Investigation of different FDM/FFF 3D printing methods for improving the surface quality of 3D printed parts

Cite as: AIP Conference Proceedings **2449**, 060001 (2022); https://doi.org/10.1063/5.0090805
Published Online: 01 September 2022

Mihail Zagorski, Yavor Sofronov, Denitsa Ivanova, et al.

Investigation of Different FDM/FFF 3D Printing Methods for Improving the Surface Quality of 3D Printed Parts

Mihail Zagorski [a], Yavor Sofronov [b], Denitsa Ivanova [c], Krasimira Dimova [d]

[1] *Faculty of Industrial Technology, Technical University – Sofia, 8 Kl. Ohridski Blvd, 1000 Sofia, Bulgaria*

[a] Corresponding author: mihail.zagorski.tu@gmail.com
[b] ysofronov@tu-sofia.bg
[c] ivanovadenitsa608@gmail.com
[d] krdimova@tu-sofia.bg

Abstract. This paper study presents an investigation of three different FDM/FFF 3D printing methods. For the purposes of the study a 3D model of a part with cylindrical surfaces is built. The created model is 3D printed using three different methods: traditional slicing with uniform layer height, adaptive slicing and non-planar slicing. A comparison between the three produced samples is made in regard to the surface quality, printing time, volume of the used material, weight of the sample and deviations from the nominal geometry.

INTRODUCTION

FDM (Fused Deposition Modeling) or FFF (Fused Filament Fabrication) is a technology for 3D printing with deposition of molten material. FDM is one of the oldest technologies for Additive Manufacturing - patented in 1989 by S. Scott Crump - co-founder of Stratasys. In recent years FDM/FFF 3D printing has become the most affordable 3D printing technology not only for the industry and the science, but also for hobbyists and small businesses, mainly because of lower prices of FDM machines and material (filament) compared to other 3D printing technologies [1, 2].

One of the main disadvantages of FDM/FFF 3D printing is the so-called stair-stepping effect, which is especially noticeable on inclined or curved surfaces [3, 4]. It affects the smoothness and the overall quality of the non-planar surfaces. A visualization of stair-stepping effect is shown on Fig. 1 [6].

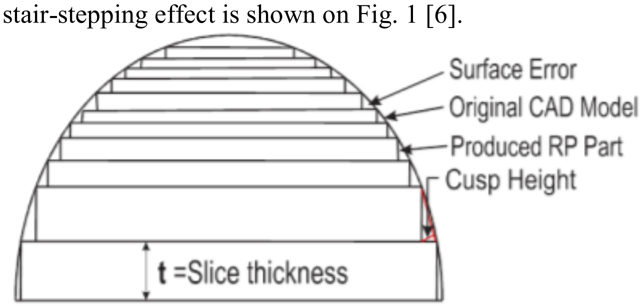

FIGURE 1. Visualisation of stair-stepping effect.

The stair-stepping effect could be reduced by using different FDM/FFF methods for slicing the 3D model. This paper study presents an investigation of three different FDM/FFF 3D printing methods applied on one and the same model which is specifically designed for the task. It is printed using the three methods: traditional slicing with uniform layer height, adaptive slicing and non-planar slicing.

AIP Conf. Proc. 2449, 060001-1–060001-7; https://doi.org/10.1063/5.0090805
Published by AIP Publishing. 978-0-7354-4397-6/$30.00

EXPERIMENTAL DETAILS

A solid 3D model with intersecting cylindrical surfaces and fillet is built using parametric modeling [5]. Its overall sizes (LxWxH) are 40x25x7 mm. The 3D model is shown on Fig. 2.

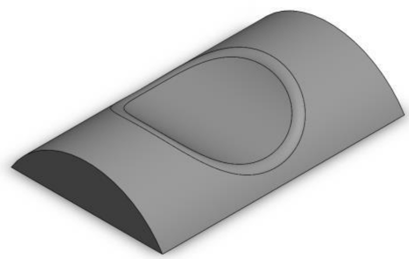

FIGURE 2. Isometric view of the 3D model.

After the creation of the solid 3D model it is exported in STL file format with the highest possible accuracy and resolution for better approximation of the triangular mesh. A tolerance of 0.002 mm for the linear dimensions and 0.5 degrees for the walls and holes is achieved. The created STL mesh has 320,048 elements (triangles).

The created STL is then imported in Slic3r – a slicer software for FDM/FFF 3D printers. A special add-on for non-planar 3D printing is installed [7].

A Creality Ender 3 FDM/FFF 3D printer equipped with a nozzle with diameter of the outlet 0.4 mm is used for the purposes of the study. The length and angle of the nozzle and the geometry of the 3D model are compliant to the limitations of nozzles at different angles – Fig. 3 [8].

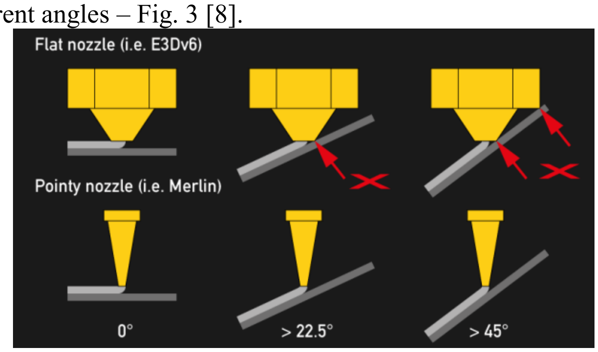

FIGURE 3. Limitations of nozzles at different angles.

The three samples are printed from one and the same roll of PLA and with the same slicer settings (print temperature, heated bed temperature, orientation, 100 % infill, print speed, etc.).

Virtual visualization of the layers of the sample printed with uniform layer height - 0.2 mm (Sample 1-ULH) is shown on Fig. 4.

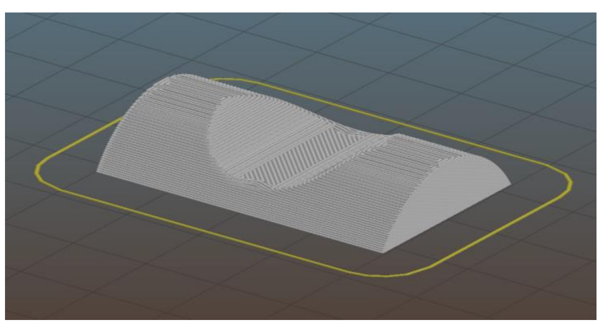

FIGURE 4. Virtual visualization of uniform layers of Sample 1-ULH.

Activation of the option for adaptive layers, “Use adaptive layers”, is required for printing the sample with adaptive layer height (Sample 2-ALH). The setting “adaptive quality” is set to 50%. This setting affects the minimum and the maximum height of the layers. Virtual visualization of the layers and a graph of variations of layer heights is shown on Fig. 5.

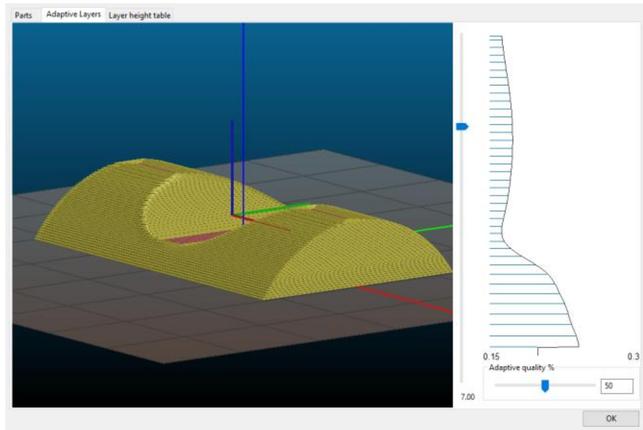

FIGURE 5. Virtual visualization of adaptive layers and a graph with variations of layer heights of Sample 2-ALH.

In non-planar 3D printing, material is deposited by coordinated movements along all axes of the machine while the final layers are printed. Installation and activation of the non-planar add-on is required in order to use this feature. A maximum angle (depends on the nozzle type) of 60° and a maximum nozzle height of 8.2 mm (determines the maximum height of the printed non-planar area) are set. Virtual visualization of the layers of the sample printed with non-planar layers (Sample 3-NPL) is shown on Fig. 6.

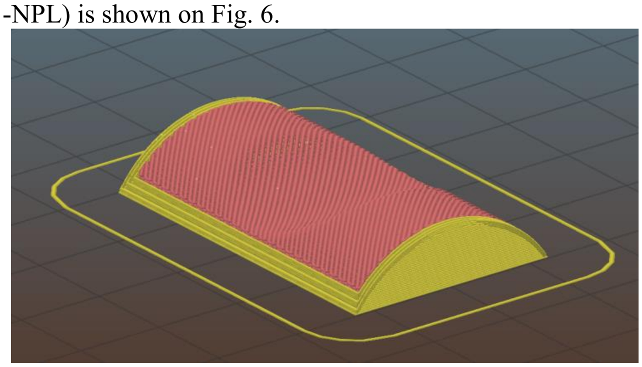

FIGURE 6. Virtual visualization of non-planar layers of Sample 3-NPL.

RESULTS AND DISCUSSION

Sample 1-ULH – Uniform Layers

The printing time for Sample 1-ULH is 29 minutes and 7 seconds, the volume of the used material is 4.20 cm3 and the weight of the sample is 5.24 g. Photos of Sample 1-ULH are shown on Fig. 7.

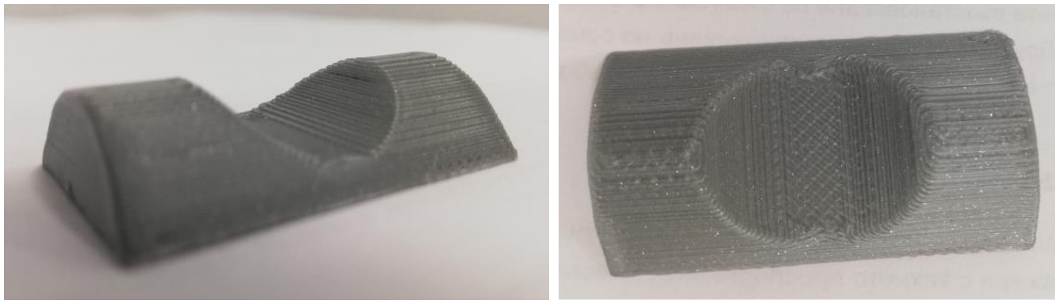

FIGURE 7. Photos of Sample 1-ULH.

The stair-stepping effect on Sample 1-ULH is clearly visible, especially on the convex and concave surfaces.

Sample 2-ALH – Adaptive Layers

The printing time for Sample 2-ALH is 30 minutes and 38 seconds, the volume of the used material is 4.19 cm3 and the weight of the sample is 5.24 g. Photos of Sample 2-ALH are shown on Fig. 8.

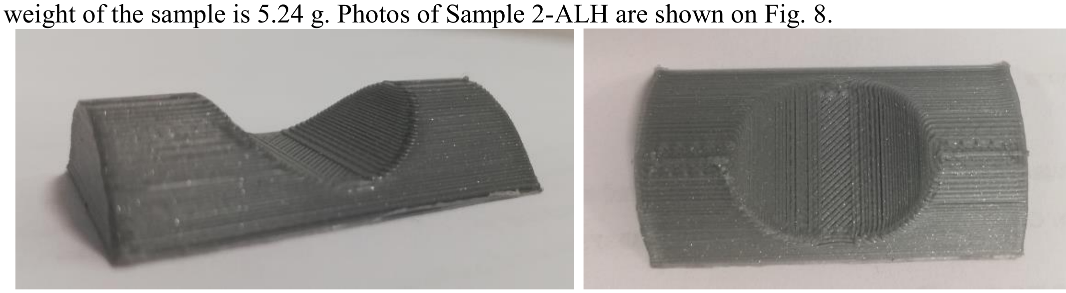

FIGURE 8. Photos of Sample 2-ALH.

Sample 2-ALH shows a slight improvement of the surface quality on the sides of the part but the stair effect is still visible, especially on the concave surface.

Sample 3-NPL – Non-Planar Layers

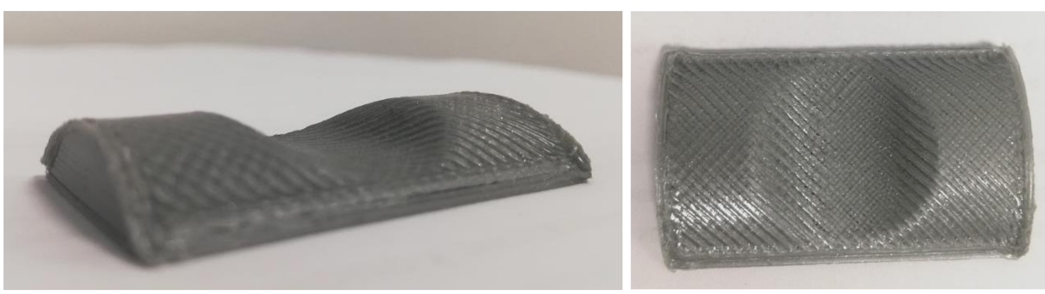

FIGURE 9. Photos of Sample 3-NPL.

Sample 3-NPL has a non-planar layer pattern. The surface is smoother than the surfaces and the stair-effect is avoided.

In Table 1 a summary of the data for the three samples is presented.

TABLE 1. Summary of the data for the three samples.

	Printing Time (min)	Material Volume (cm3)
Sample 1-ULH	29:07	4.20
Sample 2-ALH	30:38	4.19
Sample 3-NPL	37:20	4.30

Deviations from the Nominal Geometry

The three samples are scanned with a high-precision 3D scanner Amann Girrbach Ceramill Map 400 [9]. Scanned data is compared to the nominal geometry of the 3D model. The results are presented in the following figures: figure 10 – comparison between Sample 1-ULH and nominal geometry, figure 11 – comparison between Sample 2-ALH and nominal geometry, and figure 12 – comparison between Sample 3-NPL and nominal geometry.

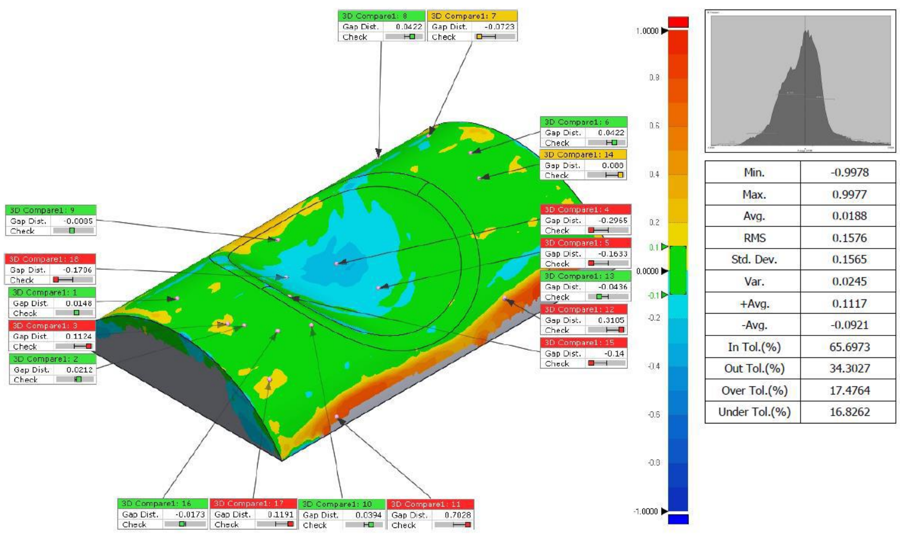

FIGURE 10. Comparison between Sample 1-ULH and nominal geometry.

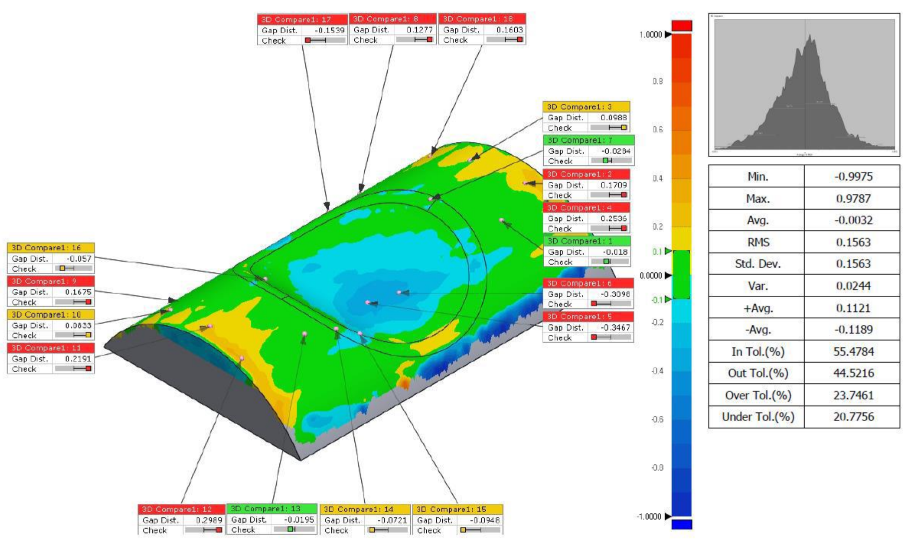

FIGURE 11. Comparison between Sample 2-ALH and nominal geometry.

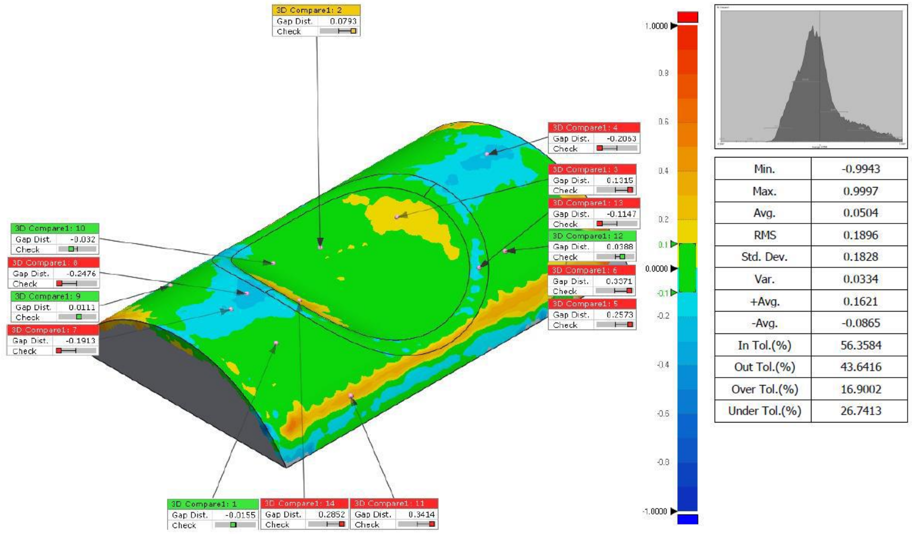

FIGURE 12. Comparison between Sample 3-NPL and nominal geometry.

CONCLUSIONS

In the course of the research, certain advantages and disadvantages of the different methods are clearly highlighted. The following conclusions are made:

In terms of minimum printing time and minimum amount of used material it is most appropriate to use the methods for planar 3D printing (with uniform or adaptive layers);

The quality of the surfaces obtained using the method of 3D printing with adaptive layer height (Sample 2-ALH) does not differ much from those produced with uniform layer height (Sample 1-ULH);

In terms of deviations from the nominal geometry Sample 1-ULH and Sample 2-ALH show slightly better results – the biggest deviations for the two samples are in the concave area of the part. Sample 3-NPL has bigger average overall deviations but has more precise concave area compared to Sample 1-ULH and Sample 2-ALH.

In conclusion, the most suitable for the production of the specific part is the method of non-planar 3D printing, which shows great potential for development. If more functionality to adjust process parameters is created, this method could evolve and for certain applications it could displace conventional planar FDM/FFF 3D printing methods.

ACKNOLEDGEMENTS

This work has been supported by project DH17/23 "Research and development of methods and tools for rapid digital development and rapid materialisation of personalised IMplants through hybrid TECHnology – IMTECH".

REFERENCES

1. Todorov G and Kamberov K 2017 Virtual Engineering: CAD/CAM/CAE&PLM Technologies (Direct Services – Sofia, in Bulgarian).
2. Paoletti, Ingrid & Ceccon, Lorenzo. (2018). The Evolution of 3D Printing in AEC: From Experimental to Consolidated Techniques. 10.5772/intechopen.79668.
3. Yasa, Evren & Poyraz, Özgür & Ugur Solakoglu, Ezgi & Akbulut, Guray & Oren, Soner. (2016). A Study on the Stair Stepping Effect in Direct Metal Laser Sintering of a Nickel-based Superalloy. Procedia CIRP. 45. 175-178. 10.1016/j.procir.2016.02.068.

4. Quan, Zhenzhen & Wu, Amanda & Keefe, Michael & Qin, Xiaohong & Yu, Jianyong & Suhr, Jonghwan & Byun, Joon-Hyung & Kim, Byung & Chou, Tsu-Wei. (2015). Additive manufacturing of multi-directional preforms for composites: Opportunities and challenges. Materials Today. 255. 10.1016/j.mattod.2015.05.001.
5. Todorov, G., Y. Sofronov, B. Romanov, T. Gavrilov. New Product Developmentand Production in Extremely Short Terms – Safety Goggles. International conference on Creative Business for Smart and Sustainable Growth 9 - 11 June 2020.
6. Sikder, Snahungshu & Kishawy, H. A. & Barari, Ahmad. (2014). Effect of Adaptive Slicing on Surface Integrity in Additive Manufacturing. 10.1115/DETC2014-35559.
7. Ahlers, Daniel. (2018). 3D Printing of Nonplanar Layers for Smooth Surface Generation.
8. https://hackaday.com/2016/07/27/3d-printering-non-planar-layer-fdm/ - Visited on 04.02.2021.
9. Galeva, Hristina & Uzunov, T & Sofronov, Yavor & Todorov, Georgi. (2020). Evaluation of the accuracy of the optical scanners used in the modern dental practice. Journal of Physics: Conference Series. 1492. 012017. 10.1088/1742-6596/1492/1/012017.