Influence of technological parameters of FDM-print on the strength characteristics of samples of polyamide

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Abstract: *The article presents the results of a study of the influence of technological parameters of FDM-printing of samples based on aliphatic polyamide on the deformation and strength characteristics of products based on it. The anomalous nature of the increase in the tensile strength during the destruction of samples obtained by increasing the print speed is shown. A decrease in the strength of the samples was noted with an increase in the number of simultaneously printed products. The main factor determining the strength characteristics of FDM products is interlayer autohesion. The need for the use of materials science solutions that contribute to an increase in interlayer interaction in products obtained by layer-by-layer deposition is indicated.*

Keywords: *FDM-PRINTING, NYLON, TECHNOLOGICAL PROPERTIES, STRENGTH*

1. Introduction

Rapid prototyping technologies are currently used to create working models of simple parts and aggregate mechanisms. Fused deposition technology (FDM), developed in 1992 by Scott Crump, is used in mechanical engineering. FDM prototyping technology uses three-dimensional objects, based on solid-state models created in computer-aided design software (CAD), to create products. Low strength of the finished product in combination with limited accuracy in shape and size is the main disadvantage of this printing technology [1]. The high level of residual thermal stresses that create subsequent deformation and shrink of the product is the main reason for this. The mechanical properties of the resulting product are anisotropic due to the layered and oriented method of guiding the consumable polymer. In addition, the seams between the layers in the product are noticeable, which affects the final roughness of the finished model. Of course, products made by the FDM method are inferior to the method of stereolithography in the accuracy of size and shape, but the FDM method has found wide application due to the low cost of manufacturing the product, as well as the comparative ease of handling a 3D printer in most design tasks [2]. The mathematical model of the product created in the CAD system is written in the stl-format, after which it is transferred to a special slicer program for controlling FDM technology. The program orientates the product, breaks it into horizontal sections (layers) and calculates the paths of movement of the print head. If necessary, supporting structures are automatically generated for overhanging fragments of the product.

ABS-plastics are the most popular 3D printing supplies. This polymer is odorless, non-toxic, melts at 220-240 ° C. The material has high dimensional stability. It is traditionally used for the manufacture of automobile parts, stationery, housings, household appliances, furniture, sanitary ware, as well as in the manufacture of toys, souvenirs, sports equipment, and medical equipment using injection molding technologies. Its main drawback is its sensitivity to ultraviolet rays and precipitation. To solve these problems and obtain parts with a high level of performance, filament manufacturers for FDM printers offer polyamide under the general trade name Nylon. For all the advantages of this material, one should also be aware of its shortcomings, which include: high hygroscopicity (up to 12 wt.%), sensitivity to print parameters (print speed and temperature, cooling mode, etc.).

It is known that one of the main factors determining the deformation-strength characteristics of polymer products obtained by the FDM technology of 3-dimensional printing is the nature of the interlayer auto-adhesion of the polymer. Interlayer autohesion is a type of adhesion that characterizes the interlayer interaction of surfaces of polymers homogeneous in chemical composition [3]. Autohesion determines the basic properties of a product, its strength and durability. Issues of autohesion are especially relevant in the manufacture of large-sized products and serial printing due to the significant temperature difference between successively applied polymer layers. Low autohesion combined with high shrink stresses cause warping, deformation and premature failure of 3D products. This is appeared when the temperature and speed parameters of printing are incorrectly selected most clearly [4]. The problems of autohesion of polymer layers in products obtained by FDM printing are currently poorly understood and consumers of polymer filament for 3D printing rely on the recommendations of manufacturers of equipment and supplies for printing. In [5], the authors found out the effect of 3D printing technological parameters on the interlayer interaction in semi-finished products based on ABS plastic and polylactide (PLA). In [5], the authors found out the effect of 3D printing technological parameters on the interlayer interaction in semi-finished products based on ABS plastic and polylactide (PLA) and established an increase in autohesion interaction with an increase in the contact temperature of polymer layers.

1. 2. Research methods

Establishing the influence of technological parameters of 3D printing of samples based on aliphatic polyamides, most often used as structural materials in the manufacture of engineering products, on the deformation-strength characteristics of the resulting products is the aim of this work. High deformation-strength (σs not less than 60 MPa) and tribotechnical characteristics (self-lubricating compositions) in combination with an acceptable cost are among the main advantages of these materials.

Polyamide 6 (PA6) from the manufacturer SANVIGOJ (China) in the state of delivery of the filament with a diameter of 1.75 mm was used as an object of study. Printing standard samples in the form of blades type 1 according to GOST 11262-80 in various settings of the 3D printer was performed for research. The 3D printer FlashForge Dreamer in combination with the «CraftWare 1.19» slayser-program, which provides the necessary print settings, was used to print standard samples. Previously, the polymer filament was subjected to temperature control in an oven at a temperature of 95 ± 5 ° C for 4 hours to reduce the moisture content of not more than 0.01 wt.%. The deformation-strength characteristics of the test samples were evaluated on a tensile testing machine RM-500 in the uniaxial tension mode at a speed of 50 mm / min with fixation of the strain and the corresponding tensile force. Printing of polymer blades in the established test modes was carried out in an amount of at least 5 sets for the reliability of the research results. The results were processed using mathematical statistics methods using the Microsoft Excel 2010 spreadsheet editor. Thermophysical processes that occur when a polymer filament based on polyamide 6 is heated were carried out on a Termoscan-2 derivatograph in the differential thermal analysis (DTA) mode when the test sample was heated in quartz crucibles in an air atmosphere at a rate of 5 ° C / min.

3. Results and discussions

DTA analysis of the studied polymer material showed a narrower range of the endothermic melting effect of PA6 (Fig. 1) in the range of 240-270 ° C in comparison with the recommended printing temperature range of the studied filament in the range of 240-270 ° C.

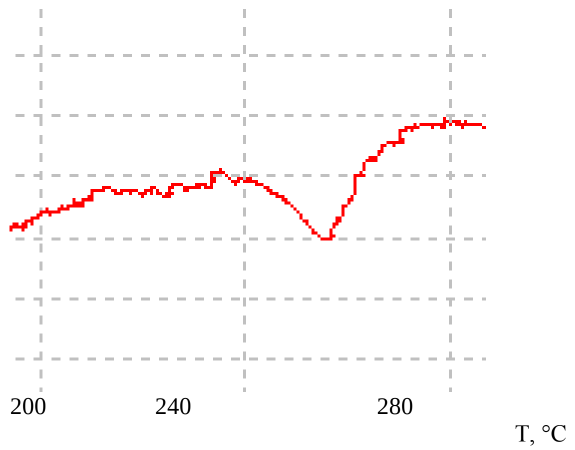

Fig. 1 *Fragment of a thermogram DTA filament Nylon SANVIGOJ (PRC)*

To achieve satisfactory results of 3D printing of products based on polyamides, it is recommended not to exceed the temperature of the heating of the print table above 70 ± 3 ° C. In addition, to avoid warping and peeling in this work, a coating based on polyvinylpyrrolidone (PVP) was used as an adhesive for printed products. In this case, the residual traces of PVP coating on the back side of the printed samples did not significantly affect their strength characteristics due to the high fragility of the adhesive [6]. The influence of the print temperature of the samples was studied at a print speed of 40 mm / s and a print layer height of 200 µm using a mesh structure to fill the sample volume and its location at an angle of 45 ° to the axis of extension of standard blades. It was shown that an increase in the print temperature of samples within 240–265 ° C leads to an increase in the tensile strength (Fig. 2), which is consistent with the conclusions of the authors of [5]. In this case, 260 ° C should be considered the optimum printing temperature, since a subsequent increase in temperature leads to an increase in the level of internal stresses, which in turn is due to an increase in the temperature gradient between the applied and the previous polymer layer. This assumption is supported by the fact that the relative elongation during fracture of the samples does not exceed 5%.

It is generally accepted among users of FDM printing technology that the minimum print speed (less than 20 mm/s) combined with the minimum print layer thickness (less than 100 microns) allows to achieve high accuracy in the dimensions and geometry of the product. However, it was shown in [7] that the strength characteristics of various grades of polyamides reach their maximum values when the thickness of the printed layer increases to a value corresponding to the diameter of the nozzle of the printing extruder. In addition, the influence of the extrusion rate on the autohesion processes of interlayer interaction in the process of FDM printing should be taken into account. Thus, a study of the effect of print speed on the strength characteristics of standard samples based on PA6 (Fig. 3) indicates the need for additional studies to explain the nature of the established dependence.

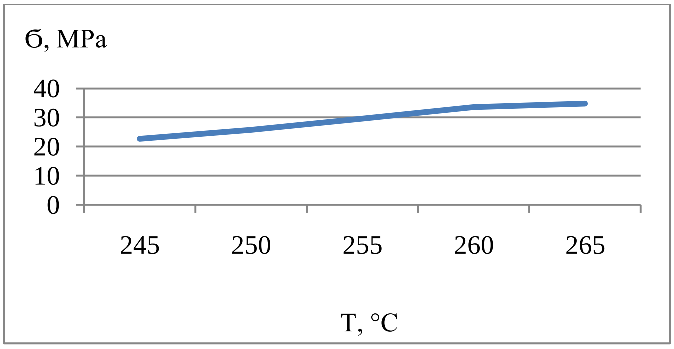

Fig. 2 *- Dependence of the uniaxial tensile strength of samples based on PA6 obtained by FDM printing technology, on the print temperature*

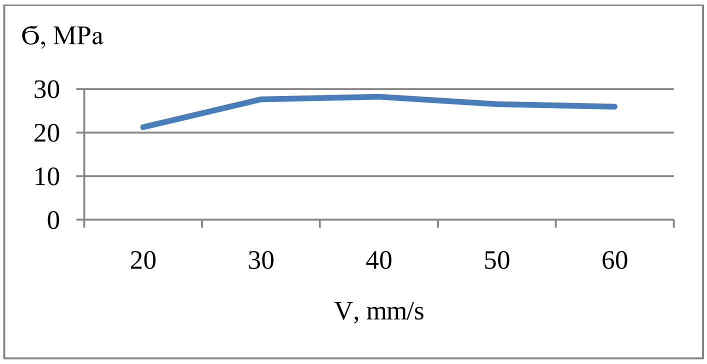

Fig. 3 *– Dependence of the uniaxial tensile strength of samples based on PA6 obtained by FDM printing technology, on the print speed*

It can be assumed that the strength characteristics of polymer products based on PA6 obtained by FDM technology are also dependent on their size (the area of the printed layers).

To evaluate this assumption, standard samples were printed in the form of Type 1 blades with a circulation of 1 to 5 products printed simultaneously in layers. It should be noted that an increase in the time of subsequent overlapping of the printed layer with PA6 melt at a printing speed of 40 mm / s over 200 s (Fig. 4, circulation of 3 products or more) leads to a noticeable decrease in the tensile strength of the samples. This, in turn, also requires a detailed examination of the identified dependence.

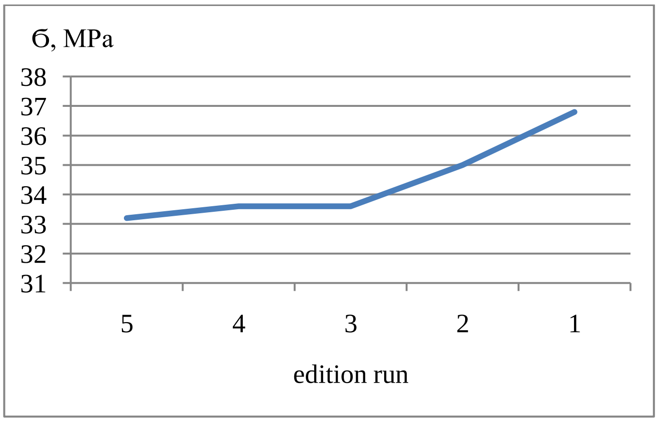

Fig. 4. *Dependence of uniaxial tensile strength of samples based on PA6 obtained by FDM printing technology on the number of simultaneously printed products*

4. Conclusion

To increase interfacial interaction in polymer composite systems, the facts of the effective use of finely dispersed detonation-carbon synthesis modifiers are known [8], which provide an increase in impact strength (at least 30%) when their content is in the range of 0.05–0.1 mass%. In addition, the introduction of compatibilizers into the composition of thermodynamically incompatible mixtures of the "polyamide-polyolefin" type provides an optimal combination of the deformation-strength and technological characteristics of composites based on aliphatic polyamides. Obviously, the solution to the problems of using polyamide filament to obtain high-quality products using FDM technology should be carried out with the involvement of voiced experience. The use of a copolymer of ethylene and vinyl acetate (SEVA) in amounts of 5..10 wt.% to increase the compatibility of PA6-HDPE mixtures does not provide the expected compatibilizing effect due to the course of oxidation processes characteristic of SEVA at temperatures above 150 ° C and requires additional administration thermostabilizers [10].

Thus, when determining the technological parameters of 3D printing of polymer products using FDM technology, it should be taken into account that engineering products based on PA6 along with accuracy criteria also require taking into account the manifestation of interlayer autohesion, the nature of which is determined by various printing parameters, the main of which are print temperature , print layer thickness and printable area.

5. References

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