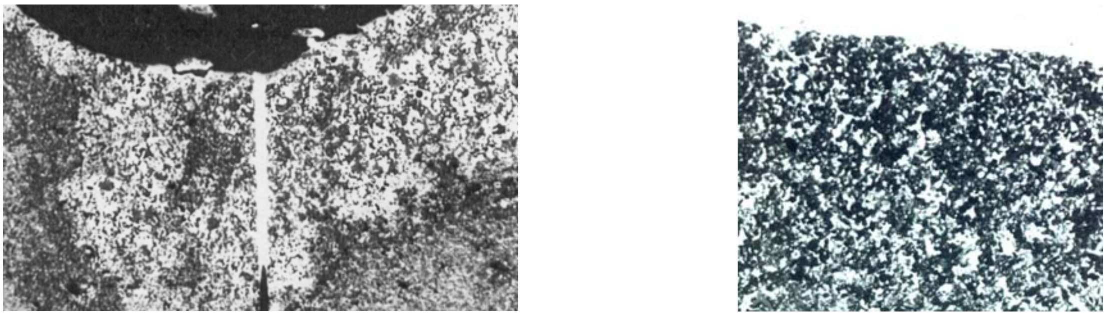
Fig. 2. Use of brazing in manufacture of a conveyor component [9]

Fig. 3. A component of a tractor transfer gear case [10]



a b

Fig. 4. Joint of parts made of a Fe-C-Cu powder alloy by brazing (increasing ×150): a – slow solidification of the solder; b – fast solidification of the solder

3) the impossibility to produce parts with internal slots, side holes, and undercuts.

To overcome these limitations, presses with an increased power are used. For instance, Dorst (Germany) develops and produces presses with a power of 1200 tons and 1600 tons [6].

In the manufacture of long-length components, extrusion forming is used [3 – 7]. Components with holes and slots are produced by pressing followed by mechanical processing.

Recently, the interest to the manufacturing methods of composite components consisting of several parts pressed individually has intensified [8].

4. JOINING OF POWDER COMPONENTS BY BRAZING

Brazing is an effective manufacturing method of components of complex configuration [9 – 11]. This method is successfully used by firms in the USA and Japan. The striking examples of using the brazing method are components of conveyors (Fig. 2) and a component of a tractor planetary gear transmission (Fig. 3). In brazing of powder components, the principal problem is open porosity. Depending on the compacting pressure and the mean particle size of the base powder, the pore diameter ranges from 10 μm to 100 μm and above. An increase in the compacting pressure leads to a decrease in the pore size, but cannot provide their complete disappearance. Capillary forces in pores are larger than in the clearance between components in brazing, as a result of which the hard solder is removed from the clearance (Fig. 4, a). To perform high-quality brazing, the negative influence of porosity must be eliminated. This can be achieved by the following methods:

- increasing the density of a whole components;
- increasing the density of only the surface of a components (to prevent the penetration of hard solder in the pore system).

In the case where the porosity of the whole component must be increased to eliminate open porosity, a density of (7.25 – 7.35) g/cm^3 is to be obtained. For most components, the attainment of this density requires the use of double pressing and double sintering. In this connection, brazing can be successfully performed during the last sintering operation/

The new brazing method consists in using special hard solder, which penetrates into a clearance between components joined by brazing, but does not penetrate into pores. This is possible if the hard solder solidifies rapidly in pores (Fig. 4, b). Solidification in pores can be achieved in the case where a reaction between the hard solder and the matrix material takes place. In the case of this method, the hard solder penetrates into pores, its melting point rises, and it solidifies. If the composition of the hard solder and the brazing temperature are correctly chosen, brazing can be performed during sintering. This method is preferable, since it does not require the introduction of additional operations to the manufacturing process of components and is easily introduced in mass production.

At present, there exist two types of hard solders used in this method. The first solder is a Ni-Cu-Mn-Si-B alloy developed in the early 1970s. When the hard solder penetrates into pores, certain erosion of the iron matrix occurs. Erosion and diffusion change the composition of the hard solder, which causes the solidification of the solder in pores. In the composition of the alloy which moves in the clearance, certain changes occur, which also limits the fluidity of the alloy.

Another hard solder was developed at the end of the 1980s [11]. It is a variant of the first-mentioned solder, but with an increased fluidity. The fluidity increases on adding iron. Iron also limits the erosion of the matrix and lowers the solidification temperature.

5. MANUFACTURE OF COMPOSITE POWDER COMPONENTS BY THE INFILTRATION METHOD

The method of infiltration of powder components with metallic melts is extensively used. Its main application is the manufacture of high-density articles. Pores of a powder compact are filled with copper melt or melts of copper-base alloys due to the action of capillary forces of the porous body.

In recent years, the infiltration method was used in the manufacture of composite components consisting of several parts [10, 11]. One of such applications is stages of centrifugal pumps, which are produced by a number of enterprises [12]. Compacts of cases, impellers, and bushings are pressed individually, and their sintering is performed simultaneously with infiltration of the whole complex of components with melt. Using infiltration, particular attention must be paid to the consideration of the used impregnant with the aim to calculate correctly the efficiency of infiltration for the attainment of a concrete final density.

Fig. 5. Components of a centrifugal pump before and after sintering. Diameter of details – 80 mm

The maximal amount of the impregnant which can be used depends on the existing pore volume in an iron compact since only these pores can be filled with melt.

The principal factors in the determination of the amount of the impregnant are as follows:

1) the open pore volume;
2) the set final density after infiltration;
3) the set final copper (impregnant) content;
4) the efficiency of the used impregnant.

Temperatures and protective media used in infiltration and those used in traditional sintering of iron-base components are practically the same. The difference is that the impregnated components are usually placed not on a conveyer belt, but on ceramic trays or saucers [13] to prevent damage of the belt of the furnace by excessive molten material and losses of the impregnant as a result of flowing down from the conveyer belt.

Some types of impregnants require a dew point of 0 ºC to prevent the undesirable strong sticking of residues (Fig. 6). Sticking tough residuals can be removed only by filing and grinding of compacts with abrasive material.

In [14], the following cycles of one- and two-stage infiltration are proposed:

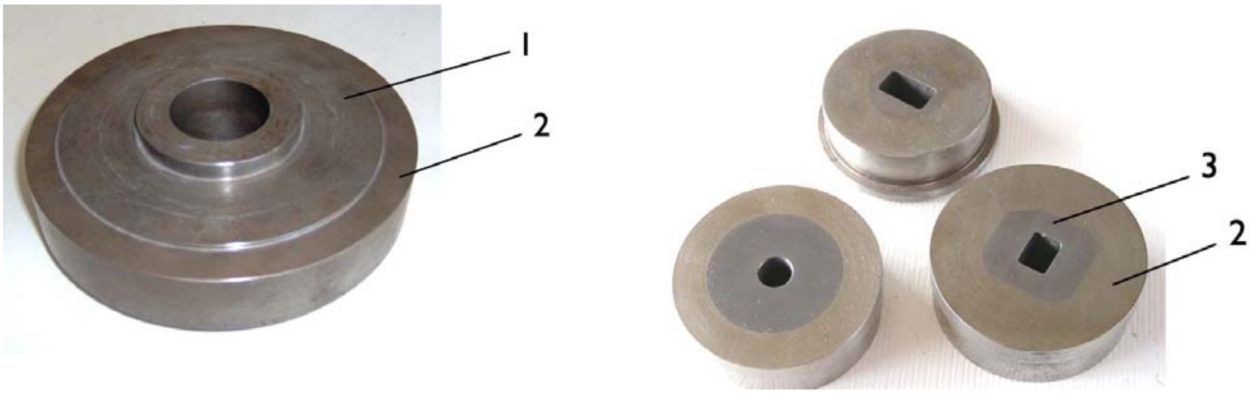
One-stage process.

15 min in the temperature range (680 – 760) ºC (for the burnout of lubricant);

Fig. 6. The presence of residuals of the infiltrant in infiltration of Fe-C with copper. Diameter of details – 80 mm

Table. Properties of some impregnants produced by States Bronze Powders [9]

Indicator	Impregnants		
	C128-L	XF-1	XF-4
Cu content, %	92	95	95
Fe content, %	1	2	2
Lubricant content, %	0.5	0.5	0.5
Density, %	3.2/3.4	3.2/3.5	3.2/3.5
Flowability, s/50 g	35/45	34/45	30/40
Green density at 20 ton, g/cm^3	7.3	7.5	7.1
Green density at 30 ton, g/cm^3	7.6	7.8	7.6
Efficiency of using	95.4	98.0	96.7
Coefficient of infiltration, I_F	120.3	117.4	121.8



a b

Fig. 7. Components consisting of several parts: a – worm-wheel compact (external diameter – 180 mm); b – inserts of mold dies (external diameter – 45 mm); 1 – nave, 2 – Fe-C-Cu ring, 3 – WC-Co insert

10 min (minimum) in the temperature range (1010 – 1040) ºC for the dissolution of graphite);

30 min at 1120 ºC (for sintering-infiltration).

Two-stage process.

The first run: 15 min in the temperature range (680 – 760) ºC (for the burnout of lubricant);

30 min at 1120 ºC (for sintering);

The second run: repetition of the above cycle in the presence of the impregnant.

States Bronze Powders (USA) is a leading company in the production of copper-base compositions for infiltration (Table) [9].

The correct choice of the impregnating composition as well as sintering and infiltration conditions provide a good contact in the joint zone, which is a critical region from the viewpoint of the adhesion strength of components [15].

6. MANUFACTURE OF COMPLEX-SHAPED COMPONENTS BY THE MAGNETIC PULSE COMPACTION METHOD

The magnetic pulse compaction method makes it possible to extend the field of application of powder metallurgy [16]. Features of the method enable one to press powder layers on steel compacts made by casting or forming (Fig. 7). Dimensions of parts can be increased due to using step pressing [17]. To rise the density and the efficiency of the used forming envelope, it is expedient to use the infiltration method [6, 8].

CONCLUSIONS

The manufacture of complex-shaped components is a tendency in the modern powder metallurgy. Infiltration with metallic melts is a progressive method, which has many modifications.

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