ASPECTS OF THE FRICTIONAL MATERIALS APPLICATION FOR THE MACHINERY PARTS

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Abstract
Powder metallurgy is a rapidly developing industry that produces powders from metals and other inorganic materials and sintered articles thereof. The use of powder metals, alloys and refractory compounds has begun in ancient times.
Even then, powders of gold, copper and bronze were used for decorative purposes in the manufacture of ceramics and as components of paints in painting.
One of its main advantages is the ability to reduce process losses of materials, since the mechanical treatment of some kinds of casting and even rolled stock into chips takes up to 60-70% of the metal.

Keywords: Powder forming; annealing; powders preparing; screening; pressing; compressibility; compactibility; formability; pressing curves; repressing pressure; elastic aftereffect.

1. Introduction
Methods of powder metallurgy are used for manufacturing of materials and articles:
1) with unique properties unattainable by means of other technologies;
2) with usual level of properties, but cheaper.
These methods can be used for manufacturing of articles made of materials which formation by another way is impossible or unprofitable, for example, of non interfusing materials, compositions of metals and nonmetals.

Such materials include refractory metals, solid carbide alloys, porous and friction materials, magnetic materials and magnetodielectrics, diamond-like materials, cermets.

Traditional technological process of powder metallurgy includes the following steps: obtaining of powders, molding of blanks thereof, sintering and final processing (sizing, crimping, heat treatment, etc.) of article. Its improvement has led to the establishment of specific operations which include gasostatic pressing of powders, their molding by injection into a matrix, powders obtaining in conditions of ultrafast (10^6-10^{7o}C/s) cooling and other operations that extend the capabilities of powder metallurgy.

Powder forming. Forming is a technological process of blanks (i.e., bodies with a predetermined shape, size and density) production by means of bulk material compacting and its original volume reduction. Forming is one of the main methods of consolidation of material in powder metallurgy and ceramic technology. Consolidation is the process of obtaining connected solid materials from individual components. Compacting of powder is carried out by pressing in metal molds or elastic membranes by slip forming, rolling and other methods.

2. Methods

An important place in the overall scheme of production of materials and products from metal powders is occupied by the processes of *powders preparing* for molding. The main preparing operations of powders are annealing, screening and blending.

Annealing of powders is used in order to increase their plasticity and therefore to improve compactibility, compressibility and formability. Heating is usually carried out in shielding medium (reducing, inert or vacuum) at temperatures of metal powder of about 0.4 - 0.6 T_m.

Screening (classification) is a process of separation of powders according to particle size on fractions which are then subjected to forming or used for obtaining mixtures of desired composition from desired particle size. Sieve classification of powders or separation of particles by size by means of air separators are most often used in the practice of powder metallurgy.

The process of *mixing* of metal powders lies in preparation of homogeneous mechanical mixture of different metals powders and of their mixtures with powders of nonmetallic materials. For the mixing different types of mixers are used: drum, screw, paddle, centrifugal, planetary or conical and continuous-operation plants. Mixing medium can be both gaseous (usually air or inert gas) and liquid (water, alcohol, gasoline, etc.). In the liquid medium mixing, which is called a "wet" mixing, is much more intense, however it is not always economically advantageous.

Mixing of powders is one of the most important operations of powder metallurgy, which determines further steps of technological process and physical and mechanical properties of articles. Quality of powders mixing under production conditions is monitored by technological properties of charge and chemical analysis of test portions. Preparation of powder mixture typically completes the cycle of preparation to the forming of powders.

Pressing is a forming of powders in dies or shells under pressure. The simplest die structure scheme is shown in Figure 1.

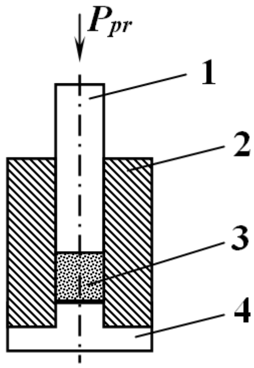

Figure 1. Die: 1 – upper punch; 2 – matrix; 3 – compacted powder; 4 – lower punch (support)

Powder is placed into the cavity of the matrix, after which the punch is applied by pressure called compaction pressure P_{pr}. While pressing the powder is behaving like a fluid with the difference that because of the friction of particles about each other, on the walls of the matrix and on the punches, the pressure distribution in it is nonuniform: it is lower on the walls of the matrix and is higher in the direction of compacting. For the same reason the pressure (and therefore density) is nonuniform over the cross section and height of compact. Possibility of implementation of powder compacting process and compacts obtaining (press blanks) is determined by three interconnected characteristics: compressibility, compactability and formability.

Compressibility is the ability of powders to form a compact under the influence of certain pressure.

Compactibility is the increase of powders density during compaction at a predetermined pressure.

Formability is the ability of blanks to retain the shape in a predetermined range of material porosity. In the technical literature, the terms "compressibility" and "formability" are often used interchangeably.

Compressibility depends on properties of the powder (particle size and shape, the degree of their cold hardening, the flow rate of powder), on powder pretreatment (e.g., reduction, annealing), on preparation charge method (e.g., introducing of the plasticizer or lubricant into it). Formability depends on powder grading, the nature of formable material, shape and surface condition of powder particles. To characterize the compactability (and compaction process in general) they build compaction curves.

Pressing curves are dependences of relative density of the compact to pressing pressure (relative density is the ratio of actual density of powder to non-porous density of the material).

Figure 2 shows that the most intense powder compaction occurs at the first step of the process (a).

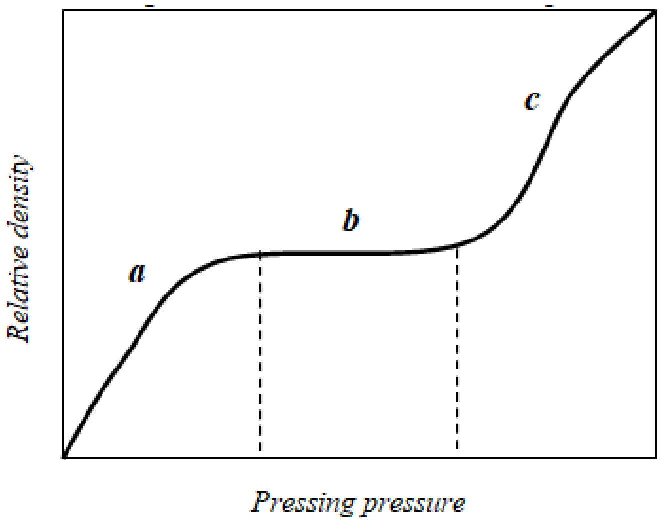

Figure 2. The idealized curve of powder compaction of ductile metals

That step is related to redistribution of particles in space due to their displacement and denser packing under the influence of external forces. The second stage (b) is characterized by the fact that powder particles are packed densely as possible and have a certain resistance to compression. That causes the pressing pressure increase but the density of the powder body for some time is not increased. Finally, when the pressing pressure exceeds the compressive strength of the powder particles, their plastic deformation starts and compaction process enters the third stage (section *c*). From this moment the plastic deformation covers the whole volume of each particle, the particle motion is actually stopped and they are fixed.
In the process of pressing these steps are proceeding simultaneously and the curve of compaction of most powders is monotonic and there is no explicit horizontal line in the middle section. Deformation of individual particles begins under low pressures, and sliding of particles continues at high loads. Therefore, in the first stage there is mainly movement of particles, and at last stage there is plastic deformation of them. The more plastic metal is, so the lower pressures are necessary to start compaction of the compact by the deformation of particles.
As it was mentioned, the degree of compression of the powder in different sections of a compact varies. Significantly lower pressure than in the direction of pressing is transferred on the side walls of a die. In this regard, an important value is the so-called *coefficient of side pressure* ξ. This is a ratio of side (horizontal) pressure P_h, i.e. pressure of powder on the walls of a die to pressure pressing P_{pr}:

$$\xi = \frac{P_{\text{г}}}{P_{\text{пр}}} = \frac{1-v}{v} \leq 1 \qquad (1)$$

where ν - Poisson's ratio of material powder. The value ξ is typically 0.2 - 0.5, and the more plastic material is the bigger ν, and hence ξ are. For example, for tungsten ξ = 0.2, for iron - 0.39, tin - 0.49, copper - 0.54, silver - 0.72 and lead - 0.79. Side pressure decreases in the direction from the surface of punch along the height of compactable briquettes since frictional forces arising between the moving particles of the powder and the walls of a die, reduce the amount of axial pressure of pressing.

Pressing process is accompanied by the formation of residual stresses in the compact. The accumulation of residual stresses connected with such phenomena as elastic aftereffect of compaction and differences between the value of pressing pressure and repressing pressure.

Repressing pressure is a force required for repressing of briquette from the die after its compaction. It is proportional to the compaction pressure and depends on the friction coefficient between compact and die and Poisson ratio of compressible powder. Typically, repressing pressure is taken equal to 0.2 - 0.35 from compaction pressure. The higher compressible briquette and smaller cross-sectional area the greater repressing pressure is.

Elastic aftereffect is a phenomenon of increasing the size of compact when removing the compaction pressure, as well as when ejecting of the briquette of the cavity of die. The value of elastic aftereffect depends mainly on the characteristics of powder being formed (dispersibility, particle shape, state of their surfaces, mechanical properties of material), compaction pressure, presence of lubricant, elastic properties of matrix and punches. Relative change of linear dimensions after elastic aftereffect is determined from the expression

$$\delta_1 = \frac{\Delta l}{l_0} \cdot 100\% \qquad (2)$$

where δ_l - the value of elastic aftereffect; l_0 - length (diameter) of briquette located in die under compaction pressure; Δl - absolute expansion of briquette along the length (diameter) after release of pressure of compaction or ejecting from the die.

Elastic aftereffect along the height of briquette (0.5 – 0.6%) is larger than in transverse direction (0.1 – 0.3%). This is due to the fact that axial compacting force is higher than side pressure and the presence of elastic deformation of mold block, whereby the height of briquette increases after release of pressure.

3. Results and Discussion

Slip casting is forming of blanks by filling the forms with casting slip. Stable homogeneous suspension of powder in liquid (slip) is poured into a porous (usually gypsum) form and dried.

Then the article is removed from the form and sintered.

Gypsum forms have certain disadvantages: limited lifetime, low absorption rate of liquid from slip when reusing, difficult removal of articles of complex configuration from forms. Therefore, for manufacturing of forms other materials which have sufficient durability and are able to absorb liquid phase of slip, such as paper, are sometimes used. Slip casting is used to obtain porous semifinished products and articles.

Rolling of powders is continuous forming of powder mass between rollers of rolling mill. Processes of rolling of powders and compact metals are very different, although they have a number of common features. The powder from charging device (hopper) is poured into the gap between two rotating rollers toward one another (Figure 3).

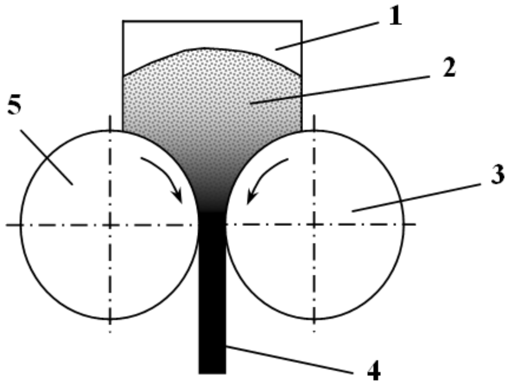

Figure 3. The diagram of powder rolling: 1 – hopper; 2 – powder; 3, 5 – rollers; 4 – blank

4. Conclusion

Particles are entrained into the gap by skin-friction forces and compacted forming a bar with strength sufficient for transferring into a sintering furnace. Compacted state of the blank is provided by deformation, mechanical interlocking and diffusion welding of particles. The process of powder rolling by its physical nature may be regarded as continuous pressing which begins in the zone of particles deformation and finishes at the outlet from the gap between rollers.

Rolling of powders is carried out in different ways. They differ from one another by arrangement of rollers (vertical, horizontal rolling), temperature of treated powder (hot, cold), and powder feeding mechanism (gravitational, force). Rolling is used to form porous articles (filters, electrodes, etc.). Blanks and semifinished products like tapes, bars, sheets, wires, etc. Rolling of powders is widely used in ceramic processing technology.

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