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THE INFLUENCE OF CUTTING DEPTH ON SURFACE ROUGHNESS OF 3D PRINTED PARTS

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Abstract: *The development of additive manufacturing, particularly Fused Deposition Modeling (FDM), has enabled rapid prototyping and the production of functional parts with complex geometries. However, FDM-printed components often exhibit high surface roughness due to their layered structure. To enhance the surface quality, post-processing techniques such as CNC milling are applied. Among the key machining parameters, cutting depth (ap) significantly influences the final surface finish. This paper investigates the relationship between cutting depth and surface roughness in post-processed 3D printed parts made from thermoplastic materials. Experimental results and literature data suggest that lower cutting depths result in finer surface finishes due to reduced cutting forces and thermal effects, while higher depths may lead to increased roughness and surface defects. The findings highlight the importance of optimizing cutting parameters to improve the dimensional and surface quality of FDM-produced components.*

Keywords: *cutting depth, surface roughness, FDM, 3D printing, post-processing, CNC milling*

1. INTRODUCTION

Additive manufacturing, commonly known as 3D printing, is a method that creates a functional and fairly intricate working prototype directly from a digital version of a three-dimensional (3D) model that has been designed using computer-aided design (CAD) software. Unlike computer-aided manufacturing (CAM) technologies, which achieve the desired geometry by subtracting material, 3D printing constructs the model layer by layer [1]. While 3D printing is revolutionizing prototyping and manufacturing in specific applications, it has not yet replaced the widely used methods of CNC machining and injection molding. Nevertheless, integrating CNC machining with 3D printing can significantly reduce manufacturing times and enhance the efficiency of meeting design requirements [2].

Milling is a common finishing technique for 3D printed components that removes the appearance of the stepped surfaces, thereby broadening the range of 3D printing uses to include parts with enhanced precision and strength. The combination of FDM and milling post-machining technology represents a method with low energy consumption, low cost and sustainable potential. According to the literature, the three most commonly used factors in post-machining are: feed rate (Vf), cutting speed (V) or spindle speed (n) and depth of cut (ap) [3].

Many researchers investigated the influence of machining parameters on the surface quality of 3D printed parts.

Pămărac et al. investigated milling parameters for machining FDM parts, where PLA and ABS were the main materials. According to the study, spindle speed of 3500 rpm was the optimal speed for milling 3D printed parts [4].

Li et al. investigated a hybrid manufacturing process. Depending on the printing angle (from 20 to 90 degrees), the surface roughness varied. In this hybrid process, after the milling process, the reduction in surface roughness ranged from 17,332 and 56,021 µm to 4,870 and 24,511 µm [5].

Noorani et al. investigated post processing of 3D printed thermoplastics in their study and achieved high accuracy and excellent finish, which is still a limitation for 3D printing [6].

Ramulu et al. examined the machining of polymer composites and concluded that increasing cutting speed leads to less surface roughness [7].

Keresztes et al. investigated the machinability of 3D printed polymers. They concluded that by increasing the feed rate and depth of cut, the cutting force decreases [8].

Wang et al. investigated the milling process of carbon fiber reinforced polymer composites, and found that temperatures increased with cutting speed [9].

Hussain et al. studied the machinability of glass fiber reinforced polymer materials in their study. It was found that with increasing feed rate, the surface roughness increases, while it decreases with increasing cutting speed [10].

This paper shows the impact of machining on 3D printed parts and the improvement of surface quality, as well as the impact of machining parameters, primarily cutting depth, on the surface roughness of 3D printed parts.

2. MATERIALS AND METHODOLOGY

Solidworks 15x64 edition CAD software was used to model the specimens with outgrowths (Figure 1). The 3D CAD model was saved as an STL file and imported into Ultimaker Cura 4.11.0 software.

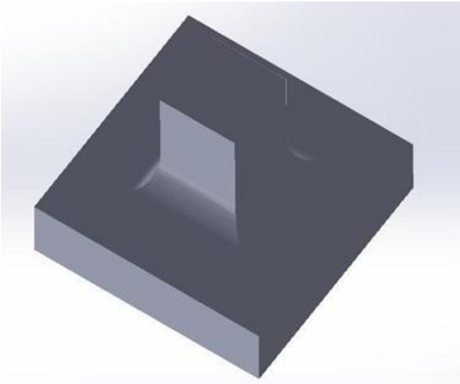

Figure 1. Sample created in SolidWorks

Specimens were printed for testing surface roughness before and after machining using a Creality CR10-s 3D printer (Figure 2), located at the Faculty of Technical Sciences in Kosovska Mitrovica. The printer specifications are as follows: working area of 300 x 300 x 400 mm, nozzle diameter of 0.4 mm, a normal printing speed of 60 mm/s, and a maximum speed of up to 100 mm/s. The material used for printing was PLA.

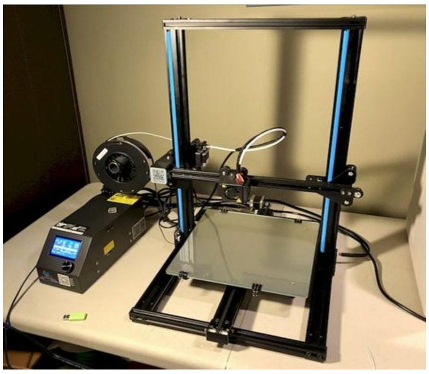

Figure 2. Creality CR 10-s 3D printer

The machine used for machining was a Haas VF-3SS vertical milling machine with three CNC-controlled axes (Figure 3), located at the Faculty of Engineering in Kragujevac. The Haas VF-3SS vertical milling machine features the following: X-Y-Z axis range: 1016–508–635 mm; maximum speed: 12000 rpm; maximum auxiliary speed: 21.1 m/min; maximum power: 22.4 kW. The tool used for machining was a 3-tooth, 6 mm diameter solid carbide (VHM) end mill.

Figure 3. HAAS VF-3SS milling machine

The spindle speed, the speed of the auxiliary movement and the cutting width for all specimens were unchanged, while the cutting depth (a) was varied from 0.1 to 0.4 mm for the first 4 specimens, while the fifth workpiece remained unprocessed.

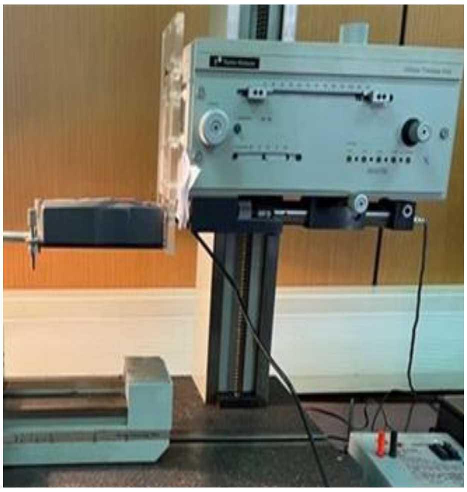

Figure 4. Talysurf-6 roughness measuring device

Surface roughness was measured on a computerized measuring device Talysurf-6 (Figure 4) with an ISR-C002 INSIZE measuring device connected to a computer. Basic data about the device: device dimensions are 141x55x40 mm, measuring range 160 µm, measurement accuracy ±10 %, resolution 0.01 µm, movement speed 0.02 —/s, 0.04 —/s, measurement of 21 roughness parameters.

3. EXPERIMENTAL RESULTS

After the completion of the 3D printing process, the surface roughness was measured on all specimens, then 4 specimens were machined with different cutting depths, after which the surface roughness was measured while one specimen remained untreated. Table 1 shows the surface roughness values before and after processing.

Table 1. Surface roughness before and after machining, in µm

Specimen	PLA 1	PLA 2	PLA 3	PLA 4
Ra before (µm)	5.574	6.556	4.282	3.846
Ra after (µm)	1.064	1.201	1.569	1.681

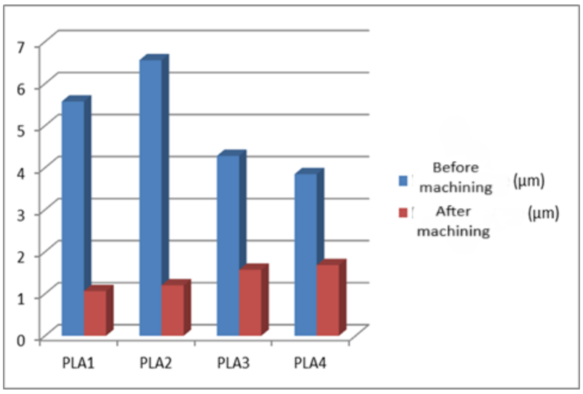

Figure 5. Surface roughness before and after machining

From table 1, it can be noted that in the case of specimen PLA 1, which was machined to a depth of 0.1 mm, the surface roughness before machining was 5.574 µm, while after machining it was significantly reduced and amounted to 1.064 µm. For specimen PLA 2, which was machined to a depth of 0.2 mm, it can be seen that the roughness before machining was 6.556 µm, and after machining it was 1.201 µm. For specimen PLA 3, which was machined to a depth of 0.3 mm, it is noted that the roughness before machining was 4.282 µm, while after machining it was reduced to 1.569 µm. For the

PLA 4 specimen, which was machined to a depth of 0.4 mm, the roughness before machining was 3.846 μm, while after machining it was 1.681 μm. From Figure 5, it can be seen that milling can significantly reduce the surface roughness of 3D printed parts. In addition, it can be seen that the machining parameters can have a great impact on the surface roughness, because in this case, with increasing cutting depth, the surface roughness also increased.

4. CONCLUSION

3D printing is a fast way of producing parts, but in order to achieve a high quality surface, it is necessary to use some post-processing methods.

From the aspect of improving surface roughness, in all samples, the surface roughness was significantly reduced by machining, before machining Ra was 5.574 μm, while after machining it has a significantly lower value of Ra of 1.064 μm. This indicates that CNC milling has a great impact on improving surface finish. Also, machining parameters such as cutting depth have a direct impact on surface roughness, with the roughness increasing with increasing cutting depth. These analyses confirm the effectiveness of CNC machining in improving dimensional accuracy, reducing geometric deviations, and improving surface roughness for all materials used.

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