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THE STRESS-STRAIN STATE (SSS) CALCULATION OF HEAVY LOADED ELEMENTS OF A NEW-DESIGNED PRESSING DEVICE (PD)

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The results analysis of calculating the stress-strain state (SSS) of heavily loaded elements of new powder metallurgy equipment by using an analytical method and a deformation model of metal strength is presented here. The influence of tools construction on the heavily loaded elements of the pressing device stress-strain state is determined. It is shown that the new equipment for powder metallurgy has a sufficiently high rigidity of the unit structure and satisfies the strength condition. It is noted that pressing of long length profiles on the proposed pressing device will lead to the production of finished products of high quality. As a result of the equipment SSS calculating, rational structural dimensions of main units of the pressing device were determined.

Keywords: long length profile, pressing device, screw unit, stress-strain state, powder

INTRODUCTION

New methods of manufacturing precision shaped products from metal and ceramic powders are currently widely used in various industries [1,2]. These methods are especially widely used in the production of new weapons, electronics, aerospace and other equipment.

Power Injection Molding (PIM) -technology, as a widespread method of metal casting (MIM-technology - Metal Injection Molding) and ceramic (CIM-technology - Ceramic Injection Molding) products appeared in the world relatively recently [3-5]. Until now, the growth rates of the production using PIM technology remain quite high.

Analysis of the literature data [6,7] shows that in the well-known MIM technologies for the production of parts from powder materials, raw materials called "feedstock" are first produced. For the production of feedstock, powder mixtures are uniformly mixed with a polymer binder, heated, and thus granular material is obtained.

Then the following steps are applied [7,8]:

- The feedstock is loaded into the hopper of the automatic injection machine (AIM) and during the heating in a metal cylinder up to 170 - 200 °C, the polymer binder melts, the granulate turns into a single mass. Then the spaying is made under the pressure of molten feedstock, the melt fills a mold which is heated to a temperature of 125 to 145 °C, where the material is cooled and solidified under the pressure to obtain a primary billet, which is called «green».

- At the second phase, the polymer binder is removed from the «green» billet in two stages. The polymer binder is extracted with a solvent or burned out in a "debinding" furnace in an atmosphere of inert gas and nitric acid vapor at a temperature of 110 - 140 °C. The detail obtained after removing the binder is called «brown».

- The final phase of the MIM process is the sintering of «brown» billets in a vacuum furnace. During the sintering, semi-finished product enters into a special high-temperature furnace with a controlled atmosphere, where at temperatures of 1 290 - 1 400 °C, its particles are finally sintered and the finished part is formed.

The uniqueness of MIM technology is characterized by many features [9,10]. Here are some of them: widespread use; complicated shape of parts; cost savings; high final density of parts; large material opportunities; high performance, good finished part surface and stability; the ability to produce large quantities of parts; high utilization rate of the material – 0,97 - 0,99.

However, for known MIM technology realization, molding machines of complex design are used, while for the release of each part a special tool is designed and manufactured, which leads to high financial costs. It should be noted that it is impossible to produce "green" long length profiles using the known MIM technology.

To eliminate the shortcomings of the existing MIM - technology, we used a pressing device (PD) of a new design. This PD will be used to manufacture long length profiles of various sizes from polymer-metal compositions.

Obtaining high-quality "green" long-length profiles from polymer-metal composites with desired properties is rather complicated process. At the same time, a properly designed and well-manufactured PD tooling allows to ensure the required dimensional accuracy of "green" profiles, to obtain a high-quality surface, to keep physical and mechanical properties of used polymer-metal material.

The purpose of the work is to calculate the strength of the heavily loaded parts of the pressing device, which

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allows obtaining "green" long length profiles of required quality.

MATERIALS AND RESEARCH METHODS

PD of a new design is proposed in this work. The pressing device consists of screw and pressing units. The screw unit (extruder) includes a drive, a raw material (feedstock) hopper, a feeder, a heated cylinder, a screw, heaters and a matrix in which a replaceable filter is installed. The press unit contains a frame, a diameter fixed to the frame, a movable working slider, a hydraulic drive, and a heated container rigidly fixed to the frame. A compression ram is fixed to the working slider.

The production of profiles on this PD is carried out in the following way. Solid feedstock enters a hopper equipped with a shutter, from where it is transferred through a dosing feeder to a heated cylinder. When moving along the axis of the heated cylinder, the granules are gradually heated to 170 - 200 °C and, due to the appropriate geometry of the screw, are compacted and the binders melt, turning into a melt with a thixotropic viscosity, depending on the shearing rate. After partial melting, the resulting suspension is subjected to intense shear deformations in the die, ensuring that the suspension material acquires the required thixotropic properties. It should be noted that only the polymer binder melts in the screw unit, the volume ratio of which rarely exceeds 40 %. At the end of this stage, molten feedstock is injected under pressure into the PD container.

Extrusion of profiles is the last stage in the production of «green» long length profiles, carried out in the press unit. The press unit is a continuation of screw unit. For pressing, the feedstock obtained in the screw unit is filled into container heated to a temperature of 125 to 145 °C, where the billet is squeezed out under pressure through the matrix mesh, and then the material is cooled and solidified to obtain profiles of the appropriate shape.

PD strength calculating method was realized by using the methodology which is given at this work [11]. The method makes it possible to investigate the calculation of the stress-strain state (SSS), of separate links and the mechanism as a whole.

To calculate the energy-power parameters of wires from polymer-metal composites pressing on PD, the method described at the works [11,12] was used. This method uses the principle of superposition, i.e. pressing force P is determined by the formula:

$$P = R_m + T_{cr} + T_m + T_p \tag{1}$$

where R_m is a component of the effort to overcome the power of internal forces (on the deformation itself); T_{cr} is a component of the effort to overcome frictional stresses on the container walls; T_m is a component of the effort to overcome the frictional stresses on the matrix surface or the cut stresses of the dead zone; T_p is a component of effort to overcome the frictional stresses on the calibrating belt of the matrix.

Friction coefficients ψ_c, ψ_m, ψ_b on the container, matrix and calibrating belt were determined from the reference book [13].

At determining the pressing force of wires made of polymer-metal compositions, the base value of the deformation resistance was taken equal to the yield strength of the polymer-metal compositions, i.e. $\sigma_{s0} = 10$ MPa. The value of mean resistance to deformation was taken as an arithmetic mean, i.e. $\sigma_{s2} = 12$ MPa. By analyzing the literature data, the deformation resistance σ_{s3} was taken equal to 25 MPa.

The strength and rigidity of PD parts were investigated by pressing wires with a diameter of 2 mm. Powder obtained in a screw unit was used as a primary blank.

Due to the pressing in the new PD is carried out in a container heated to a temperature 125 to 145 °C, a three-layer container was used at the work. Bushing material: working one - steel grade 4X2B with σ_{02} = 1 050 MPa, intermediate and outer materials - 5XHM with σ_{02} = 700 MPa.

The pressure of the metal on the inner surface of container was calculated, relative tightness value for fastening the bushings was chosen: inner and middle $\left(2\delta/d_c\right)_1$ = 0013; middle and outer $\left(2\delta/d_c\right)_2$ = 0004, 2δ - absolute tightness, d_c - bushes coupling diameter.

The bushings fit temperature to ensure assembly with the selected interference was calculated at the work. In this case, the coefficient of thermal expansion was taken equal to $12{,}5\cdot10^{-6}$ 1/deg.

It has determined the contact pressures on the bushings mating surfaces after their hot assembly. With this, the material elasticity modulus of all bushings was taken equal to $2{,}15\cdot10^{5}$ MPa.

The stresses acting on the surfaces of each bushing of the fastened container were determined using the appropriate formulas.

RESULTS AND THEIR DISCUSSION

The results of calculating the process of pressing wires from polymer-metal compositions showed that for the pressing process on PD, an effort of 1 730, 8 kN is required. Wherein, a pressure of 130 MPa acts on the inner surface of the container.

By calculating the temperature of bushings fit, we established following:

- heating temperature of the middle bushing to fit it on the inner bushing must be equal to: Δt_1 = 190 – 240 °C;

- heating temperature of the outer bushing to fit it on a block of fastened inner and middle bushings must be equal to: Δt_2 = 150 – 200 °C.

Analysis of obtained data shows that the heating temperatures of the bushings do not exceed the limiting values – 500 – 550 °C.

It was found that when the middle bushing fits onto the inner bushing, the contact pressure will be equal to 13,65 MPa, and when the outer bushing fits onto a block of fastened inner and middle bushings, it will equal to 7,16 MPa.

During calculating the stress from the action of internal and external pressure, the following values of tangential and radial stresses were obtained, respectively:

- to the inner bushing:

- $\sigma_\tau^{\rho_в}$ = 149,5 MPa; $\sigma_r^{\rho_в}$ = - 139,65;
- $\sigma_\tau^{\rho_н}$ = - 73,56 MPa; $\sigma_r^{\rho_н}$ = 0;

- to the inner surface of the middle bushing:
  - $\sigma_\tau^{\rho_в}$ = 51 MPa; $\sigma_r^{\rho_в}$ = - 41,5 MPa;
  - $\sigma_\tau^{\rho_н}$ = - 32,73 MPa; $\sigma_r^{\rho_н}$ = - 17,7 MPa;
- to the outer surface of the inner bushing:
  - $\sigma_\tau^{\rho_в}$ = 16,76 MPa; $\sigma_r^{\rho_в}$ = - 13,64 MPa;
  - $\sigma_\tau^{\rho_н}$= - 10,71 MPa; $\sigma_r^{\rho_н}$ = - 5,79 MPa;
- to the inner surface of the outer bushing:
  - $\sigma_\tau^{\rho_в}$ = 39,85 MPa; $\sigma_r^{\rho_в}$ = - 12,77 MPa;
  - $\sigma_\tau^{\rho_н}$ = - 9,34 MPa; $\sigma_r^{\rho_н}$ = - 7,17 MPa;
- to the outer surface of the middle bushing:
  - $\sigma_\tau^{\rho_в}$ = 62,2 MPa; $\sigma_r^{\rho_в}$ = - 19,93 MPa;
  - $\sigma_\tau^{\rho_н}$ = - 5,62 MPa; $\sigma_r^{\rho_н}$ = - 4,67 MPa;
- to the outer surface of the outer bushing:
  - $\sigma_\tau^{\rho_в}$ = 42,27 MPa; $\sigma_r^{\rho_в}$ = 0 MPa.

The calculation of the resulting tangential and radial stresses made it possible to obtain the following values:

- on the inner surface of the inner bushing: σ_τ = 9,85 MPa; σ_r = - 73,56 MPa;
- on the inner surface of the middle bushing: σ_τ = 9,5 MPa; σ_r = - = - 50,43 MPa;
- on the outer surface of the inner bushing: σ_τ = 6,05 MPa; σ_r = - 19,43 MPa;
- on the inner surface of the outer bushing: σ_τ = 30,51 MPa; σ_r = - 19,94 MPa;
- on the outer surface of the middle bushing: σ_τ = 56,58 MPa; σ_r = - 24,6 MPa;
- on the outer surface of the outer bushing: σ_τ = 42,27 MPa; σ_r = 0,0 MPa.

Calculation of equivalent stresses of the investigated surface made it possible to obtain:

- on the inner surface of the inner bushing: σ_{eq} = 79 MPa;
- on the inner surface of the middle bushing: 55,8 MPa;
- on the outer surface of the inner bushing: 23,0 MPa;
- on the inner surface of the outer bushing: 44 MPa;
- on the outer surface of the middle bushing: 73,73 MPa.
- on the outer surface of the outer bushing: 42,27 MPa.

At this article, the strength safety factor was determined for each bushing of the container: working bushing – n_1 = 13,29; intermediate bushing – n_2 = 15,9; outer bushing – n_3 = 16,6.

Due to the fact that the calculated values of the safety factors are much higher than the permissible n = 1,3-2,0, the strength condition is fulfilled for all container bushings.

Next, we calculated the strength of press ram for the compressive pressing force. In the calculation, it was assumed that the pressing force was applied along the central longitudinal axis of the press ram. By calculation, the following compression stresses were obtained: σ_1 = 198,2 MPa. Subsequently, the value of the allowable compressive stress was determined σ = 1 167 MPa, taking the safety factor as n = 1,2.

In this way, the calculated data show that during the pressing of wires, the value of the equivalent stresses von Mises does not lead to the pressing device parts destruction. As a result, the construction of matrix and press ram of the pressing device meets the specified stiffness parameters and fully satisfies the requirements when applying all types of loads during pressing the wires of a given size.

Thus, a new PD with the designed dimensions will be operated without breakage.

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CONCLUSIONS

- On the base of the results modeling, it has been proven that the stress values arising in heavily loaded PD parts during feedstock processing do not exceed the maximum permissible stress.

- In consequence of SSS equipment modeling, the rational structural dimensions of PD main units were determined, as well as the regularities of SSS distribution on heavily loaded parts of new equipment were obtained.

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