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LAYERS OPTIMISATION OF THE PLA PARTS FORMED BY ADDITIVE TECHNOLOGIES

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Abstract: Achieving required layer quality and its consistency is one of the key things for the effective implementation of the additive technologies, such as 3D printing. Experiments which were conducted at the Department of the Production Engineering, Faculty of Mechanical Engineering, University of Belgrade, were acquired optimal parameters that led to better parts quality produced of PLA polymer with widely used commercial 3D printers. Parameters that were varied during the experiments were nozzle temperature and printing speed. After production, all parts were microscopically observed and their surfaces roughnesses were measured. It is established that different values of these parameters can lead to diametrically different quality of layers that cause different quality of the printed parts.

Key words: Rapid prototyping, 3D printing, PLA polymer, Layer quality

1 INTRODUCTION

Rapid prototyping [1-3], need for custom parts, requirements for the complex shape parts for medical purpose [4-8], etc. are one of the main reasons for introducing additive technologies. Conventional technologies such as cutting or plastic deformation are very expensive to be applied in these fields and, on the other hand, inadequate in some cases [9]. The intensive development of additive technologies has led to the possibility of parts producing using different types of starting material which play a key role in the Additive Manufacturing process (liquid resin, polymer powder, polymer filament, polymer films) [9-11]. As the deposition of these material layers is accomplished by different methods, additive technologies can be divide into many groups, and one of them is Fused Filament Fabrication (FFF). This method of forming the parts that belongs to additive technology was created in early 1990s. The accuracy of the obtained parts

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depends from generated shrinkage [12]. Fused Deposition Modeling (FDM)/Fused Filament Fabrication (FFF) and Stereolithography (SLA) present two most common 3D printing technologies nowadays [13]. First of these two technologies (FFF/FDM) uses preformed polymer as the building material in the form of filament. Practical use of these technology to the real application is widespread among industries and household around the world. One of the reasons is that these technologies are very simple to use. However, producing the parts that meet required surface roughness and part geometry can be very hard.

2 FUSED FILAMENT FABRICATION

By using the Fused Filament Fabrication method (Figure 1), parts are being built by the layers deposition of melted polymer. At first they are build on the printing bed, and later every new layer is formed on the previous one. As have been already told, this method uses preformed polymer in the way of filament that can be different sizes (diameter of the filament). Printing nozzle is fed with the filament by the feeder that pools the filament from the spool. Speed of pooling the filament is in the function of the printing bed travelling speed. As the polymer travels through the nozzle, it becomes melted, which is then applied to the desired surface according to the programmed path of the printing bed, and in some cases nozzle or combined. In order to maintain the stickiness of the first layer on the printing bed, printing bed needs to be heated to the certain temperature that depends of the polymer itself. To achieve fast curing of the melted polymer, special part cooler has to be used. Moreover, for preventing melting the filament in the nozzle throat, nozzle cooler is needed.

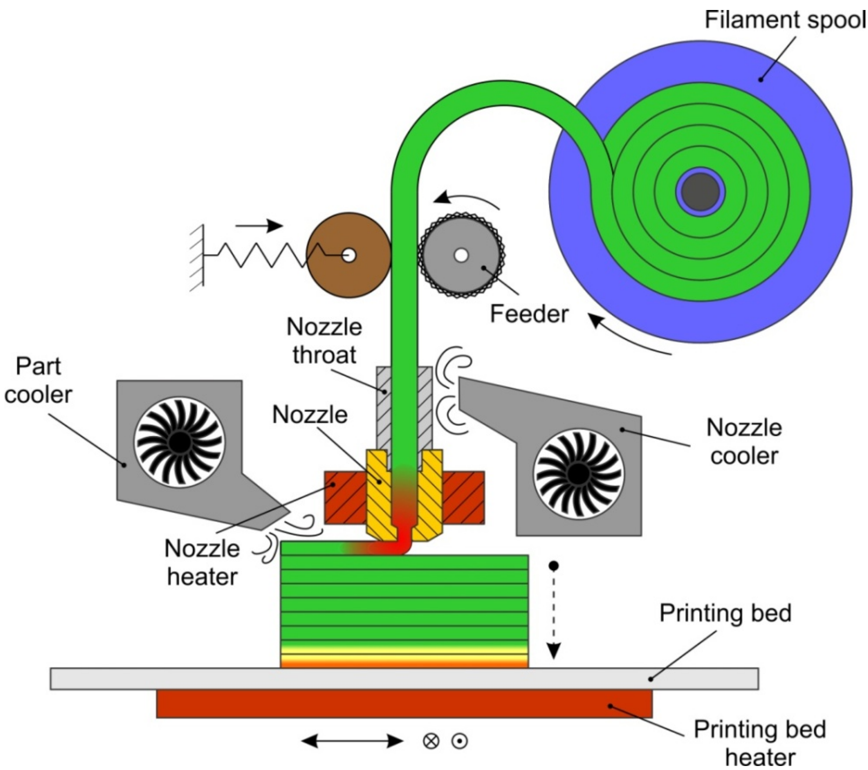


Figure 1. *Schematic representation of Fused Filament Fabrication method*

3 DEFINING OF THE ISSUE

Filaments which are printed can be formed from various materials such as PLA, ABS, etc. Each of these materials have their recommended melting or printing temperature, that values in the range from 170 up to 255 °C. However, not all temperatures provide the same printing results. Adequate binding of the layers directly depends on the printing temperature. Moreover, consistency and desired shape of the layer, and essentially, the entire part geometry depends on the printing temperature. Depending on how the layers are bonded, the roughness of the surface may vary.

Another parameter that can significantly affect the quality of the layer or whole part is the printing speed. In the most cases, the printing speed is in the function of the rigidity of the printer itself.

In order to make the product that meets the minimum requirement in the way of surface quality, geometry and integrity of the structure, it is necessary that these parameters be precisely determined. This is also the goal of this paper, more precisely, to determine printing temperature and optimum printing speed for making the parts of PLA polymer on commercial 3D printer.

4 EXPERIMENTAL SETUP

Conducted experiments were based on the formation of the parts that had same dimensions and geometry (Figure 2). Parts were printed from PLA polymer by varying the printing temperature and speed, whose values are in the Table 1.

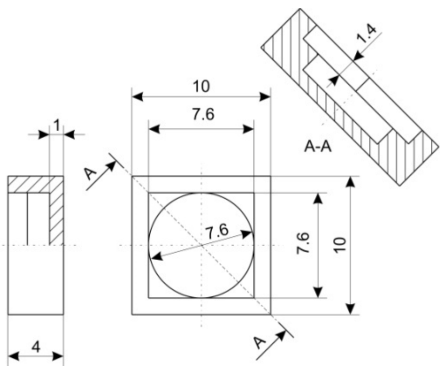


Figure 2. *Test part drawing.*

Printing bed was being preheated on the 60 °C which is adequate for achieving stickiness of the first layer to the printing bed. In order to achieve faster curing of the layers, during every experiment, part cooler was used. Height value of every layer was selected to be 0.2 mm. In order to achieve more smoother surface, layer height can be even lower, but the printing time is increased.

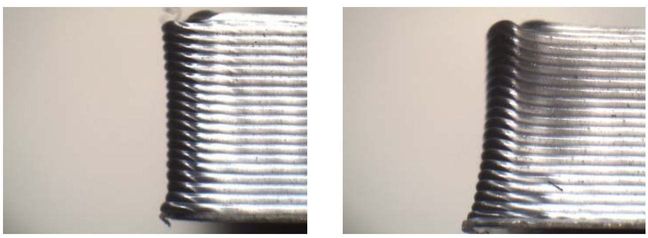
After printing of the parts was finished (15 in total), each part was microscopically observed for analyzing bindings of the layers and possible undesired phenomena. Moreover, roughness of the outer surfaces was measured in order to determine the influence of the varied parameters.

Table 1. *Experiment plan*

Exp. no.	Printing temperature [°C]	Printing speed [mm/s]
1.	170	40
2.		80
3.		120
4.	180	40
5.		80
6.		120
7.	190	40
8.		80
9.		120
10.	200	40
11.		80
12.		120
13.	210	40
14.		80
15.		120

5 RESULTS

Before the printing process or the first part of the experiments were conducted, it was necessary to establish if the part cooler was necessary to be used. After tests, it was determined that the part cooler exclusion led to high intensity of the part deformation. This could be explained as the consequence of the insufficiently fast part curing (Figure 3).



a) b)

Figure 3. *Side surfaces profiles a) with and b) without part cooler.*

Even when the part was cooled by a cooler, there was a slight degree of deformation between the initial layers due to the heating bed. This led to unequal curing of the whole part.

In the next conducted experiments done by the plan presented in the Table 1, 15 parts, in total, were formed. In order to determine the influence of the regimes on the parts geometry, side surfaces profiles of the every printed part were measured. It was determined that the best results were obtained when the nozzle temperature value was 180 °C and the printing speed 40 mm/min (Figure 4). Partially poorer printing results were obtained while the value of the nozzle temperature was 190 °C. In the case when the nozzle temperatures were lower, printing speed had a major impact on the print quality, while with the nozzle temperature increase, this influence became negligible.

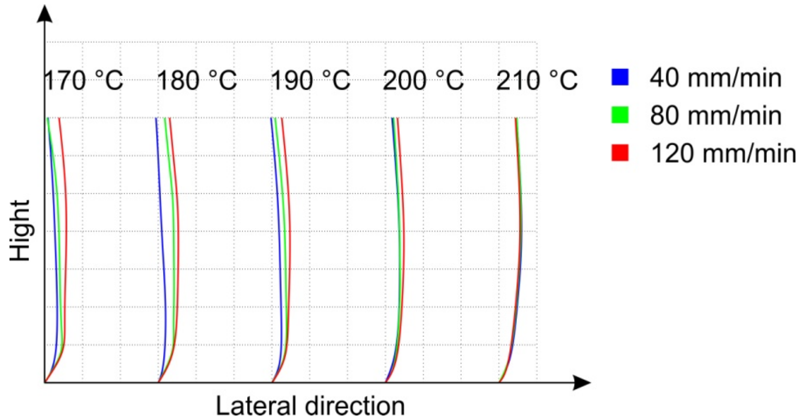


Figure 4. *Profiles of the side surfaces in the function of nozzle temperature and printing speed.*

With the increase of the nozzle temperature, longer time was necessary for layer to be cured. During this time, in small percentage, layer became squeezed and more oval. The greater the nozzle temperature, the greater the degree of the layer deformation was (Figure 5).

Results from microscopic observations were presented in the Figure 6. It can be observed clearly visible change in the part quality, depending on the nozzle temperature and printing speed. During the change of the printing nozzle direction, it was very important to obtain desired edge geometry of the printed part. By varying the nozzle temperature and printing speed, for the PLA polymer, the best results of the 3D printing when changing the direction of the nozzle (print) can be expected when the value of the nozzle temperature is 180 °C and the printing speed 40 mm/min (Figure 6). Moreover, the best upper surface quality was obtained with the same parameters of the 3D printing. For both types of nozzle trajectory, it can be clearly seen that with the increase of the nozzle temperature, a shiner surfaces were obtained. The dominant influence of the printing speed referred to the part quality in the form of unwanted phenomena caused by vibration of the system. These undesired phenomena can be clearly seen on the horizontal surfaces in the Figure 6 in terms of the variable density of the applied layer.

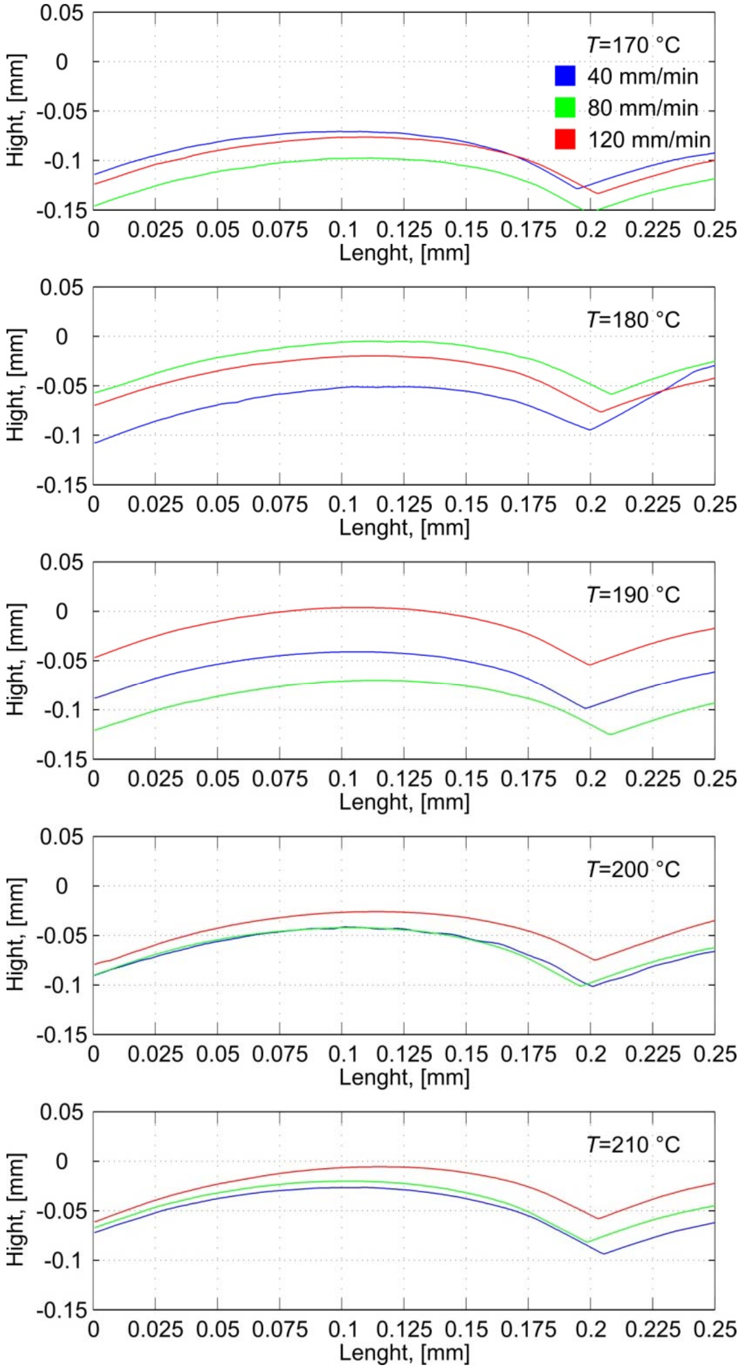


Figure 5. *Profiles of the layers in the function of nozzle temperature and printing speed.*

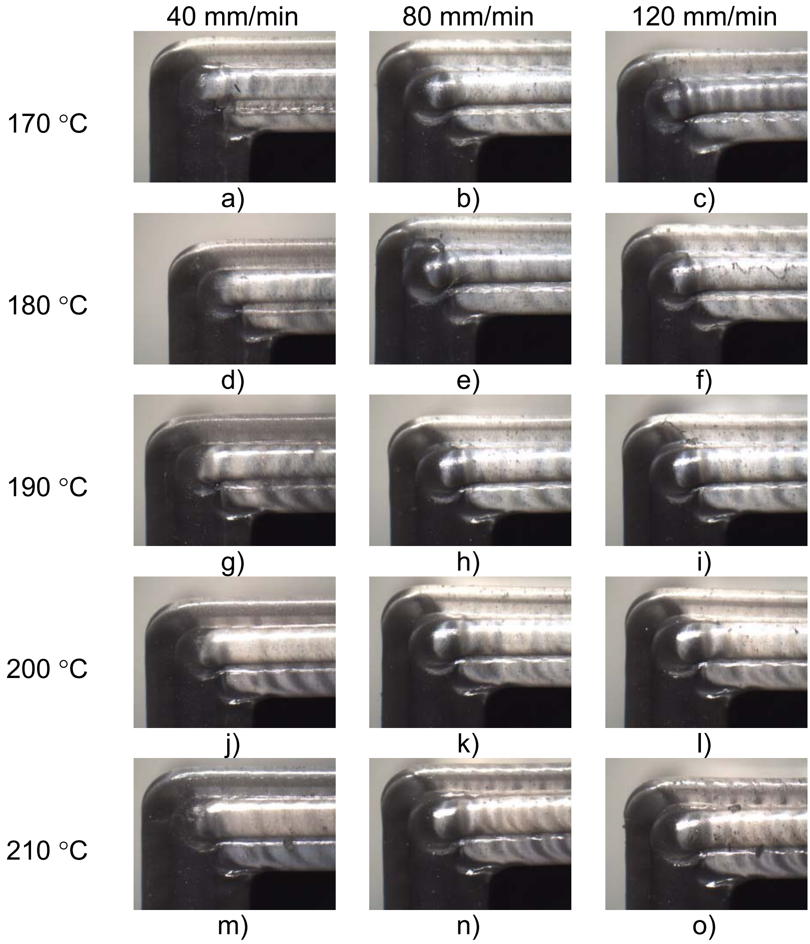


Figure 6. *Corner and upper surface results.*

6 CONCLUSION

Usage of the Fused Filament Fabrication (FFF) technologies has great potential in the different industries such as military, pharmaceutical, automotive, etc.. One of the main problems that arise in its application is obtaining a part with desired quality, which mainly depends on the process regimes.

With the experiments conducted at the Department of Production Engineering, Faculty of Mechanical Engineering, University of Belgrade, optimal parameters for the production of the parts of PLA polymers using Fused Filament Fabrication (FFF) technology were determined.

It was found that the best parts quality was obtained in the case when the value of the nozzle temperature was 180 °C, and the printing speed 40 mm/min, although the recommendation of the polymer manufacturer for the nozzle temperature value was 215 °C. Additionally, by using the part cooler, better part geometry was achieved. When printing the parts with higher nozzle temperatures, 200 °C and above, printing speeds did not have a significant impact on the quality of the tested parts.

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