Journal of Manufacturing Engineering, September 2024, Vol. 19, Issue. 3, pp 082-088
DOI: https://doi.org/10.37255/jme.v19i3pp082-088

SME
ESTD 2005

SLICING ON THE TESSELLATED MODEL FOR THE 3D PRINTING PROCESS BASED ON THE VARIABLE THICKNESS LAYERS

***Samrat hazra, Gourab Ganguly, and Subhajit Chattopadhyay**

[1]Department National Institute of Technical Teachers Training and Research, Kolkata, West Bengal-700106, India

Abstract

Additive Manufacturing (AM) is a modern technology that enhances manufacturing by building thin layers of material from digitized (3D) designs, entirely constructed using advanced CAD software. This method facilitates the creation of new types of objects with unique material properties. However, while AM is often hailed as the next industrial revolution, significant challenges remain for its successful commercialization. This project focuses on the microstructural aspects and the dimensional accuracy of the product. Additionally, the paper discusses the slicing algorithm and the material extrusion process in detail.

Keywords: *Additive Manufacturing (AM), CAD, 3D Printing and Slicing.*

1. Introduction

Additive Manufacturing (AM), or rapid prototyping (RP) or 3D printing, was initially developed for building prototypes from digital models. However, it is now used for many other purposes due to improvements in the build quality of the machines [1]. Consequently, large-scale production of products is now possible directly through AM technology. The fundamental principle of this technology is to build components by adding material layer by layer. Each layer represents a cross-section of the part at a certain height. These cross-sections are obtained by slicing the CAD model with a specified thickness.

The AM process consists of several steps that convert the CAD model into the final part. First, a 3D model is created using SolidWorks software and translated into the STL format. The model is sliced into layers, generating a toolpath for each layer. Afterward, the toolpath is sent to the machine, where the part is fabricated layer by layer [2]. Finally, post-processing steps such as removing support material, sanding, and gluing are often necessary, depending on the material and the type of machine used. This typical AM process is illustrated in Fig. 1. The steps shown in the blue dotted field are the focus of this research [1].

The two main categories of cutting techniques for slicing a digital model into layers are STL-based and direct slicing, as determined by the gathered data [3]. Although direct slicing naturally generates more unique paths directly from the 3D model, STL-based cutting is more relevant for most use cases. The STL file structure is the most commonly used format. Therefore, due to its universality, this discussion is centered on the STL-based cutting method.

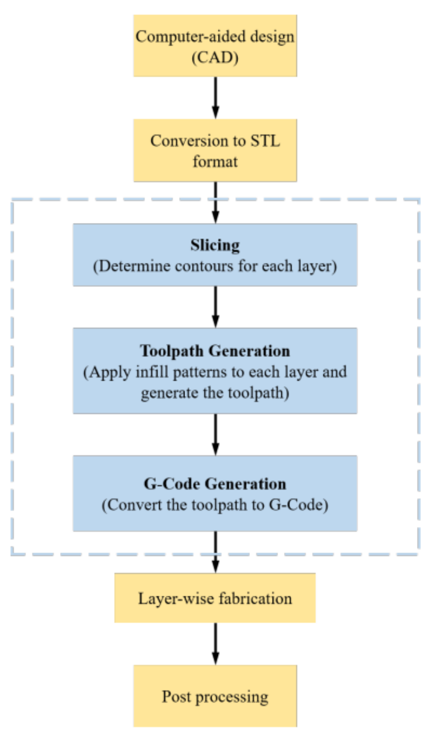

Fig. 1 A Basic Additive Manufacturing System

**Corresponding Author - E- mail: samrathazra.2013@gmail.com*

Journal of Manufacturing Engineering, September 2024, Vol. 19, Issue. 3, pp 082-088
DOI: https://doi.org/10.37255/jme.v19i3pp082-088

1.1. Opportunities

i. Prototyping and launching in the market as soon as possible.
ii. Innovation.
iii. Business cases to rapid application.

1.2. Costs savings

i. It's much more effective to use AM-built aerospace parts.
ii. AM of metal parts, combined with part redesign, can show drastic cost savings.
iii. The field considers the implication of electricity consumption in AM production as a cost savings component.

1.3. Challenges

There are various challenges in the global adoption of AM [4]:

i. Attraction towards conventional manufacturing.
ii. Economic difficulties.
iii. Intellectual Property.
iv. Educational Relevance.
v. Materials capacity.

2. Literature Review

The present project reviews recent trends in additive manufacturing strategies and their applications. It also discusses the various materials used for additive manufacturing, such as ceramics, polymers, composites, and biomaterials [5]. The survey highlights that fused deposition modeling has garnered significant attention from researchers. Additionally, some gaps in the literature are identified and reported.

More attention should be paid to non-planar slicing, course planning on curved surfaces, multi-degree-of-freedom (DOF) additive manufacturing equipment [6], and printing under pressure. Therefore, a comprehensive understanding of the current status and challenges is crucial. With appropriate technologies, it is possible to achieve printed components with enhanced surface quality, reduced support structures, and improved isotropy. Finally, recommendations for future improvements in slicing and course planning are provided.

2.1. Objective

i. To develop and evaluate a slicing algorithm for tessellated models to reduce the geometrical error caused by the stair-step effect in the final part.
ii. To realize a path planning and G-Code generation system for converting the STL model into the final part.
iii. To assess the dimensional accuracy of the product.
iv. To study the microstructure of a 3D-printed product.

3. Materials and Experimental Methodology

3.1. STL File Format

In 3D printing technology, objects are constructed layer by layer. The ideal format for cost savings in this process would be a series of polygons with heights corresponding to their z-values or a collection of meshed surfaces representing each layer [7]. However, objects can be sliced with specific layer thicknesses to achieve extraordinary build speeds and precision. Therefore, it is more practical to characterize the model in a format that accommodates all possible slicing techniques. An example of an STL model is illustrated in the figure below. The STL file format encodes the surface geometry of a 3D model using tessellation, as shown in Fig. 2(a). This format tessellates the surface with unordered triangular patches.

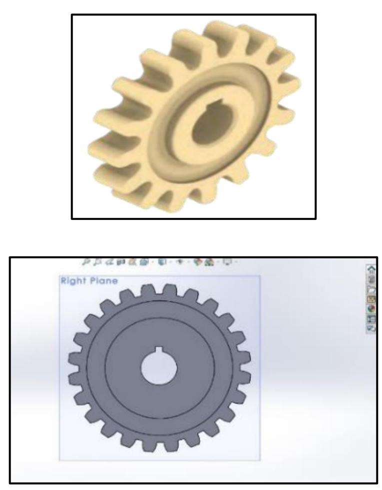

Fig. 2 (a) Spur gear of STL model, (b) Spur Gear model designed in solid Works.

Journal of Manufacturing Engineering, September 2024, Vol. 19, Issue. 3, pp 082-088
DOI: https://doi.org/10.37255/jme.v19i3pp082-088

Table 1 Dimensional difference between Input and output

Sl. No	Input Dimension (mm)	Output Dimension (mm)
1	2	1.340
2	10	7.321
3	2.66	1.621

We have designed the same spur gear in the Solid Works software to check its proper Dimensions. Fig 2(b) shows the model developed using Solid Works software. The studies state a clear difference between the input and output dimensions, the primary final product dimension, shown in Table. 1.

3.2. Cura Model of Spur Gear

Now, we have constructed the product with the algorithm in the CURA Software, where we will compare the starting and End phases of the simulation. Fig 3(a) and (b) below show the variation of the simulations done in the Cura software.

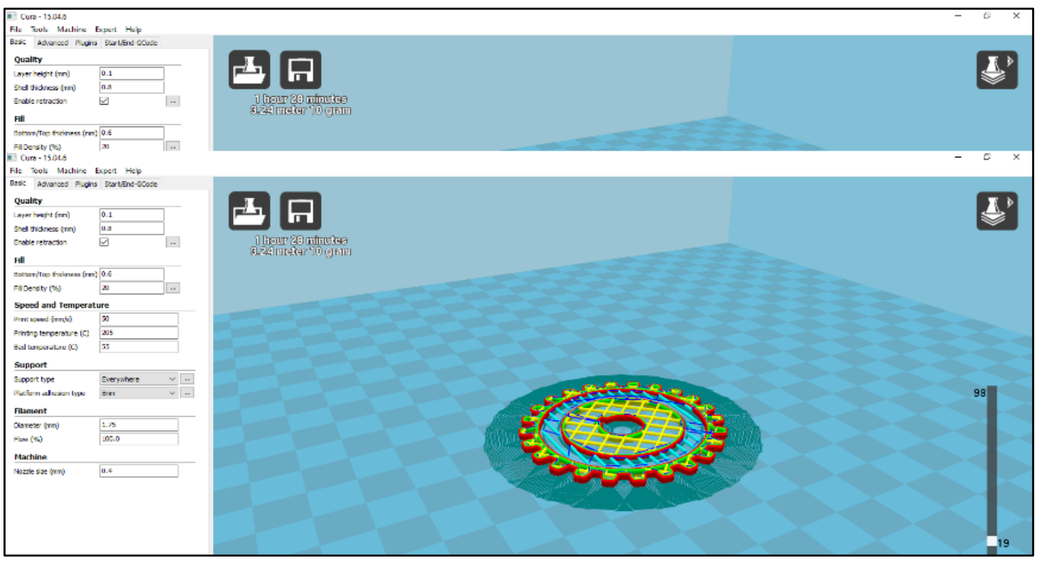

Fig. 3 (a) Early Stage of simulation in the CURA

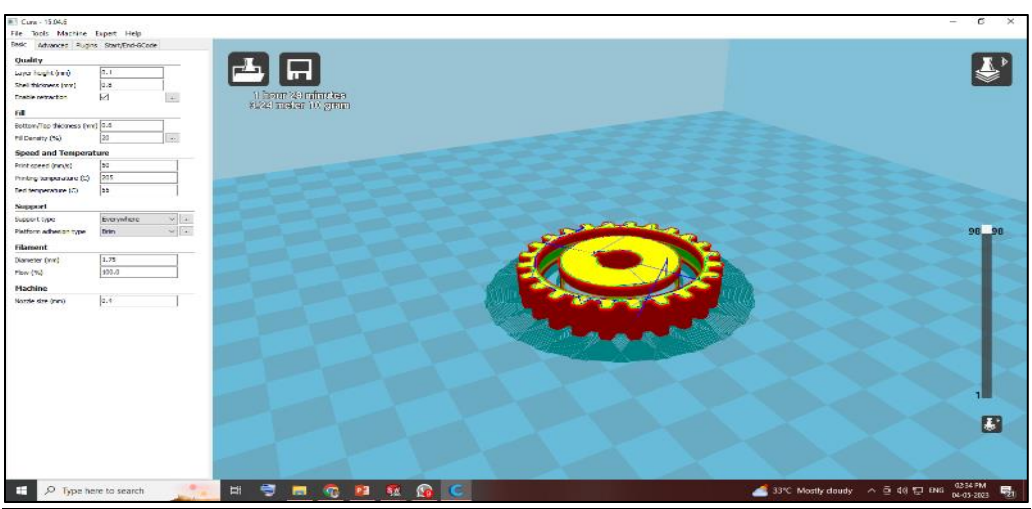

Fig. 3 (b) Final Stage of simulation in the CURA

Journal of Manufacturing Engineering, September 2024, Vol. 19, Issue. 3, pp 082-088
DOI: https://doi.org/10.37255/jme.v19i3pp082-088

3.3. Slicing Algorithms

Once the tessellated model is formatted into STL files, it is prepared for slicing into a series of layers. This process involves reducing the 3D model using a series of planes at regular heights and then modifying these layers to align with the path the 3D printer's extruder will follow. Due to the stacking of flat layers, the printed object will exhibit a stair-step effect. Meanwhile, thinner layers can minimize geometric inaccuracies, leading to longer print times [8]. Adaptive cutting was initially developed to reduce the stair-step effect without significantly increasing print time. Although adaptive cutting can create surfaces within a specific tolerance, it does not eliminate the stair-step effect. To address this issue, numerous researchers have proposed curved layer cutting. Various techniques to offset the top surfaces have been developed and evaluated. The algorithms used in the following product development are detailed in Annexure 1.

4. Results and Discussion

4.1. Stair-Step Effect

The stair-step effect, inherent to the uniform slicing process, arises due to the stepped edges. There are two types of stairs: outside and inside stepped edges, as illustrated in Figure 1. In this representation, the contour of the layer edges is considered squared. The presence of the stair-step effect is a significant concern for prototype quality. Reducing the layer thickness can improve the surface finish but at the expense of a longer build time [9]. Figure 4 illustrates the inside uniform slicing process of the stair-stepped edge of a spur gear.

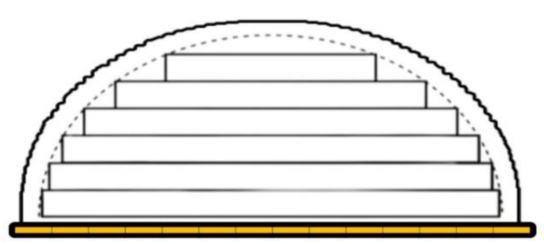

Fig. 4 Stair Stepped edge of Spur Gear

4.2. Material Extrusion

Fused deposition modeling (FDM) is a standard cloth extrusion technique in which fabric is drawn through a nozzle, as shown in Fig. 5. The place is heated and deposited layer by layer using the capability of the layer. The nozzle can pass horizontally, and the platform strikes up and down vertically after each new layer is deposited [10]. FDM is an in many situations used approach used by many inexpensive, domestic, and hobby 3D printers. The system has many factors that affect the remaining model but has brilliant plausibility and viability when these elements are suitably controlled. While FDM is like all other 3D printing processes, as it builds layers with the aid of way of layer [11], it varies in the truth that material is added via a nozzle under constant stress and in a non-stop stream. This strain needs to be stored steadily and at a continuous pace to allow accurate results. After the final deposition process is done, we collect the finished job, which is shown in Fig.6.

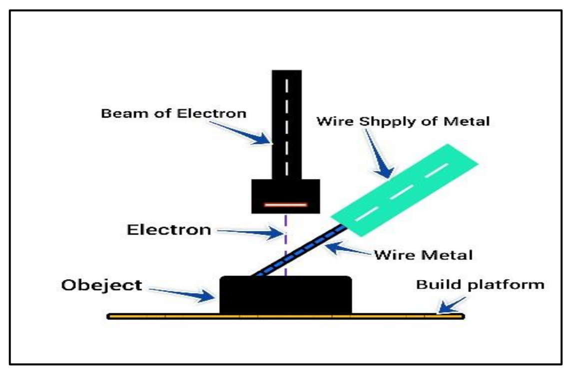

Fig. 5 Metal Extrusion process

Fig. 6 Final Prepared Job.

4.3. Microstructure in 3D printing

Generally, we check the microstructure States of the 3D printing product for the location of the thickness of every strut scale of tens of microns starting from 0.2mm to 0.5mm; it has the advantage quintessential to alternate the mechanical properties of objects (met materials) [12] such as elasticity, resistance, and hardness. In other words, It was done to allow the object

Journal of Manufacturing Engineering, September 2024, Vol. 19, Issue. 3, pp 082-088
DOI: https://doi.org/10.37255/jme.v19i3pp082-088

to become flexible and lighter. The sample has to adhere to the geometric constraints (shape regulations) and thickness constraints (minimum thickness control), or it can be done by the mechanical optimization process (microstructure form and topological optimization) [13]. The new thing that has evolved in this technology is to determine the build and maintenance of 3D printers and steps towards research to make specialized mechanical properties. Fig 7. shows the Different Layers of Slicing on the Toolmaker Microscope.

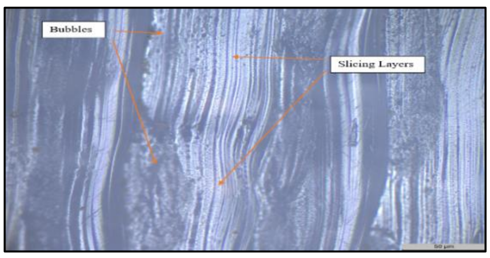

Fig. 7 Different Layers of Slicing Shown in Tool Maker's Microscope

As we can see in the given picture, Bubbles are inside the layers of the job, which led to the surface roughness and lousy surface finish. It also creates an excess gap between two Slicing layers and even makes the layer Thicker than the other layers. Excess Bubbles make the Layer hollow from the inside, which impacts the Stress and reduces the Stiffness at a particular point.

4.4. Dimensional accuracy of the product

Dimensional accuracy in 3D printing refers to how cautiously the measurements in your CAD structure suit the section as quickly as it is printed. (14). Many factors can positively (or adversely) affect the dimensional accuracy of your 3D printed parts, such as the gorgeous of the filament material, thermal contraction, or over- or under-extrusion, usually in FDM. As shown in Table, the studies state a clear difference between the input and output dimensions, the primary final product dimension. 1.

Table 1 Dimensional difference between Input and output

Sl. No	Input dimension (mm)	Output dimension (mm)
1	2	1.340
2	10	7.321
3	2.66	1.621

By the above graph [Fig. 8] we can identify the exact variation between the input and output dimensions.

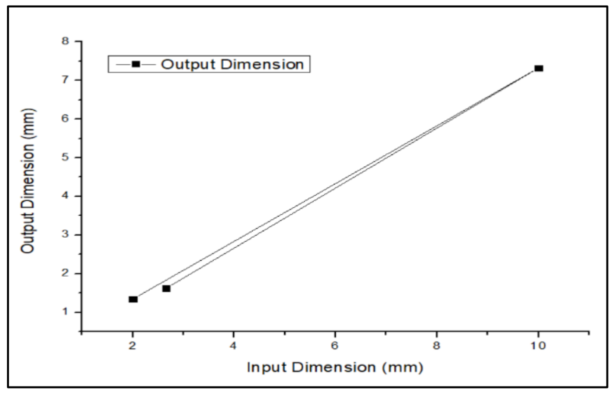

Fig. 8 Diagram between Output dimension and Input dimension

Many elements can positively (or adversely) affect the dimensional accuracy of your 3D printed parts, inclusive of the fine of your filament (15), thermal contraction, and over- or under-extrusion (for FDM specifically). Other factors, such as the first-class machine, computer calibration, high-quality resin, and post-processing, can also influence the dimensional accuracy of your parts. (16).In Fig, 9. It shows the exact dimensions we developed during product design on the Solid Works software.

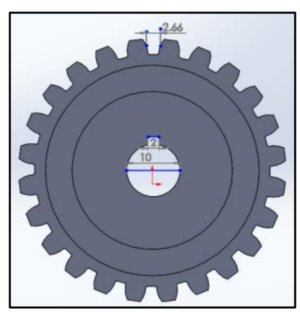

Fig. 9 Dimension is given at the time of Product Designing

Now, we have checked the Dimensions of the finished product, which was done by the 3D printing machine, and compared the difference between the dimensions of the Designed product and the finished product. The following Fig 10(a), (b), (c) shows the dimensions of the product developed in the 3D printing machine.

Journal of Manufacturing Engineering, September 2024, Vol. 19, Issue. 3, pp 082-088
DOI: https://doi.org/10.37255/jme.v19i3pp082-088

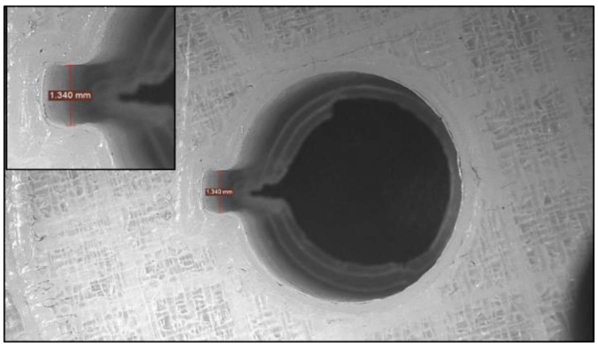

Fig. 10 (a), Dimension of the gear key after the finished product is ready

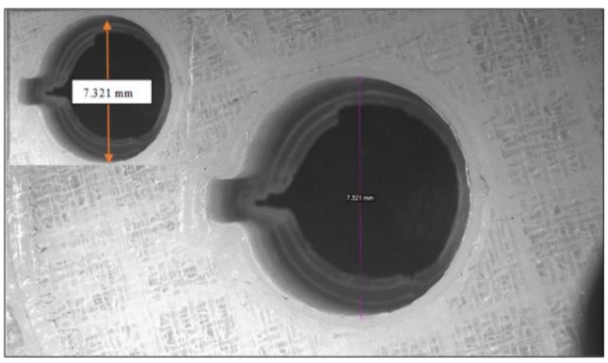

Fig. 10(b), Dimension on the center Hole Dia of the 3D product

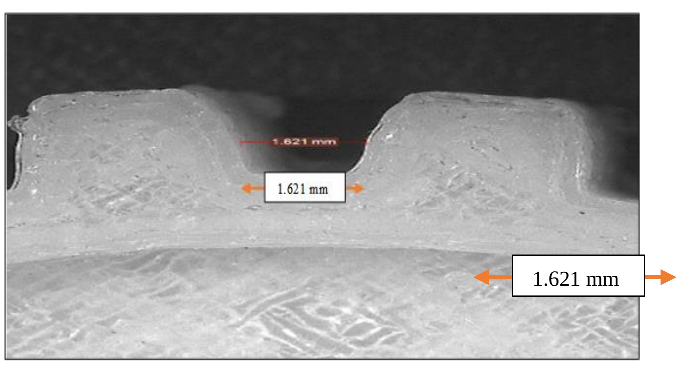

Fig. 10(c), Dimensions of the gap between the two Teeth of the gear

From this figure above, it is concluded that the finished product dimension is much smaller than the designed dimension, and we can see that the product dimension is reduced significantly in all three cases.

5. Conclusion

This research explored various aspects of the additive manufacturing process, focusing on the microstructure, dimensional accuracy, and the slicing algorithm for tessellated models. Our experiments demonstrated the following key findings:

1. Microstructural Analysis: Bubbles and surface roughness significantly impacted the quality of the final product. Adjustments to retraction settings, print speed, temperature, and other parameters, such as activating coasting settings and adjusting fan speed, can minimize defects and improve surface finish. These optimizations are crucial to reducing internal voids, enhancing the mechanical properties, and achieving consistent layer thicknesses.
2. Dimensional Accuracy: Our results revealed that the final product dimensions were consistently more minor than the original CAD model dimensions, primarily due to high filament compactness, thermal contraction, and mechanical issues like belt tension. Optimizing print settings, such as reducing heat and print speed and ensuring proper lubrication and maintenance of the printer's mechanical components, is essential to improve dimensional accuracy.

This research highlights the importance of optimizing microstructural properties and dimensional accuracy in additive manufacturing. Future work should focus on refining these processes to enhance the quality and performance of 3D-printed parts.

References

1. *O. Diegel, A. Nordin, and D. Motte, Additive Manufacturing Technologies, Springer Series in Advanced Manufacturing, 2019, pp. 19–39.*
2. *B. Evans, "The Science and Art of 3D Printing".*
3. *P. Mohan Pandey, N. Venkata Reddy, and S. G. Dhande, "Slicing procedures in layered manufacturing: A review," "Rapid Prototyping Journal," vol. 9, no. 5, pp. 274–288, 2003.*
4. *W. Oropallo, L. A. Piegl, P. Rosen, and K. Rajab, "Point cloud slicing for 3-D printing," "Computer-Aided Design and Applications," vol. 15, no. 1, pp. 90–97, 2018.*
5. *Alias Wavefront Corp., "Alias Wavefront History," Available: http://www.aliaswavefront.com/eng/about/history/index.shtml.*
6. *Electronic Industries Association, "Interchangeable variable block data format for positioning, contouring, and contouring/positioning numerically controlled machines," "Electronic Industries Association," 1980. Available: https://www.computerhistory.org/collections/catalog/102785172.*

7. K. Lee, "Principles of CAD/CAM/CAE Systems", "Computer-Aided Design", vol. 32, pp. 227–228, 1999. Available: http://portal.acm.org/citation.cfm?id=520853.
8. R. Scopigno, P. Cignoni, N. Pietroni, M. Callieri, and M. Dellepiane, "Digital Fabrication Techniques for Cultural Heritage: A Survey," "Computer Graphics Forum", vol. 36, no. 1, pp. 6–21, 2017.
9. J. Q. Oberhauser, "Design, Construction, Control, and Analysis of Linear Delta Robot," "Russian College of Engineering and Technology", vol. 147, no. 1, pp. 11–40, 2016.
10. B. Evans, "Practical 3D Printers: The Science and Art of 3D Printing", 2012.
11. E. Krassenstein, "Polar 3D Launches Unique Polar Coordinate-Based FFF 3D Printer at CES 2015," "3DPrint.com", 2015. Available: https://3dprint.com/35656/polar-3d-printer-ces-2015/.
12. H. L. Oo, K. Z. Ye, and Y. H. Linn, "Modeling and controlling of temperature in 3D printer (FDM)," in "Proc. 2018 IEEE Conf. Russian Young Researchers in Electrical and Electronic Engineering (ElConRus)", 2018, pp. 1738–1742.
13. R. Melnikova, A. Ehrmann, and K. Finsterbusch, "3D printing of textile-based structures by Fused Deposition Modelling (FDM) with different polymer materials," "IOP Conference Series: Materials Science and Engineering", vol. 62, no. 1, 2014.
14. S. H. Ahn, M. Montero, D. Odell, S. Roundy, and P. K. Wright, "Anisotropic material properties of fused deposition modeling ABS," "Rapid Prototyping Journal", vol. 8, no. 4, pp. 248–257, 2002.
15. S. H. Ahn, C. Baek, S. Lee, and I. S. Ahn, "Anisotropic tensile failure model of rapid prototyping parts - Fused Deposition Modeling (FDM)," "International Journal of Modern Physics B", vol. 17, no. 8-9, pp. 1510–1516, 2003.
16. L. Novakova-Marcincinova and I. Kuric, "Basic and Advanced Materials for Fused Deposition Modeling Rapid Prototyping Technology," "Manufacturing and Industrial Engineering", vol. 11, no. 1, pp. 1338–6549, 2012.

.

.

