Extruder for the production of metal-polymer filament for additive technologies

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Abstract. In the process of performing the work, an extruder was designed for the manufacture of metal-polymer filament for additive technologies, of sufficient power, characterized in that it has a cooled screw, which allows to reduce the forces for mixing the mass, as well as a tungsten carbide coating, which has high wear resistance. The extruder will be loaded with a pre-prepared mixture consisting of polymer and metal powder.

1. Introduction

Over the past few years, the world has seen a sharp increase in publication activity in the field of FDM-printing with composite materials. Basically the authors try to solve two problems:

1. To find a cheap alternative to the Selective Laser Melting (SLM) technology, the cost of equipment for which starts from $ 1 million [1-6].

2. Printing of functional products from polymers modified with powders in order to give them special physical and mechanical properties, such as high hardness and wear resistance, electrical conductivity, photocatalytic properties, high tensile, compressive and bending strengths [7-13].

1.1. Printing metal products on FDM printers as a cheap alternative to SLM technology

Currently, Selective Laser Melting (SLM) is the only additive metal fabrication technology that is well established for industrial applications. The essence of this technology lies in the layer-by-layer fusion of metal powder with a high-power laser beam. The main disadvantage of this technology is the high cost of the equipment, which usually starts from $ 1 million. This problem constrains the development of metal 3D-printing. A promising direction is printing products from metal-polymer filaments on 3D printers which implement the Fused Deposition Modeling (FDM-printers). For printing, a filament which is a mixture of metal powder with a polymer that acts as a binder is used. After printing the product, the bonding element is removed from it thermally or chemically, and it is sintered in an oven. In this case, the product is reduced in volume by 15-20%. The implementation of this method is possible on inexpensive FDM printers, the cost of which is three orders of magnitude cheaper than SLM printers. The first experiments to test this technology began only in 2018, and at present, almost all of them are conducted on filaments from BASF, the line of which consists of only one material - Ultrafuse 316LX. At the same time, in the future, using this technology, it is possible to produce parts not only from steel, but also from non-ferrous alloys, hard alloys, ceramics, etc.
1.2. Printing of polymers modified with metal powders

The main purpose of modifying polymeric materials with metal powders is to impart special physical and mechanical properties to them, such as high hardness and wear resistance, electrical conductivity, photocatalytic properties, high tensile, compressive and bending strengths. All of the above significantly expands the spheres of using these materials as construction materials, among which the military and space industries, security systems, machine and instrument making, biomedicine, energy and electronics, aviation and automobile industries. As a rule, in all of these industries, great importance is attached to the weight of products, which everyone is trying to reduce. The use of modified polymers with low specific mass and not inferior in their performance indicators to metal analogs, significantly expands the design possibilities.

2. Purpose and tasks of work

The purpose of this work is the design and manufacture of an extruder for the manufacture of metal-polymer filament for FDM printing. Extruders for creating plastic filament exist, but they are of little use for the manufacture of metal-polymer filaments due to their low power and durability.

To achieve this goal, it is necessary to solve the following tasks.
1. To develop a technology for mixing polymer and powder materials
2. To design an extruder for filament production, to determine its main parameters of operation
3. To make an extruder.

3. Mixing filament components

Before making the filament, the metal powder and the binder granules must be thoroughly mixed. The mixture can be produced both in small batches and continuously. Mixing machines can be used for small batches. Suitable for large scale production z- and s-shaped mixers, single and twin screw extruders are used. Some ceramic powders are coated with stearic acid before mixing to improve homogeneity of mixture.

The twin-screw extruder prevents agglomeration and provides the greatest homogeneity due to high shear forces [1, 3, 5]. Also, this method provides the greatest roundness of the final powder.

The mixing temperature depends on the viscosity of the material. For more viscous materials, a higher temperature is required, for less viscous materials, a lower temperature. In work [5], the extruder consisted of 13 heating zones from 25°C to 210°C.

The final mixing step is to sift the powder to improve uniformity and remove agglomerates of the powder.

As part of the work, the authors carried out a series of preliminary experiments on mixing T5K10 hard alloy powder with ABS polymer. It was revealed that the greatest homogenization of the composition of the mixture is possible when mixing plastic and powder in a dissolved state. For this, the polymer was previously dissolved in solvent 646 (Fig. 1), after which a hard alloy powder was added to it. Mixing was carried out in a glass bottle, which was then placed for 5 minutes into the OTEC mini unit. Then the mixture was dried in an oven at a temperature of 85°C within 30 minutes.

Figure 1. Mixing components.
4. Design and manufacture of extruder

Since the filament is supposed to be extruded not from ordinary polymers, but from polymers mixed with metal powders, the first task was to determine the schematic diagram of the installation, as well as the form in which the mixture will enter the hopper. Initially, it was assumed to design a twin-screw extruder in which mixing of the mixture, softening of the polymer and further extrusion of the filament will take place. However, due to the fact that obtaining a homogeneous mixture composition in this case is very problematic, it was decided to separate the mixing process and the extrusion process.

During the experiments, it was decided to mix the polymer and powder as follows:

1. The polymer is poured into a flask and filled with a solvent in a certain proportion (depending on the material).
2. After that, the flask is placed in an OTEC mini unit and stirred to speed up the dissolution process.
3. After the polymer has dissolved, the required amount of metal or hard alloy powder is poured into the flask and the mixture is stirred again until full homogenization.
4. After that, the mixture is poured into a container and dried until the solvent has completely evaporated.
5. The dry residue is milled.

The resulting powder will be poured into the hopper of the extruder.

At the first design stage, the main geometric parameters of the screw and barrel were determined. It is assumed that the extrusion chamber will be divided into three zones: feeding, compression, dosing. The depths of the channels in each zone were determined, as well as the dimensions of each zone. The step of screws, the angle, and the thickness of the coil have been calculated. The maximum productivity of the extruder is preliminary calculated, which will be approximately 7.5 kg/h. The required screw speed and also the approximate torque have been calculated. Based on these data, a geared motor was selected that will drive the screw with the ability to adjust the speed using a frequency converter. Heating elements are selected (3 ceramic heaters for each zone and one for nozzle).

The main distinguishing feature of the designed extruder from the existing ones is the cooled screw design, which will avoid jamming the screw due to clogging of the channels with material.

Due to the fact that the extruder is designed for a filament consisting of polymer and metal powder, the screw must have increased wear resistance in order to avoid abrasion. To solve this problem, it is planned to apply a ceramic coating on it by a gas-flame method. As the basis for the winding system was used the system proposed in [14].

The main parameters of extruder:
- Screw diameter: \( D_s = 26 \text{ mm} \)
- Screw length \( L_s = 400 \text{ mm} \)
- Feeding zone length \( L_F = 0,25L = 0,25 \times 400 = 100 \text{ mm} \)
- Compression zone length \( L_P = 0,35L = 0,35 \times 400 = 140 \text{ mm} \)
- Dosing zone length \( L_d = 160 \text{ mm} \)
- Barrel diameter \( D_b = D_s + 2\delta = 26,26 \text{ mm} \)

where \( \delta \) is the clearance \( \delta = 0,005D_s = 0,13 \text{ mm} \)

Channel depth:
- In the feed zone \( h_1 \approx 0,12D = 3 \text{ mm} \)
- In the dosing zone \( h_3 \approx \frac{3}{4} \text{ compression ratio} = \frac{3}{4} = 0,75 \text{ mm} \)

Screw step: \( t \approx D_s = 26 \text{ mm} \)

Coil thickness: \( e \approx 0,1D = 2,6 \text{ mm} \)
A drawing of the designed extruder is shown in Figure 2.

Figure 2. Extruder drawing.

Currently, work is underway to manufacture an extruder (Figure 3) on the equipment of the Center for Collective Use "Engineering and Industrial Design " of the Sevastopol State University.
Figure 3. Extruder parts manufacturing.

5. Conclusions
An extruder was designed, which will make it possible to obtain metal-polymer filament for 3 D printers using FDM technology.

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