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MODELING OF STRESS-DEFORMED CONDITIONS OF HEAVY LOADED ELEMENTS OF NEW EQUIPMENT OF METAL INJECTION MOLDING TECHNOLOGIES

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Preliminary Note – Prethodno priopćenje

For the production of Metal Injection Molding (MIM) with the technology of long profiles, a pressing device and a multi-roll mill of a new design are proposed. The analysis of the results of mathematical modeling of the stress-strain state (SSS) of heavily loaded elements of new equipment for powder metallurgy using the finite element method and the deformation model of metal strength is presented. The influence of changes in the content of the binder of metal powders obtained in the screw assembly, as well as the size of the initial powder, on the stress-strain state of the heavily loaded elements of the pressing device and the multi-roll mill, respectively, was determined.

Keywords: profile, pressing device, multi-roll mill, stress-strain state, mathematical modeling

INTRODUCTION

The rapid progress observed recently in the field of foundry production is associated with the possibility of obtaining strong and high-precision products of complex shapes from metals by injection molding of highly filled polymer compositions called feedstock [1,2]. MIM technology (MIM technology - Metal Injection Molding) consists of processing highly filled polymer materials by injection molding (obtaining a “green part”), debinding (removing a polymer binder - obtaining a “brown part”) and forming a monolithic metal product by sintering. Properties of the final product depend on each technological stage.

Features of injection molding of metal powder mixtures (MIM-technology), the advantages and disadvantages of this technological process for the manufacture of casting blanks are shown in this work [3]. It can be seen from the materials of this work that the size and composition of the initial powder has a great influence on the quality of the final product.

Nowadays, there are no general requirements for metal-powder compositions used in the MIM technology. There are no standards for materials for MIM technology and methods for assessing the properties of materials obtained by traditional technologies.

Powders of various fractional composition are used in different machines [4-6]. One of the parameters characterizing the powder is the average particle diameter - d_{50}, which ranges from 10 to 100 microns. At the same time, different manufacturing companies of MIM technology machines recommend working with a certain list of materials, usually supplied by the manufacturer.

In connection with the above, obtaining powders from local raw materials is a strategic task in the development of high-tech casting methods.

The purpose of the work is to develop a design of a multi-roll mill and a pressing device, which makes it possible to obtain metal powders and “green long profiles” of the required quality.

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MATERIALS AND RESEARCH METHODS

In this work, it propose a pressing device (PD) and a multi-roll mill (MRM) of a new design [7].

A multi-roll mill is used to produce metal powders, and a pressing device is used to make long profiles from polymer-metal composites.

Note that PD consists of screw and press units. The screw assembly (extruder) includes a driver, a raw material hopper (feedstock), a feeder, a heated cylinder, a screw, heaters and a matrix in which a replaceable die is installed. The press unit contains a frame, a cross-section fixed to the frame, a movable working slider, a hydraulic drive, and a heated container rigidly fixed to the frame. A ram and a die are attached to the working slider.

The production of profiles in this PD is carried out in the following sequence. Solid feedstock enters a hopper equipped with a valve, 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 up 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 shear rate. After partial melting, the resulting suspension is subjected to intense shear deformations in the matrix, ensuring that the suspension material acquires the required thixotropic properties. Only the polymer binder melts in the screw assembly, the volume fraction of which rarely exceeds 40 %.

The extrusion of the profiles is the last step in the production of “green long profiles”, carried out in the press unit. The press unit is a continuation of the screw unit. For pressing, the feedstock obtained in the screw unit fills a container heated to a temperature of 125 to 145 °C, where the workpiece is squeezed out under pressure through the die point, and then the material is cooled and solidified to obtain profiles of the appropriate shape.

In the manufacture of profiles according to the proposed technology, fine powders of iron, non-ferrous metals and alloying elements and other fractions ranging in size from 10 to 40 microns will be used as a starting material.

To obtain such powders in work proposed by multi-roll mill new design [7].

The multi-roll mill contains a cylindrical body in which the rolls are installed, the upper, support and annular flanges and star-shaped cross-section with center pillar... A loading hopper is installed in the upper part of the body, and an unloading hopper, a mounting flange, an electric motor and a storage device, hermetically connected to the body, are installed in the lower part. An exhaust fan with adjustable capacity is connected to the top of the hopper.

Material shredding in multi-roll mill carry out as follows. After starting the mill, the material intended for grinding is fed through the feed hopper to clearance between rolls, center rack and the wall of MRM. Rotating rollers press the crushed material against the inner wall of the housing and the central rack and crushed into smaller particles. The speed of the airflow created by the ventilation system and passing between the cylindrical body, the rolls and the central rack ensures that particles of the crushed material of permissible size hover in the airflow, separating them from the larger particles in the process of grinding. At the same time, small particles of crushed material of permissible size are carried out by the airflow from the grinding zone into the unloading hopper with a storage. Getting into the unloading hopper, the airflow rate drops sharply, particles of the crushed material fall out of the airflow, settle on the accumulator and then are removed from the hopper. The capacity of the exhaust fan is set so that the performance of grinding bodies in the form of conical rotating rolls between the inner semicircular grooves of the wall of the cylindrical body and in the star-shaped cross-section of the central rack of the mill; it allows you to gradually grind the crushed material to an acceptable size throughout the volume of the cylindrical body. Wherein the symmetrical arrangement of the grinding bodies around the circumference of the body creates a uniform load on the grinding bodies, which leads to a decrease in the wear of the grinding bodies, the central column and the body walls during operation, as well as to an increase in the homogeneity of the crushed material.

Making a gap between the large lower base of the rolls, the mill stand and the housing wall equal to the size of the powders obtained allows obtaining a homogeneous crushed material of acceptable size.

The method of computerized strength calculation of PD and MRM was implemented using the CreoParametric finite element analysis program [8]. The CreoParametric computer modeling system allows to study the kinematics, dynamics of mechanisms with the ability to calculate the stress-strain state (SSS), both of individual links and the mechanism as a whole.

The initial data for the calculation are the solid-state geometric model of the PD and MRM structure, the forces and conditions of fixing, as well as the conditions for conjugation of the kinematic pairs of the PD and MRM structure [9].

While designing PD and MRM in the CreoParametric environment, we created a three-dimensional geometric model of each part from the working drawings and assembled the PD and MRM nodes. Next, we imported the model into the CreoParametric preprocessor and selected the materials of the parts, their mechanical and physical properties. After that, the kinematic and static boundary conditions were formed, the design mechanical scheme was modeled, the finite element mesh was applied, and the SSS was determined. At the end of the design, the level of the obtained elastic deformations and stresses in the volume of each part was assessed in relation to the required stiffness and strength criteria and the corresponding changes were introduced into the design of the PD and MRM.

Materials for PD and MRM parts were selected from the program database. Steel 9X1 with the following mechanical properties was adopted as the material for the PD and MRM body: modulus of elasticity - 2,1 + 11 Pa; with a tensile strength of 880 MPa, Poisson’s ratio – 0,283; shear modulus – 8,1839 + 10 Pa. Tool materials chose steel stamps 40XC with mechanical properties: modulus of elasticity 214 × 103 MPa, with ultimate strength R_m = 981 MPa, Poisson’s ratio 0,3. The material of other parts of PD and MRM was Steel 45 with the following mechanical properties: modulus of elasticity – 2,034E + 11 Pa; Poisson’s ratio – 0,29; with ultimate strength R_m = 650 MPa density – 7 833,394 kg/m^3.

Strength and rigidity PD parts investigated by pressing wires with a diameter of 2 mm. Powder with different binder content obtained in the screw assembly was used as the initial workpiece.

Strength and rigidity parts MRM investigated when obtaining powders with a particle size characteristic of MIM technologies - in the range of 10 – 40 microns from 40KhMA steel. Powders with a particle size of 2 500 – 2 600 μm were used as a starting material.

RESULTS AND DISCUSSION

The calculations performed on finite element models of the PD showed that:

- maximum equivalent Mises stress in heavily loaded elements of a new design press in the manufacture of wires from powders with a binder content of 30 %, 40 %, 50 %, 60 %: do not exceed the maximum permissible value of their ultimate strength. In this case, the largest equivalent von Mises stress arise in the bed, movable slider, hydraulic cylinder, ram and PD die. In our opinion, an increase in the equivalent stress during pressing of powders with a relatively small amount of binders is associated with an increase in the friction force between the powders and the deformation of the powders themselves during pressing. Note that when pressing wires with any binder content obtained maximum values of equivalent stresses according to von Mises do not exceed the maximum permissible tensile strength for the material of heavily loaded parts;
- under the action of the applied horizontal forces, the movable working sliders bend in the direction of the force action, which leads to the occurrence of maximum deflections in the same direction of pressing. Therefore, the central part of the working sliders is elastically deformed in the horizontal direction. The maximum value of the elastic deformation of the bed, in the working slider, appears when pressing wires with a binder content of 30 %.

When pressing wires from powders with a binder content of 30 %, 40 %, 50 % and 60 % in the middle of the working slider, the bed, in the area of the container matrix fastening, the maximum moving. Their values when pressing wireswith a binder content of 30 %, 40 %, 50 % and 60 %, respectively, are equal: 0,0008427 mm; 0,0004143 mm; 0,0001352 mm; 0,00007162 mm.

Note that the obtained calculated values of the equivalent Mises stresses when pressing wires with a binder content 30 %, 40 %, 50 % vs. 60 % do not exceed the upper limit of the permissible contact fatigue stresses. This circumstance suggests that even a slight deviation from the technological process will not lead to the appearance of defects on the surface of the bed, working slider, container, matrix, ram, etc.

The results obtained showed that the equivalent von Mises stresses during pressing of wires with a binder content 30 %, 40 %, 50 % vs. 60 % changes abruptly.

Thus, the calculated data show that when pressing wires with a given binder content and size, the value equivalent von Mises stress does not lead to the destruction of press parts. As a result, the design of the casing of the pressing device meets the specified stiffness parameters and fully meets the requirements when applying all types of loads when pressing wires of a given size.

The calculations of the SSS of the mill carried out on finite element models showed that:

- the obtained maximum values of the equivalent stresses in the rolls and the central rack of the mill do not exceed the maximum tensile strength value of 981 MPa for a given material. In this case, the elastic deformation of the rolls does not exceed the value 0,0247634, which guarantees the manufacture of powders in the required range of dimensional changes;
- maximum values of equivalent stresses (440 MPa) in the mill drive does not exceed the maximum tensile strength value of 981 MPa for the given material. In this case, the value of the equivalent deformation does not exceed 0,00249. It should be noted that the maximum values of stresses and strains are observed in the teeth of the gear wheels;
- calculated maximum values of equivalent stresses in the mill housing (112 MPa) do not exceed the maximum tensile strength value of 880 MPa for this material. In this case, the elastic deformation of the rolls does not exceed the value 0,00462, which guarantees the manufacture of powders in the required range of dimensional changes;
- contact stresses in the surface layer of heavily loaded parts of the new mill do not exceed the permissible values;
- the distribution of the safety factor over the design of the mill as a whole satisfies the strength condition (the calculated safety factor does not exceed the accepted safety factor).

Thus, new PD and MRM with projected dimensions will be operated without breakage.

CONCLUSIONS

Based on the simulation results, it is proved that the stress values arising in the details of PD and MRM during the processing of feedstock and powders do not exceed the maximum permissible stress.

As a result of modeling the SSS of the equipment, the rational structural dimensions of the main units of the PD and MRM were determined, as well as the regularities of the distribution of SSS in the details of new equipment were obtained.

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Note: The responsible for English language is lector from Satbayev University