Additive technologies for prototyping. Control of geometrical characteristics of abs plastic details for determining the original print sizes

A V Tignibidin, S V Takayuk
Omsk State Technical University, 11 Mira Ave., Omsk, 644050, Russia
E-mail: takayuks@mail.ru

Abstract. Plastics of various types, such as ABS, PLA, etc. are used to create prototypes of parts by the method of layer-by-layer deposition (FDM). The low cost of these plastics determines the relevance of using this type of prototyping when developing models. One of the main problems with the use of 3D printing is plastic shrinkage when using heating platforms. The article presents the results of the study of the “Cube” detail after different printing modes to determine the most preferable mode when using universal ABS plastic. For the production of products with high requirements to the geometric characteristics, recommendations on making changes in dimensions at the stage of modeling parts are proposed, which allows us to eliminate the problem of material shrinkage.

1. Introduction
Every day there is an improvement in digital technologies, which allows the use of innovations in various areas of production. At the moment, in many areas of high-tech production, humanity begins to rest on the ceiling of the technical capabilities of traditional materials processing methods. The introduction of innovative methods of prototyping and production, such as 3D printing, allows you to step over these barriers and implement the most daring ideas of designers and scientists. Additive technologies are among the most advanced and sought after in the world. Additive technologies is the layer-by-layer building up and synthesis of an object using computer 3d technologies. In modern industry, these are several different processes, as a result of which a 3d object is modeled. Technological progress contributes to the production of many useful things for human life, health and safety, for example, additive technologies in aircraft industry help to create a more economical and light weight air transport, while its aerodynamic properties are preserved in full.

The main directions of development of mechanical engineering at present are: the use of new polymeric, composite, intellectual materials in the production of machine parts; development of new technological methods, equipment and manufacturing processes for engineering products. The first step towards the creation of the machine is the spatial design of engineering products using computer virtual digital three-dimensional models, which was made possible by the introduction of modern software (CAD programs), modeling and calculations (CAE). The introduction of the technology of "three-dimensional printing" (3D printing) provides the ability to create parts of a machine or product as a whole based on the developed 3D model in the shortest possible time and with minimal loss of materials. In this context, traditional engineering technology based on the machining of the workpiece, in which part of the material is removed (turning, milling), is “subtractive”. The main advantages of additive technologies over traditional ones are:
• reducing the complexity of manufacturing;
• reduction of terms of design and manufacture of parts;
• cost reduction of designing and manufacturing parts;
• saving engineering materials.

Modeling the process of 3D printing with the indication of various methods is presented in the study A. A. ElistratovaV. [1], however, there are no precise guidelines for working with plastics of various types.

As noted in the work of Bustillo, [5] the need to use shrinkage allowances also exists for other methods. According to the authors Artioli ,. [3] such calculations should be carried out including for silicone, in the manufacture of prostheses. A study by Arruda, [4]. Demonstrates that using a different type of printer does not solve this problem..

2. Task definition

Fast prototyping determines the creation of a prototype in the shortest possible time. This is one of the main applications of additive technologies in production. A prototype is a prototype of a product, which is necessary to optimize the shape of a part, evaluate its ergonomics, check the possibility of assembly and correct layout solutions. Therefore, reducing the time of manufacture of parts, it is possible to minimize the assembly time. Also, the prototype is a model designed for testing or testing functionality. Low-cost 3D printers are used for rapid prototyping. To estimate the necessary allowances for thermal shrinkage of the material in the simulation of prototypes with ABS plastic, 18 experiments were carried out with different modes of material extrusion and different maximum heating of the printing platform. As part of this work, the material shrinkage rate was calculated, and the optimum mode for printing with ABS plastic was chosen experimentally. The object of study was a cube with 16 mm edges.

3. Experiment

At its core, 3D printing processes consist of three steps: the formation of cross sections of the object being manufactured, the layering of these sections, and the combination of layers. Thus, in order to create a physical object, these processes only require data on cross sections; In addition, the following problems often occur in connection with other manufacturing processes.

In the international community, as well as in Russia, the established classification of additive technologies is currently not accepted. One of the classifications shares the types of technology for 3D printing. One of the most common is extrusion printing. It includes methods such as layer fusion (fdm) and multi-jet printing (mjm). The basis of this method is the extrusion (extrusion) of consumables with the sequential formation of the finished product. As a rule, consumables consist of thermoplastics or composite materials based on them.

The production cycle begins with the processing of a three-dimensional digital model. The model in the STL format is divided into layers and is oriented in the most appropriate way for printing. If necessary, support structures are generated that are necessary for printing overhanging elements. Some devices allow the use of different materials during one production cycle. For example, it is possible to print a model from one material with a seal of supports from another, easily soluble material, which makes it easy to remove supporting structures after the printing process is completed. Alternatively, it is possible to print in different colours the same kind of plastic when creating a single model.

The product is made by extruding and applying microdrops of molten thermoplastic with the formation of successive layers, solidifying immediately after extrusion.

The plastic thread is unwound from the spool and melted in an extruder — a device equipped with a mechanical drive for feeding the thread, a heating element for melting the material and a nozzle through which extrusion is carried out directly. The heating element serves to heat the nozzle, which in turn melts the plastic thread and delivers the molten material to the model under construction. As a rule, the upper part of the nozzle, on the contrary, is cooled with the help of a fan to create a sharp temperature gradient necessary to ensure a smooth flow of material. The diameter of the nozzle can vary from micrometer to centimeter and is chosen for the model of the extruder and the necessary detailing of the product.
The extruder moves in the horizontal and vertical planes under the control of algorithms similar to those used in machine tools with numerical control. The nozzle moves along the path defined by the computer-aided design (CAD) system. The model is built layer by layer, bottom to top. Typically, an extruder (also called a “printhead”) is driven by step motors or servo drives. The most popular coordinate system used in FDM is the Cartesian system, built on a rectangular three-dimensional space with X, Y, and Z axes.

FDM technology is highly flexible, but has certain limitations. Although the creation of overhanging structures is possible with small angles of inclination, in the case of large angles, it is necessary to use artificial supports, usually created in the process of printing and detachable from the model upon completion of the process.

All kinds of thermoplastics and composites are available as consumables, including ABS, PLA, polycarbonates, polyamides, polystyrene, lignin, and many others. As a rule, various materials provide a choice of balance between certain strength and temperature characteristics. The fusion fusion modeling (FDM) is used for rapid prototyping and fast production. Rapid prototyping facilitates retesting with consistent, step-by-step object upgrades. Fast production serves as an inexpensive alternative to standard methods for creating small-scale batches. Among the materials used are ABS, polyphenylsulfone, polycarbonate and polyetherimide. These materials are appreciated for heat resistance. Some variants of polyetherimide, in particular, are highly refractory, which makes them suitable for use in the aerospace industry.

4. Experimental results
To select the desired mode for prototyping and conducting an experimental calculation of the shrinkage of the material, 18 experiments were conducted. For the experiments, a cube model was selected (Fig. 2) with 16 mm edges with non-through holes to determine the effect of temperature on the print object details.
For the study, various temperatures were chosen for the extruder and the heating platform. The speed of the print, the operator, the type of plastic, the printing program and the 3D printer remain constant during the experiments. The print speed was chosen from the recommended for this plastic and is 100 mm / min. Filling volume 20% using Honeycomb filling technology. Prusa i3 Steel 3D printer and Repetier Host program were used for printing (Fig. 3).

The minimum extrusion temperature was chosen as the minimum recommended temperature of 180 degrees Celsius, the minimum temperature of the heating platform was experimentally chosen to be 70 degrees Celsius. The maximum extrusion temperature was chosen empirically temperature of 230 degrees Celsius. The maximum platform temperature was chosen as high as possible for the 3D printer used. As a result, 18 objects were printed (Fig. 4).

Successful is the experiment where printing is completed 100% automatically. Total of 18 experiments 9 can be considered successful, which is 50% of the total number of experiments. Controlled by the parameters of the cubes (Fig. 5) we take the length (l1), width (l2) and height (l3). Using the Sylvac MOD S 235 digital caliper and the VMM 150 instrument microscope with serial number 1610001, produced by Walter Uhl technische Mikroskopie GmbH & Co, we will measure the required parameters.
Figure 5. Designation of monitored parameters.

Table 1. The dependence of the length (l1) of the temperature mode (mm).

| Temperature (°C) | 70 °C | 80 °C | 90 °C |
|-----------------|-------|-------|-------|
| 180°C           | 3.6   | 10.2  | 15.45 |
| 190°C           | 0     | 4.26  | 15.41 |
| 200°C           | 0     | 13.01 | 15.55 |
| 210°C           | 0     | 15.31 | 15.83 |
| 220°C           | 15.54 | 15.54 | 15.46 |
| 230°C           | 15.7  | 15.63 | 15.68 |

Table 2. The dependence of the width (l2) of the temperature mode (mm).

| Temperature (°C) | 70 °C  | 80 °C  | 90 °C  |
|-----------------|--------|--------|--------|
| 180°C           | 1.83   | 14.92  | 14.91  |
| 190°C           | 20.87  | 14.79  | 15.24  |
| 200°C           | 16.03  | 14.94  | 15.56  |
| 210°C           | 16.65  | 14.97  | 15.76  |
| 220°C           | 14.92  | 15.2   | 15.68  |
| 230°C           | 14.68  | 15.21  | 15.47  |

Table 3. The dependence of the height (l3) of the temperature mode (mm).

| Temperature (°C) | 70 °C | 80 °C | 90 °C |
|-----------------|-------|-------|-------|
| 180°C           | 1.6   | 10.2  | 15.4  |
| 190°C           | 0.8   | 4.26  | 15.42 |
| 200°C           | 0.8   | 13.01 | 15.56 |
| 210°C           | 0.76  | 15.31 | 15.91 |
| 220°C           | 3.48  | 15.54 | 15.78 |
| 230°C           | 4.1   | 15.63 | 15.47 |

When analyzing the obtained data, it was found that the values of the monitored parameters that are closest to the model are observed when using the printing mode with an extrusion temperature of 210 °C.
C with a platform heating to 90 ° C. These parameters must be used when calculating the thermal expansion coefficient. The coefficient of thermal expansion is a physical quantity that characterizes the change in the linear dimensions of a solid with increasing or decreasing its temperature. Denote the length of the body at the initial (for example, heating temperature of the material in the extruder) temperature \( t \) by the letter \( l \), and the length of the same body at temperature \( t' \) by the letter \( l' \). The elongation of the body when heated \((t' - t)\) is equal to \((l' - l)\). The elongation of the same body when heated by 1º C will be \((t' - t)\) times smaller, i.e. it will be \((l' - l) / (t' - t)\). This is the total elongation of the whole body; it is the larger, the longer the body. The tabular coefficient of expansion of ABS plastic is 0.86, therefore, according to the theory, plastic should shrink by \((1 - 0.86) \times 100\% = 0.14 \times 100 = 14\%\). However, thermal processes occurring with plastic at the time of printing are difficult to calculate, many factors affect the printing process, such as printing time, extraneous thermal effects on the print object and the device itself, etc. After analyzing the conclusions of Romanov [6], Sun [8] and Wang [9], we take it as the initial one, that the process proceeds equally in the planes \( l_1, l_2, l_3 \) at the recommended printing speed.

To determine the actual coefficient of shrinkage of the material, it is necessary to find the average value of the edges of the cube when using the optimal mode:

\[
\text{lav} = \left( \frac{15.83 + 15.76 + 15.91}{3} \right) = 15.83 \text{ mm}.
\]

For ABS plastic when printing on a Prusa i3 Steel printer material shrinkage ratio:

\[
\text{Cous} = \frac{15.83}{16} = 0.9893 \text{ or } 98.93\%,
\]

which in practice means that the shrinkage of the material is \((100 - 98.93) = 1.07\%\) with a correctly selected optimal mode.

5. Results and discussion

To obtain the required geometrical parameters of products, it is necessary to make a correction of 1.07% during modeling. To test this hypothesis, an amendment was made to the selected “cube” model, the size of the cube ribs was 16.01712 mm, and the corrected model was 3D-printed.

When printing a fixed model with an extrusion mode of 210 ° C and heating the platform to 90 ° C, the edge values were:

| Parameter values after editing (mm). |
|--------------------------------------|
| l1        | l2      | l3      |
| 16.01     | 15.98   | 15.99   |

The average value of the cube printed with the corrections was calculated:

\[
\text{lsr} = \left( \frac{15.99 + 15.98 + 16.01}{3} \right) = 15.99 \text{ mm}., \text{ which is } 0.16 \text{ mm. more than the average value calculated without edits.}
\]

6. Summary and conclusion

In the course of the work, the ABS shrinkage coefficient was calculated during printing, which allows you to make changes directly in the process of modeling the part, while achieving the necessary geometric characteristics of the product. These calculations were verified experimentally and confirmed, however, for the most efficient printing, calculations are needed for other types of plastic with the selection of the optimal mode. From the data obtained during the study of the shrinkage of the material, it follows that it is necessary to leave allowances for processing the product after printing using an engraver. Thus, to obtain the required geometry of parts, further study of this process is necessary.

7. References

[1] Elistratova A A, Korshakevich I S 2015 3d-printing technologies: advantages and disadvantages p 720

[2] Atonal-Sánchez J, Beltrán-Fernández JA, Hernández-Gómez LH, López-Lievano A and Moreno-Garibaldi 2019 Termomechanical analysis of 3D printing specimens (Acrylonitrile
Butadiene Styrene) Engineering Design Applications. Advanced Structured Materials vol 92 pp 237-253

[3] Artioli, BO, Kunkel, ME, Mestanza, SN Feasibility study of a methodology using additive manufacture to produce silicone ear prosthese 2019 IFMME Proceedings vol 68(3) pp 211-215

[4] Arruda, LM, Carvalho, H 3D 2018 printing as a design tool for wearables: case study of a printed glove Southampton Lecture Notes in Electrical Engineering vol 505 pp 192-198

[5] Bustillo, JP, Tumlos, R, Remoto, RZ, H 2019 Intensity modulated radiotherapy (IMRT) phantom fabrication using fused deposition modeling (FDM) 3D printing technique IFMME Proceedings vol 68(3) pp 509-515

[6] Romanov V, Samuel R, Chaharlang M, Frost A and Gale B K 2018 FDM 3D Printing of High-Pressure, Heat-Resistant, Transparent Microfluidic Devices Analytical Chemistry vol 90(17) pp 10450-10456

[7] Yang T-C 2018 Effect of extrusion temperature on the physico-mechanical properties of unidirectional wood fiber-reinforced polylactic acid composite (WFRPC) components using fused deposition modeling Polymers vol 10(9) pp976

[8] Sun, Q, Rizvi, G M, Bellehumeur, C T, Gu, P 2008 Effect of processing conditions on the bonding quality of FDM polymer filaments Rapid Prototyping Journal vol 14(2) pp 72-80

[9] Wang, T-M, Xi, J-T, Jin, Y A model research for prototype warp deformation in the FDM process 2007 International Journal of Advanced Manufacturing Technology 33(11-12) pp 1087-1096

[10] Zhang Y, Chou K A2008 Parametric study of part distortions in fused deposition modelling using three-dimensional finite element analysis Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture vol 222(8) pp 959-967