

(RESEARCH ARTICLE)



Effect of software for FDM additive manufacturing on geometric accuracy and print quality

Miloš Matúš*, Peter Križan, Juraj Beniak and Lucia Ploskuňáková

Slovak University of Technology in Bratislava, Faculty of Mechanical Engineering. Namestie slobody 17, 81231 Bratislava, Slovakia.

Global Journal of Engineering and Technology Advances, 2022, 13(03), 110–120

Publication history: Received on 12 November 2022; revised on 24 December 2022; accepted on 27 December 2022

Article DOI: <https://doi.org/10.30574/gjeta.2022.13.3.0218>

Abstract

Additive manufacturing is becoming an integral part of production technologies with a constantly growing share. The paper is dedicated to the research of the geometrical accuracy of FDM technology with respect to the used control software. The aim of the experiment was to compare the 3D printer's own control software called G3DMaker and the universal control software Simplify3D, where it was possible to confirm the significant influence of the software on the quality of prints. The geometric and dimensional deviations of the samples printed in both software were compared, as well as the quality of the 3D printing surface itself.

Keywords: Additive manufacturing; FDM; Printing software; Geometric accuracy; Dimensional accuracy; Print quality

1. Introduction

Additive manufacturing has its origins in the first half of the nineties of the 20th century. Compared to other production technologies, it is very young, but despite this, it has spread rapidly during this time. According to the ISO/ASTM 52900:2015 standard, additive manufacturing is defined as the process of successively depositing and joining material, usually in thin layers, to create a tangible object from 3D model data [1]. This principle of adding material is the opposite of traditional technologies, where material is usually removed during the production process. Additive manufacturing is often replaced by the term 3D printing, when the meaning of these words is not exactly the same, and the mentioned standard ISO / ASTM 52900: 2015 also defines these terms differently. However, it can be generally said that additive manufacturing is a more massive application of 3D printing in industry [2]. This increase in the applications of additive manufacturing, together with the reduction in the price for its manufacture, ensured a tremendous rise of these technologies in the market.

Nowadays, with the development of new technological and software solutions for its improvement, it is gaining more and more potential for use in many areas. Its use covers a wide range of industries. Its main application is in the automotive industry, aviation, general engineering, space industry, biomedicine, architecture, fluid technology and, last but not least, it plays a large role in the design for printing prototypes and models under the name Rapid Prototyping in the product development process. It is in these areas that attention is paid to high geometric or dimensional accuracy and surface quality of printing parts. The resulting quality of the printing part is affected by a large number of conversions. First of all, it is important to understand the influence of individual parameters and their interrelationship for the correct setting up of printing so that the requirements placed on it are met. There are several types of 3D printing technology, but one of the most widespread and affordable is technology called Fused Deposition Modeling (FDM).

* Corresponding author: Miloš Matúš

1.1. Fused Deposition Modeling (FDM)

FDM is a 3D printing technology based on solid materials. This method uses an external continuous filament of the thermoplastic material. During this process the filament is fed through massive spool through a heated printer extruder head and is melted at the nozzle, passing the glass transition temperature, so extruded by making objects layer by layer. The layers of the material are then fused together in a pattern to form an object. Typically the primary deposition takes place in one horizontal plane or one layer at a time. After this the print head moves vertically by a small amount to begin a new layer. [3].

FDM is applicable to a wide range of thermoplastic materials. The result is a 3D product with horizontally placed layers. Bonds with surrounding fibers are created through the diffusion welding mechanism. The process of extruding the material is usually quick and cheap. Material extrusion is directionally dependent, as material is deposited along the horizontal x and y axes, but strength along the vertical z axis is weaker. The process of printing material is cheap and economical, allows the use of multiple materials and colors, is safe and portable, and can be used in an office environment [4].

1.2. Geometric tolerances and deviations

Geometric tolerances are used to indicate the relationship of one part of an object with another. The purpose of geometric tolerance is to determine the maximum permissible deviation of the real manufactured product from the prescribed dimension. For this purpose, a system of characters representing individual tolerances, which are prescribed on production drawings, was created. When prescribing geometric tolerances, it is based on the functionality of the part, because the type and size of the geometric tolerance largely determines the economic difficulty, the choice of the production method, the choice of the used technology and the machine.

Geometric tolerances are defined and characterized by the standard ISO 1101:2017 Geometrical product specifications (GPS) — Geometrical tolerancing — Tolerances of form, orientation, location and run-out. [5]

Tolerances are specified to indicate the actual size or dimension. In order to manufacture components more accurately or with minimum dimensional variations, the manufacturing facilities and the labour required become more cost intensive. In fact, depending on the application of the end product, precision is engineered selectively. Therefore, apart from considering the actual size, other geometric dimensions have to be considered while manufacturing components. The tolerances specified should also encompass such variations. Geometric tolerance is defined as the total amount that the dimension of a manufactured part can vary. Geometric tolerance underlines the importance of the shape of a feature as against its size. Geometric dimensioning and tolerancing is a method of defining parts based on how they function, using standard symbols. [6]

Under the inaccuracy of machine parts from a metrological point of view, we understand deviations of the actual surface of the part from the geometric surface. A geometric surface is a surface whose shape is determined by the drawing, it does not include roughness, waviness and shape deviations. A real surface is a surface that bounds a body and separates that body from the surrounding environment.

2. Material and methods

2.1. Measured objects

The experiment is based on a comparison of the own control software of the used 3D printer called G3DMaker and the universal control software Simplify3D. The aim is to confirm the impact of the software on the quality of the printing parts. The geometric and dimensional deviations of the samples printed by both software were compared. For this purpose, two measurement objects were designed according to Figure 1 – a hollow cylinder and a hollow prism with a trapezoidal base.

A cylinder with a concentric hole was designed for measuring circularity, concentricity of the hole and perpendicularity of the cylinder wall to the base. The prism with a trapezoidal base was designed so that the geometric tolerances of perpendicularity, angularity and parallelism could be measured. Geometric tolerances of straightness and parallelism on the edges, which were oriented differently in the working coordinate system, were also measured on both objects. Selected length dimensions were also measured.

The orientation of all measured samples with respect to the printing pad was the same and chosen with regard to the highest possible quality of the samples. The placement of both types of samples was such as to avoid printing overhanging parts.

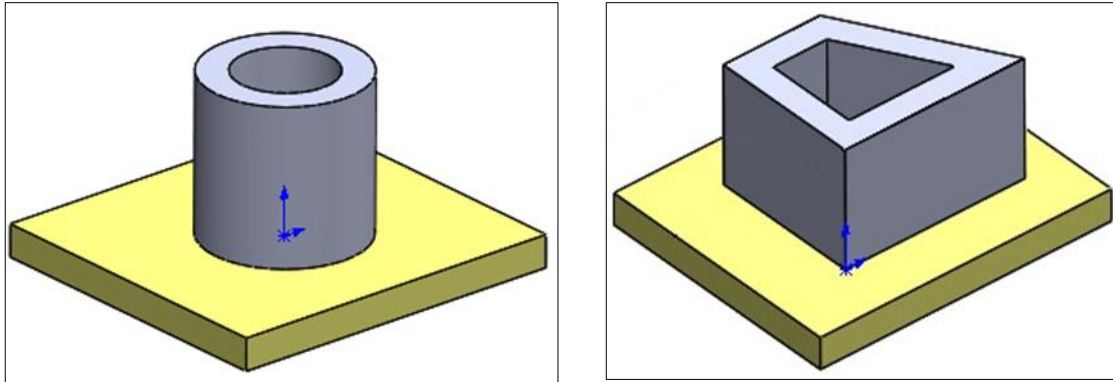


Figure 1 Measurement objects – a hollow cylinder and a hollow prism with a trapezoidal base, and their orientation on the working platform of the 3D printer

2.2. Production of samples

The Profi3DMaker printer (Fig. 2) was used for the production of samples, which falls into the category of FDM printers. Samples were printed using two software: Simplify3D a G3DMaker. Five identical samples were printed with each software at the same printing parameters.



Figure 2 Profi 3DMaker – 3D printer used FDM process

The following printing parameters were used to produce the samples:

- Material: PLA
- Print speed: 50 mm/s
- Nozzle diameter: 0.3 mm
- Layer height: 0.1 mm
- Print temperature: 220 °C
- Number of base layers: 3
- The density of filling the layers of the base: 100%
- Number of top layers: 3
- The filling density of the top layers: 100%
- The number of layers forming the walls of the sample: 2
- The density of the filling inside the sample: 5%
- Fill pattern: rectangular grid
- The temperature of the working platform: 50 °C

2.3. Used software for FDM additive manufacturing

The software for processing the model for the needs of FDM additive manufacturing is called a slicer. Slicer is a tool that converts a digital 3D model to G-code. A digital 3D model is usually in .stl or .obj format. The task of the slicer is to create individual horizontal layers from the 3D model (Figure 1). G-code is a detailed list of commands readable by a 3D printer, which allows to optimize everything it needs during the process. [7]

The printing of the measured samples was realized by two printing software: G3DMaker a Simplify3D.

G3DMaker is a custom control software for Profi3Dmaker printer. G3DMaker is user-friendly and undemanding software. Thanks to the intuitive control, the user can quickly master it and prepare the model for printing. Almost any object can be printed. It doesn't matter how complex it is. Where air printing would take place, the software automatically generates the support material and removes it after printing is complete. G3DMaker allows you to monitor the progress of the printing of individual layers even before it starts. It is therefore possible to view layer by layer how the object will be created.

Simplify3D slicer software is compatible with almost any printer. The user interface is very simple and easy to use. It contains many settings such as: extruders, layer control, different filling methods, temperature and cooling settings, automatic or manual addition of support structures, it is also possible to modify the G-code or scripts and more. Simplify3D provides a pre-print simulation that will allow you to see the steps that the 3D printer will take before the 3D model starts printing. The simulation contains information about the speed, sequence and settings used when printing. In the settings, there are two modes: basic and advanced. In the basic mode, it is possible to select basic parameters such as material, print quality, generation of support structures and others. When choosing a more advanced setting, all software settings are available, from setting temperature, cooling, speed to editing the G-code itself. The software is very fast when importing models, generating G-codes and also during simulations. [8]

2.4. Preparation of samples

After printing, the samples were freed from the fine fibers of the material on the surface (Fig. 3) so as not to change the geometry of the samples. These fibers would create a problem in optical measurement and evaluated surface points.

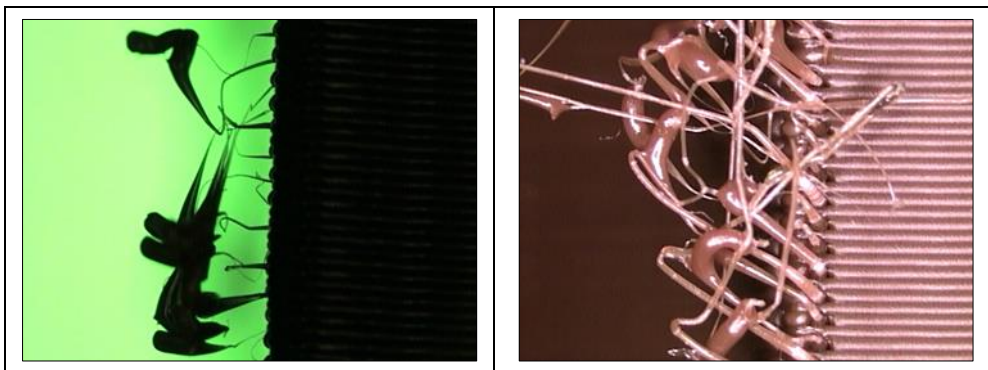


Figure 3 Detail of the fine fibers of the material before their removal

During the measurement, it was possible to focus the microscope either on the contour of the lower base as a contact surface with the working platform of the printer (visible casts that protrude through the walls of the sample) (Fig. 4a), or focus on the contour of the upper base and thus filter out the lower base with casts, since it was not the object of measurement (Fig. 4b). To improve the contrast on the measuring microscope, these casts of the lower base of the trapezoid were ground so as not to distort the measurement (Fig. 4c). In the case of the cylinder, these surfaces were measured first and ground only after they were measured, because they were partly the object of measurement. After grinding, the samples were cleaned of dirt by rinsing and then dried.

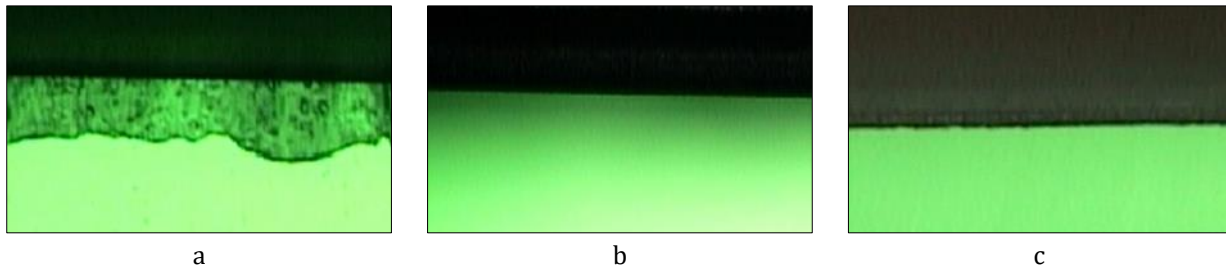


Figure 4 Sample preparation: a) detail of the lower base of the sample before grinding the cast, b) focusing on the upper base c) focusing on the upper base after grinding the cast of the lower base - sharper contour

2.5. Measuring device

A Smartscope MVP 200 device was used to measure and evaluate the geometry of the samples. It is an optical measuring device from the company OGP (Optical Gaging Product). The device uses non-contact measurement methods. The measurement is based on video recording of the part, which uses high-resolution lenses whose movement in XY is ensured by a stepper motor and in Z by a servo. The sliding scale is 0.5 μm. A wide range of lenses are used to adapt to changing conditions and magnification range. The necessary lighting to obtain the best possible image of the component is provided by LED lighting in different directions, which is increased depending on whether the surface of the sample is being examined or the greatest possible contrast between the contours of the sample and the surroundings is needed. In addition to measuring geometric tolerances, the device can also be used to examine the surface structure of objects thanks to the possibility of large zooming. Control and measurement is provided by the metrological software Measure - X (Fig. 5).

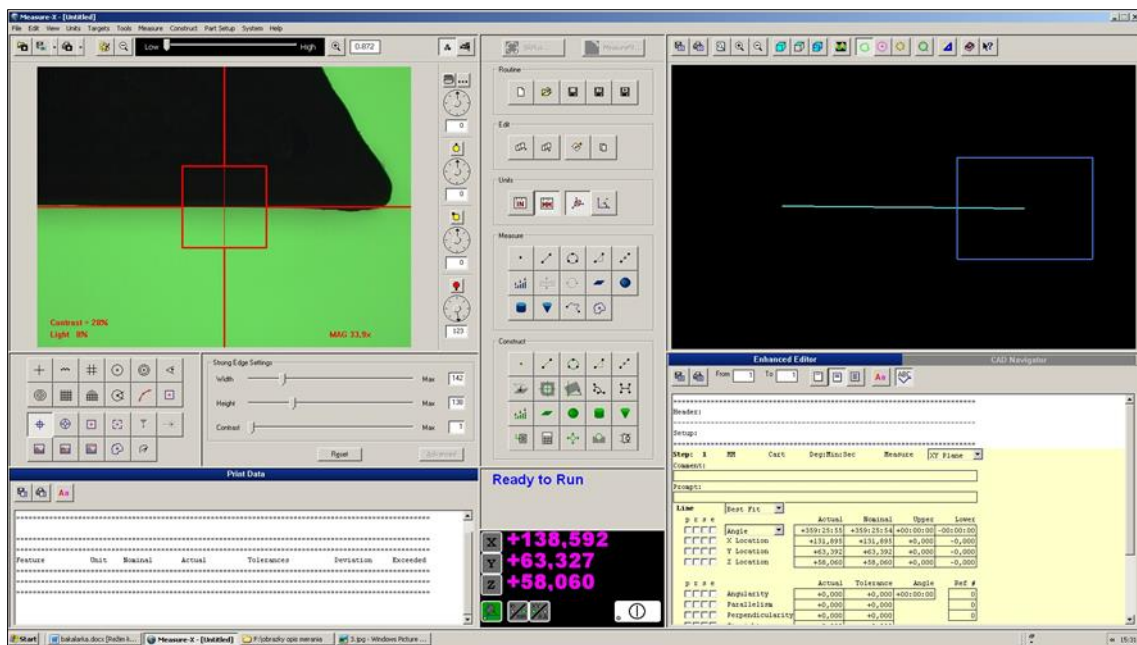


Figure 5 Measurement software Measure - X

2.6. Measurement method

The printing of two types of designed samples was realized by two software: Simplify3D and G3DMaker. Five identical samples were printed with each software at the same print parameters. Measurement of individual parameters of geometric and dimensional accuracy (Table 1) was repeated five times on each printed sample for proper statistical evaluation. Each repeated measurement on one sample was made at a different location of the sample.

Table 1 Measured parameters of geometric and dimensional accuracy

| Cylinder | Trapezoid |
|------------------|------------------|
| Straightness | Straightness |
| Parallelism | Parallelism |
| Perpendicularity | Perpendicularity |
| Circularity | Angularity |
| Coaxiality | Flatness |
| Diameter | Length |

Figures 6 - 12 graphically show in detail the individual measured parameters with the corresponding symbols for the cylinder samples and Figures 14 - 19 for the prism samples with a trapezoidal base.

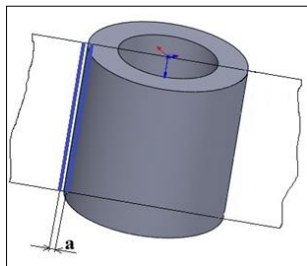


Figure 6 Straightness „a“

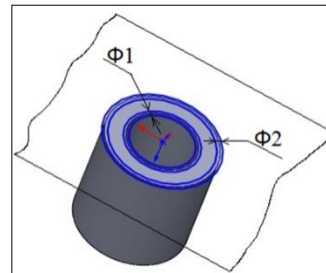


Figure 7 Circularity of the edge „φ1“ and the edge „φ2“

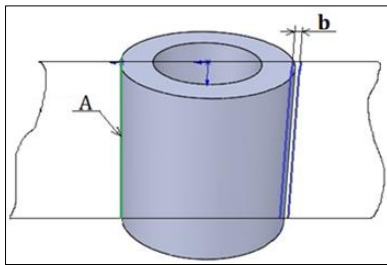


Figure 8 Parallelism „b“ with the base „A“ (b(A))

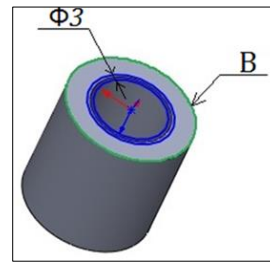


Figure 9 Coaxiality of the edge „φ3“ with the base „B“ (φ3(B))

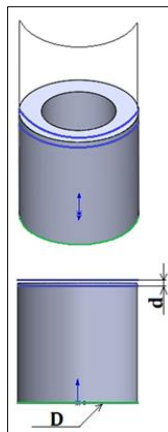


Figure 10 Parallelism of the pedestal „d“ with the base „D“ (d(D))

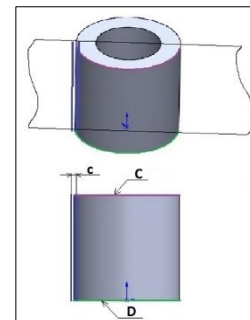


Figure 11 Perpendicularity of the edge „c“ to the base „C“ a „D“ (c(C)), (c(D))

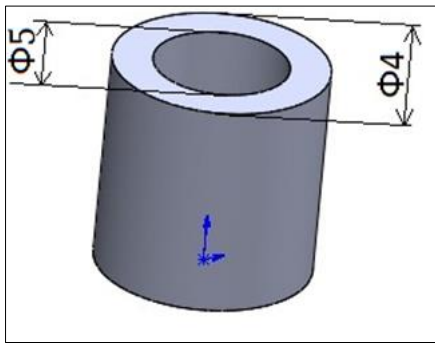


Figure 12 Diameter „ $\phi 3$ ” and diameter „ $\phi 4$ ”

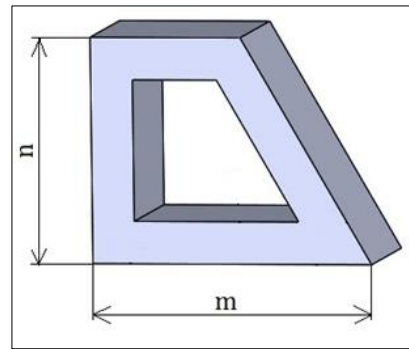


Figure 13 The length of the edge „ n ” and The length of the edge „ m ”

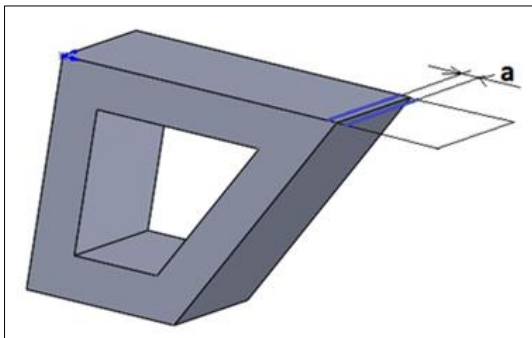


Figure 14 The straightness of the edge „ a ”

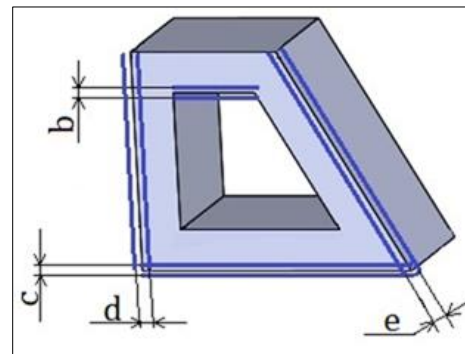


Figure 15 Straightness of edges „ b ”, „ c ”, „ d ”, „ e ”

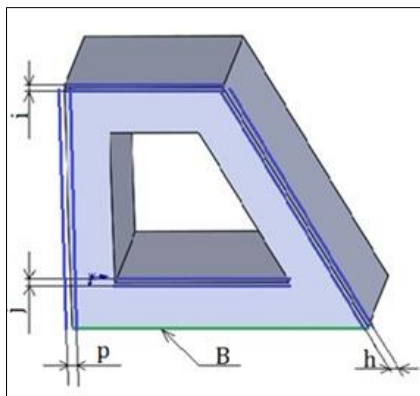


Figure 16 Parallelism of the edge „ i ” a „ j ”, perpendicularity of the edge „ p ” and angularity of the edge „ h ” to the base „ B ” ($i(B)$), ($j(B)$), ($p(B)$), ($h(B)$)

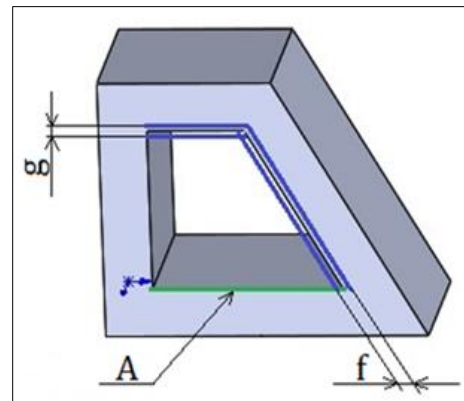


Figure 17 Parallelism of the edge „ g ” and angularity of the edge „ f ” to the base „ A ” ($g(A)$), ($f(A)$)

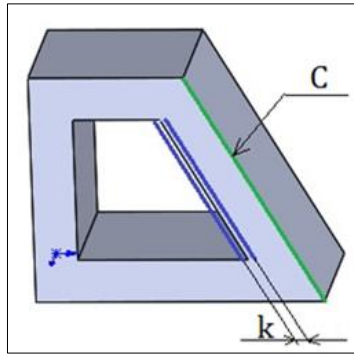


Figure 18 Parallelism of the edge „k“ to the base „C“ (k(C))

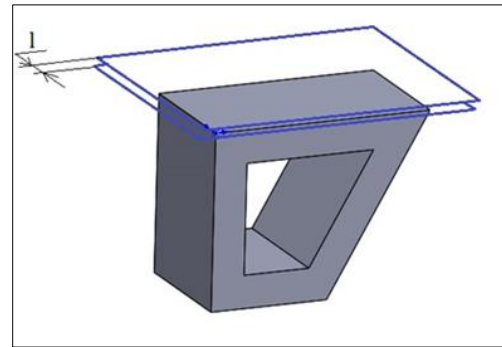


Figure 19 The flatness of the surface „l“

3. Results and discussion

3.1. Geometric and dimensional deviations

By means of the optical measuring device Smartscope MVP 200 and the measuring software Measure-X, the deviations of the individual investigated parameters of geometric and dimensional accuracy were measured and evaluated, depending on the used printing software. These measured results for the cylinder are shown in Table 2 and Table 3. The measured results for the trapezoid are shown in Table 4 and Table 5.

Table 2 Geometric deviations of the hollow cylinder

| Geometric deviation | Symbol | Simplify3D | G3DMaker |
|-----------------------------|----------------|------------|----------|
| straightness | a | 0.065 | 0.19 |
| parallelism | b(A) | 0.11 | 0.28 |
| parallelism | d(D) | 0.19 | 0.21 |
| average of parallelism | | 0.15 | 0.25 |
| perpendicularity | c(D) | 0.13 | 0.21 |
| perpendicularity | c(C) | 0.11 | 0.22 |
| average of perpendicularity | | 0.12 | 0.22 |
| circularity | $\varphi 1$ | 0.29 | 0.13 |
| circularity | $\varphi 2$ | 0.21 | 0.14 |
| average of circularity | | 0.25 | 0.14 |
| Coaxiality | $\varphi 3(B)$ | 0.15 | 0.11 |

Table 3 Dimensional deviations of the hollow cylinder

| Dimensional deviation | Diameter | Deviation | Diameter | Deviation |
|-----------------------|------------------|-----------|------------------|-----------|
| Dimension | $\varphi 4$ (mm) | | $\varphi 5$ (mm) | |
| Simplify3D | 40.27 | 0.27 | 24.44 | 0.44 |
| G3DMaker | 39.92 | 0.08 | 24.68 | 0.32 |
| Nominal size | 40 | | 25 | |

Table 4 Geometric deviations of a hollow prism with a trapezoidal base

| Geometric deviation | Symbol | Simplify3D | G3DMaker |
|-------------------------|--------|------------|----------|
| straightness | a | 0.042 | 0.065 |
| straightness | b | 0.017 | 0.025 |
| straightness | c | 0.022 | 0.03 |
| straightness | d | 0.03 | 0.022 |
| straightness | e | 0.07 | 0.036 |
| average of straightness | | 0.036 | 0.036 |
| parallelism | i(B) | 0.047 | 0.022 |
| parallelism | j(B) | 0.037 | 0.028 |
| parallelism | k(C) | 0.066 | 0.053 |
| parallelism | g(A) | 0.053 | 0.03 |
| average of parallelism | | 0.051 | 0.033 |
| angularity | f(A) | 0.071 | 0.056 |
| angularity | h(B) | 0.12 | 0.057 |
| average of angularity | | 0.096 | 0.057 |
| perpendicularity | p(B) | 0.062 | 0.028 |
| flatness | L | 0.021 | 0.056 |

Table 5 Dimensional deviations of a hollow prism with a trapezoidal base

| Dimensional deviation | Length | Deviation | Length | Deviation |
|-----------------------|--------|-----------|--------|-----------|
| Dimension | m (mm) | | n (mm) | |
| Simplify3D | 49.86 | 0.14 | 39.87 | 0.13 |
| G3DMaker | 49.94 | 0.06 | 39.91 | 0.09 |
| Nominal size | 50 | | 40 | |

From the measured results, it can be concluded that the G3DMaker software fared much worse for those parameters of the cylinder that depended on the accuracy of the cylindrical surface. Here, protrusions were formed that increase the deviations, but they did not occur when using the Simplify3D software. The straightness values of the trapezoid were the same for both software, as these protrusions did not appear on the flat surfaces of the trapezoid. All other geometric and dimensional deviations of the cylinder and trapezoid were smaller when using the G3DMaker software.

3.2. Quality of structure and surface of the print

When using the G3DMaker software, the printer did not produce a regular and uniform grid structure. Failures in the structure (Fig. 20) occurred much more frequently than when using the Simplify3D software, but their severity was comparable. These disturbances alternated uniformly with areas of splayed fibers. Building structure achieves higher quality with Simplify3D software.

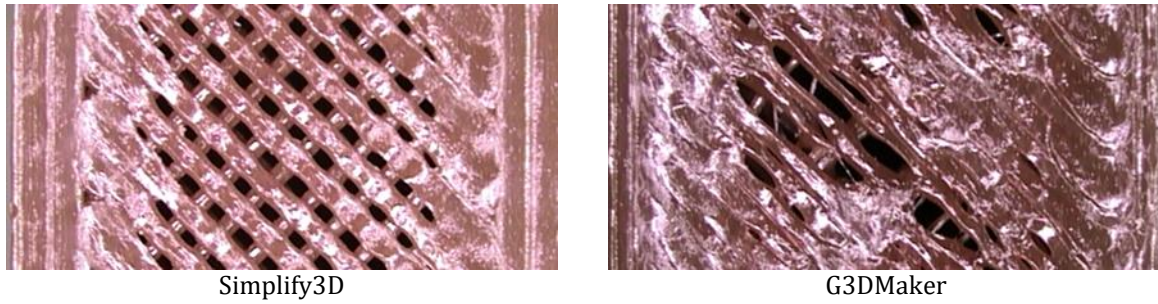


Figure 20 Building structure

The quality of the surface of the samples also differed with the software used. Protrusions regularly appeared on the cylindrical surface when using G3DMaker (Fig. 21), which was reflected in the values of geometric deviations of shape and orientation. In the case of flat surfaces of the trapezoid, such protrusions did not occur (Fig. 22).

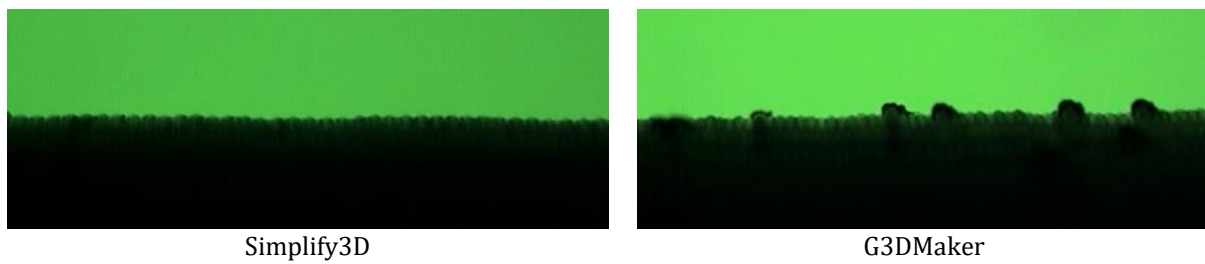


Figure 21 Cylinder surface quality

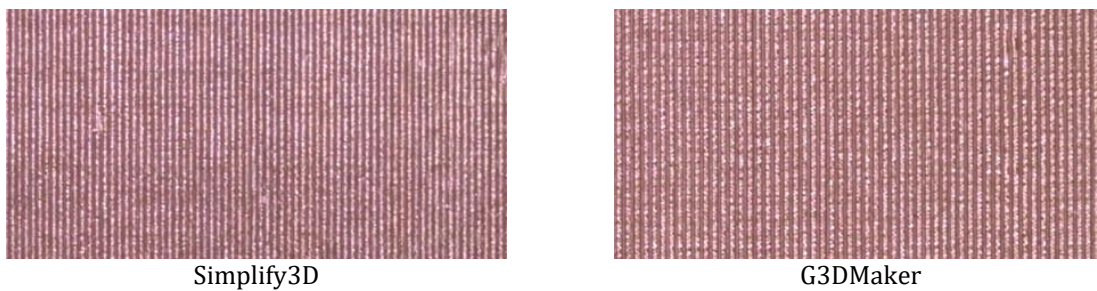


Figure 22 Trapezoid surface quality

With Simplify3D, there was a significant irregularity on the surface caused by the transition of the nozzle to the next sample during the printing process (Fig. 23). When using the G3DMaker software, only a small irregularity was created, which was difficult to observe without the use of a microscope.

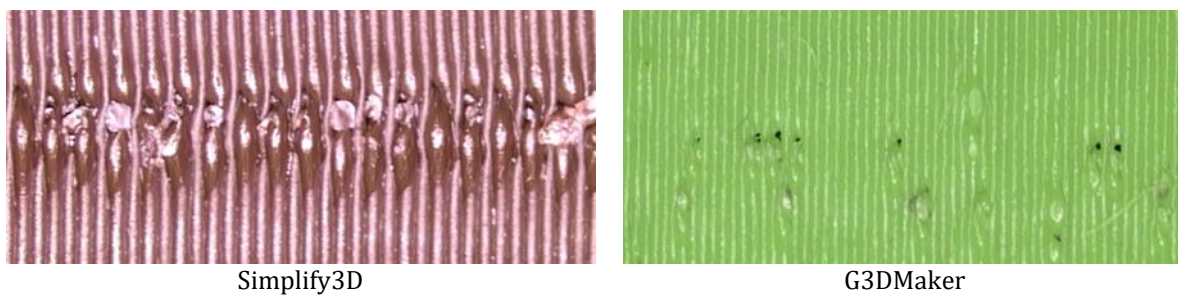


Figure 23 Surface quality - layer termination location

4. Conclusion

The aim of the experiment was to compare the control software G3DMaker with the universal control software Simplify3D used by the 3D printer. Research has confirmed the impact of software on the quality of parts. The geometric and dimensional deviations of the samples printed by both software at the same setting of the printing parameters were measured and compared. From the measured results, it can be concluded that the G3DMaker software fared much worse for those parameters of the cylinder that depended on the accuracy of the cylindrical surface. Here, protrusions were formed that increase the deviations, but they did not occur when using the Simplify3D software. The straightness values of the trapezoid were the same for both software, as these protrusions did not appear on the flat surfaces of the trapezoid. All other geometric and dimensional deviations of the cylinder and trapezoid were smaller when using the G3DMaker software. When comparing the building structure graphically, the Simplify3D software achieved better results. On the other hand, during the transition of the 3D printer nozzle from one sample to another, the Simplify3D software created a much more pronounced transition area than the G3DMaker software.

Compliance with ethical standards

Acknowledgments

The paper is a part of the research done within the project VEGA 1/0665/21 „Research and optimization of technological parameters of progressive additive manufacturing of effective protective equipment against COVID-19“ funded by the Ministry of Education of Slovak Republic and to the Slovak Academy of Sciences, and the project APVV-18-0527 “Development and optimization of additive manufacturing technology and design of device for production of components with optimized strength and production costs” funded by the Slovak Research and Development Agency. The paper is a part of the research done within the project KEGA 033STU-4/2022 „Creation and implementation of a certified course for CAx systems with elements of artificial intelligence in the teaching of mechanical engineering“ funded by the Ministry of Education of Slovak Republic.

Disclosure of conflict of interest

There is no conflict of interest.

References

- [1] ASTM F2792-10. Standard Terminology for Additive Manufacturing Technologies. 2010. West Conshohocken, PA.
- [2] Attaran, M. The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing. In: Business Horizons. 2017; 60:677- 688.
- [3] J.-Y. Lee, J. An, C.K. Chua Fundamentals and applications of 3D printing for novel materials. Appl. Mater. Today, 7 (2017), pp. 120-133.
- [4] Computer Aided Design and Manufacturing - 13.3 Types of AM Techniques. [online], Cit. [1.9.2021]. Available from: <https://app.knovel.com/hotlink/pdf/id:kt012ENJ42/computer-aided-design/types-am-techniques>
- [5] ISO 1101:2017. Geometrical product specifications (GPS) — Geometrical tolerancing — Tolerances of form, orientation, location and run-out.
- [6] Raghavendra, N.V., Krishnamurthy, L. Engineering Metrology and Measurements, Oxford University Press, India, 2013.
- [7] Lucas Carolo. What is a 3D Slicer? – Simply Explained [online]. 2020. [cit. 10.04.2022]. Available from: <https://all3dp.com/2/what-is-a-3d-slicer-simply-explained/>
- [8] Simplify3D. [online]. [cit. 17.04.2022]. Available from: <https://www.simplify3d.com/>