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DEVELOPMENT OF TECHNOLOGICAL BASIS OF 3D PRINTING WITH HIGHLY FILLED METAL-POLY-DIMENSIONAL COMPOSITIONS FOR MANUFACTURE OF METAL PRODUCTS OF COMPLEX SHAPE

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Preliminary Note – Prethodno priopćenje

This article discusses the possibilities of obtaining “green” parts by the FDM (Fused deposition modeling) method from ready-made polymer-metal compositions used in the MIM (Metal Injection Molding) technology and the technology of obtaining functional metal products of complex shape and structure. The influence of technological parameters of 3D printing on the quality of parts (presence of defects) obtained by highly filled polymers has been established. Thermogravimetric analysis was carried out to determine the melting point without changing the composition of the material. A filament was fabricated from granular feedstock material catamold 316L using the FDM technique.

Keywords: MIM, FDM, 3D printing, thermogravimetric analysis (TGA)

INTRODUCTION

Additive technologies are one of the breakthrough directions in the development of modern science and technology. These technologies are based on the scientific aspects of the behavior of materials during their high-energy processing. To obtain the specified properties of a material using additive technologies, possibly applying knowledge of materials science and understanding what structure will be formed in the finished product.

Dynamically developing at a fast pace, additive 3D printing technologies are used in progressive industries. There are several types of additive technologies based on different physical principles, such as: SLS (selective laser sintering), SLM (selective laser melting), EBM (electron beam melting), FDM, LOM (laminate object manufacturing), etc. All of them are united by one technological principle - production of products by the method of layer-by-layer construction. Like traditional technologies for forming products, each type of additive technologies has its own advantages and disadvantages.

The main material from which functional products for various purposes are traditionally obtained are metals and alloys. For the production of metal products, the most advanced in the world are two main technologies: SLM and EBM. Despite the high accuracy and good quality of the products obtained, this technology has a number of disadvantages related to both the high cost of the process equipment itself and the raw materials. In this case, the amount of powder that must be available when obtaining parts by the above methods must be multiples of the weight of the part itself. Part of the metal powder in this case cannot be restored and goes to waste. In addition, in the process of 3D printing of metal products using the SLM and EBM methods, internal stresses are often formed in the part due to the strongly expressed non-equilibrium of the processes occurring during fusion. At the same time, these technologies lead to the formation of an anisotropic microstructure in the material along the construction direction.

These features of the technologies of layer-by-layer fusion with high-energy impact on metal powder dictate the need for post-processing of the resulting products to relieve internal stresses in the material.

The now traditional technology of injection formation of polymer-powder mixtures into metal molds also uses one of the principles and advantages of additive manufacturing - the formation of products by the addition method. Powder injection molding (PIM) technology has been used since the 70 s of the XX century in high-precision production of metal products (MIM) of complex configuration and is a continuation of the development of powder metallurgical technologies. The main disadvantages of using this technology is the need to use complex technological equipment, expensive equipment for casting a “green” part; impossibility of obtaining parts with a complex internal structure.

At present, practically every home, office, and enterprise has entered available 3D printing technologies in the form of installations implementing the FDM method. These installations have the main advantage - their low price and ease of use, the ability to easily man-

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age the process of obtaining a product, a sufficiently high production accuracy and construction speed.

FDM technology uses polymer raw materials to produce complex shapes by 3D printing. At the same time, PIM starting materials, which are a polymer highly filled with metal powder, are affordable in terms of price and raw material production technology.

The main goal of this work is to study the possibility of obtaining "green" parts by the FDM method from ready-made polymer-metal compositions used in PIM technologies. The result of the work should be the scientific basis of the technology, combining the advantages of PIM and the technological capabilities of FDM.

The main task of the work was also to identify the influence of the technological parameters of 3D printing with highly filled polymers on the quality (presence of defectiveness) of the parts obtained.

The relevance of the work lies in the development of technology for obtaining functional metal products of complex shape and structure by the FDM method using feedstock used in MIM technologies as initial raw materials.

MATERIALS AND RESEARCH METHODS

Catamold 316L feedstock in the form of granules, obtained by injection molding from 316L feedstock, was selected as the research material.

Feedstock Catamold 316L - Ready for the production of sintered components in austenitic stainless steel type 316L using the BASF system. The guaranteed composition of Catamold 316L after sintering is shown in Table 1.

Table 1 **Composition after sintering / wt. % [5]**

C	Cr	Ni	Mn	Mo	Si	Fe
≤ 0,03	16 – 18	10 – 14	≤ 2	2 – 3	≤ 1	The rest

Catamold 316L feedstock is designed for molding on standard injection molding machines for thermoplastic polymers.

The 316L feedstock product is used as highly corrosion resistant components. Clocks, decorative parts, medical equipment, spare parts for the food and chemical industries.

The researchers studied metal infusion binders based solely on polymers.

Several polytetrafluoroethylene (PTFE) binders, catalytic burnout binders, polyacetal modified binders with non-catalytic strapping, polyethylene glycol binders using polyoxymethylene (POM) binders, ethylene vinyl acetate (EVA) binders, copolymers, methylcellulose and polyamides.

Thermal stabilizers are used to avoid thermal degradation of the POM at the time of the mold due to friction and dissipative heating of the compound. In addition, organic buffers are added to reduce the effect of acidic constituents on the metal.

However, during the thermal decomposition of the POM even if thermal stabilizers are added. To increase the dispersion of the powder, they are bound, several surfactants are added to the mixture. The nature of these surfactants is not specified. Polymeric metal binders, sole-based injection binders.

Filament making

Filament fabrication consists of three stages. At the first stage, a filament was made. At the second stage, the filament was cooled, and at the third stage, the filament was wound. In this process, a filament with a diameter of 1,75 mm for 3D printers is made from Catamold 316L pellets.

The filament was made on a Filabot ORIGINAL device, this device is a system of extruders that produce filament for 3D printers.

Filabot extruders produce filament in the three most common diameters: 1,75 mm, 2,85 mm and 3 mm. A nozzle with a diameter of 2,85 mm was installed in the experiment. The input material must be less than 3 mm in diameter.

When the Catamold 316L material is processed and reaches the filament state, the cooling fan blower reaches speeds of up to 70 m/s. If the fan speed is more than 70 m/s, the filament immediately freezes and retains its diameter, this process does not allow changing the diameter.

The diameter was measured with a micrometer 30 - 60 seconds after adjustment. Checking the diameter periodically.

After filament production (Figure 1), the next process is 3D printing. 3D printing was carried out on a

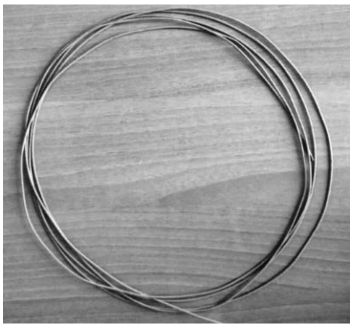

Figure 1 Catamold 316L filament

Figure 2 Installing PrintBox3D One

PrintBox3D One installation (Figure 2), which uses FDM technology (Fused deposition modeling): the model is made by depositing thin layers of molten material on top of each other.

For printing, the main parameters have been verified: layer thickness, percentage of filling, printing speed, extruded width, amount of supplied material.

RESULTS AND DISCUSSION

Differential scanning calorimetry (DSC) and TGA methods

In this analysis, material melting and weight loss were determined. Figure 3 shows three lines, the green line shows the change in weight, the blue line shows the change in heat flux, the brown line shows the change in the temperature difference.

There is no exothermic process in this picture. The decomposition process starts at temperatures above 210 °C.

Heat absorption, that is, an endothermic process occurs at a temperature difference of 166,4 °C, 394,4 °C.

And also the endothermic process in thermal molasses 166,7 °C, 396,8 °C, 471,2 °C, 514,6 °C, 766,8 °C showed. Temperature changes, distances from 190 – 600 °C decomposition decomposes, and part of the mass is lost, paraffin wax, polypropylene and stearic acid are removed.

Thermal effect from 160 – 200 °C distance, and from 354 – 410 °C distance goes. The weight loss of the sample during heating was about 8 %.

During the filament preparation process, the melting point was set to 190 °C. According to TGA analyzes, the melting process begins at about 170 °C. The composition of the material does not change, its composition remains 100 % unchanged. During the cooling process, the fan speed is set to 60 m/s. If the speed is increased, the filament changes its shape. Catamold 316L filament, very fragile and will break quickly. As a result of this work, a filament with a diameter of 1,75 mm was obtained.

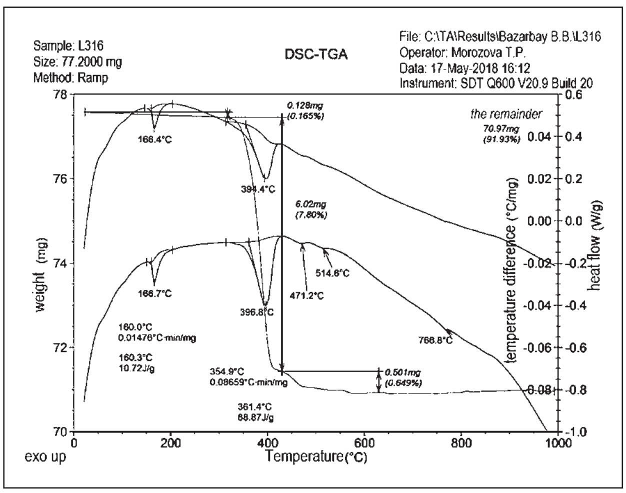

Figure 3 Result of DSC-TGA analysis

Conducting a 3D printing experiment

In this work, select the main parameters that strongly affect the printing. In the process of printing, these parameters: layer thickness, percentage of filling, speed, extruded width, the amount of supplied material changes the quality of the part.

With these parameters, 40 parts were obtained. During printing, one parameter was changed, and the rest remained unchanged. In order to determine on which parameter the process is influenced by printing. For this work, the layer thickness was changed from 0,3 mm to 0,9 mm, the filling percentage from 80 % to 100 %, and the speed from 10 mm/s to 20 mm / s, the extruded width from 0,6 mm to 1 mm, the amount of supplied material has been changed from 0,6 to 1.

Many types of defects were found after printing. This is due to overheating of the Catamold 316L, and does not have time to cool and deform, and take the wrong shape, it is printed in this mode, the extruded width is from 0,6 and the layer thickness is from 0,6, in this case, set the minimum layer print time – Figure 4.

During 3D printing, the supply of material from the extruder is constantly interrupted and occurs again. At the beginning of the filament feeding, unwanted effects in the form of bumps between the layers can creep and print 15 mm/s from this other small defect – Figure 5.

Streaks and scratches on the surface of finished prints. This can happen because a large amount of material is squeezed out of the extruder and during the movement it adheres to the surface of the print. The extruder touches the surface of the part and creates scratches. To solve these problems, in the first case, it is necessary to select the rollback of the filament, and in the second to set the rise of the extruder when moving it between the control points. The defect can be eliminated by finishing – Figure 6.

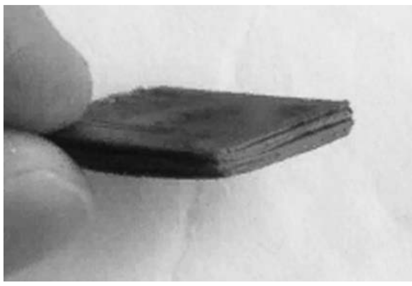

Figure 4 Detail №15

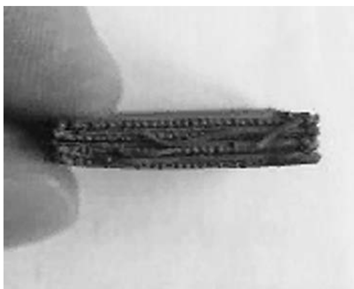

Figure 5 Detail №23

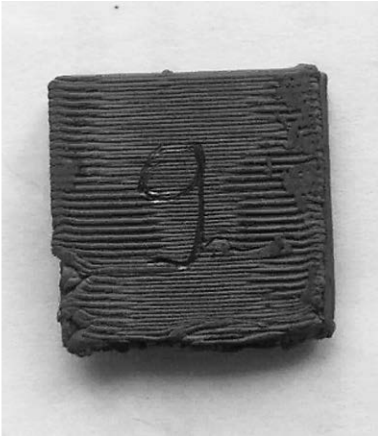

Figure 6 Detail №9

If the thickness of the layer, the speed of printing, the amount of supplied material is greater than many types of defects appear.

The main parameters at which the parts were obtained with good quality.

- Layer thickness: 0,6 mm
- Percentage of filling: 100 %
- Print speed: 25 mm/s
- Extruded width: 0,7 mm
- Amount of supplied material: 1

CONCLUSIONS

In this work, it has combined the two technologies FDM and MIM. From this work, it has been proven that it is possible to print complex parts using FDM technologies, using feedstocks used in MIM technologies as raw materials. The mechanical properties of the manufactured products are not inferior to this technology.

The products obtained after 3D printing, in the future, you can go through the stages of heat treatment traditional for MIM technologies:

Removal of polymer binder in specialized furnaces and sintering of finished products under vacuum conditions.

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