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INFLUENCE OF MACHINING PARAMETERS ON THE SURFACE ROUGHNESS OF POLYMERS

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Abstract: *CNC technologies are one of the most common technologies in all branches of industry, and milling is one of the most common machining processes in the industry. In addition to all types of materials that are available in various industries, polymers are certainly one of the most represented. Good quality of treated surfaces is certainly one of the primary goals of material processing. Manufacturing technologies such as injection molding and 3D printing cannot always deliver good surface quality, and for this reason it is necessary to additionally machining parts and materials. In addition, different parameters during machining, such as cutting speed, depth of cut, feed can have a great influence on the surface roughness and machining quality. In this paper, the effects of machining parameters for several types of polymers will be presented from the aspect of surface roughness.*

Keywords*: CNC technologies, 3D printing, Surface roughness, Polymers, Milling.*

1. INTRODUCTION

Industry and industrial production, technologies, materials and equipment in use are advancing very rapidly. One of the materials that are the most frequently used is certainly plastic materials. Dimensional accuracy and high surface smoothness are desirable characteristics of plastic products in the applications of precision machinery. To acquire these characteristics, plastic products need to undergo machining process. Injection moulding is primarily manufacturing process for plastic materials, but 3D printing technology is also gaining more and more importance. 3D printer technology can produce products of any complex shape, without having to consider processing problems, and solves the problems of designing and manufacturing complex parts and it enables the production of models of parts and assemblies from many different materials, with different mechanical and physical properties. Therefore, 3D printing technology is a very important production method in industry [1, 2]. When we have a complex geometry that is ideal for 3D printing, however, the part requires critical dimensions and fine features that cannot be achieved by printing alone, as in the case of injection moulding, CNC machining is one of the solutions that will lead to the geometrically and dimensionally accurate part that is needed [3, 4]. In machining process, surface quality characteristics are being affected by process parameters like cutting speed, depth of cut and feed rate. The parameter that certainly best shows the quality of the surface is the surface roughness, which is expressed through the average arithmetic roughness Ra. Many researchers were engaged in examining the surface roughness of 3D printed materials and polymers, as well as improving the quality of machined surfaces using CNC technologies.

Cococcetta et al. investigated the effects of the printing process and plane milling process on the post-processing quality of thermoplastic CFRP composites. The results showed that deep cooling reduced tool wear during milling and was able to completely eliminate or reduce burrs by 90% [5].

Noorani et al. machined 3D printed plastic parts and achieved high accuracy and excellent surface finish, which is still a limitation for 3D printing [6].

Boschetto et al. have developed a methodology in their work that can unlock the possibility of parts made by fused deposition modeling to be machined. A variable depth of cut was considered to avoid internal defects and eliminate initial surface morphology. The experimental campaign made it possible to determine how the depth of cut should be adjusted as well as the function of the deposition angle. A certain virtual offset model is allowed for the generation of machine code in computer-aided manufacturing. A case study characterized by functional surfaces confirmed the applicability of the method to complex geometry: A large reduction in average roughness and reliability of finished surfaces was achieved [7].

Adeniji et al. characterized surface roughness and formation of burrs during the milling of polycarbonate with reference to the milling parameters. They concluded that the depth of cut had no big impact on the surface roughness, but, the burrs formation was promoted by the lubricating effect of the coatings applied and the cutting-edge radius [8].

Wang et al. further investigated the impact of milling temperatures on carbon fiber reinforced polymer

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composites and found out that the milling temperatures increased with the cutting speed [9].

Keresztes et al. investigated machinability of polymers such as PA 6 (Mg), PA 6 (Na), POM C (Polyoximethylene), HD 1000 (UHMWPE). They found that PA 6 is toughest material in the view of cutting resistance and cutting force. By increasing feed rate and depth of cut, cutting force decreases. With increase in depth of cut and feed rate, amount of decrease in cutting force for remaining polymers are stated in descending order: PA 6 (Na), POM C, HD 1000 [10].

Jenarthanan et al. observed in his study that end mills with small helix angles develop the greatest machining force, lowest surface roughness and delamination factor. Surface roughness, machining force and delamination factor increases with increase in fiber orientation angle and feed rate, and decreases with increase in cutting speed. It is suggested that lower fiber orientation angle, lower helix angle, moderate spindle speed and lower feed rate are the ideal machining conditions for machining of GFRP composite [11].

Ramulu et al. investigated machining of polymeric composites and found that an increasing of the cutting speed leads to a better surface finish [12].

Hussain et al. studied machinability of glass fiber reinforced polymer materials. It is found that with increase in feed rate, surface roughness increases, whereas it decreases with increase in cutting speed and orientation angle, while depth of cut has lowest effect on surface roughness. Cutting forces are highly influenced by feed, followed by cutting speed [13].This paper present the effects of different machining parameters on surface roughness of plastic materials.

2. MATERIALS AND EQUPMENTS

In this work, specimens for CNC machining were printed on low-cost Creality 10-s printer, which is located at Faculty of Tehnical Science in Kosovska Mitrovica (Figure 1). Characteristics of printer are: Build area of 300x300x400 mm, nozzle diameter 0.4, print speed normal 60 mm/s - max 100 mm/s, and with wide range of materials like PLA, PETG, TPU, ABS, But ABS and PLA are definitely the most represented. 3D printed parts and other specimens were machined on CNC milling machine.

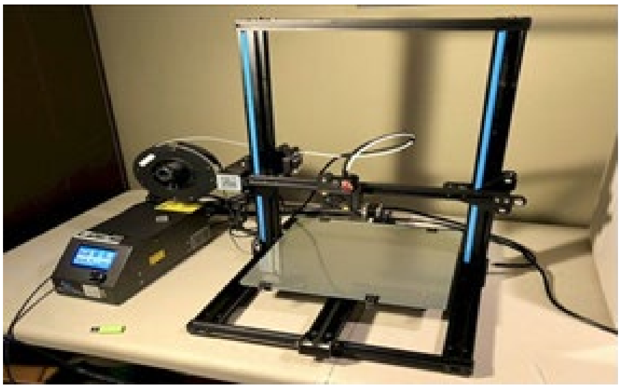

Fig.1. Creality CR 10-s 3D printer

The machine used for machining is a Haas VF-3SS vertical milling machine with three CNCs controlled axes (Figure 2), which is located on Faculty of Engineering, Kragujevac. This vertical milling machine has an axis of rotation in the Z direction axes, while the X axis represents the length of the work table, while the Y axis follows the movement of the table forward and back. All axis movements are provided by spiral spindles with a nut, and as a measuring device the system uses a linear encoder. The control unit of the HAAS VF-3SS is HAAS 2. Features of the Haas VF-3SS vertical milling machine are: H-Y-Z axis range: 1016-508-635 mm, maximum number of revolutions 12000 rpm, maximum speed of auxiliary movement 21.1 m/min, total power 22.4 kW, capacity of tools in the magazine 24+1.

Fig.2. Milling machine HAAS VF-3SS

The materials used in this research are:
A-HD500 polyethylene,
B-3D printed PLA,
C-HD1000 polyethylene,
D-3D printed PLA,
E-PVC,
F-Polyoxymethylene (POM).

The samples marked with B and D were made of the same material, but the difference is in the manufacturer and color. Specimen B is made by Ultimaker, and color was yellow, and specimen D is made by Devil Design, and color was natural.

The tool used is a spindle cutter made of hard metal (VHM), and surface roughness was measured with a TALYSURF-6 measuring system connected to a computer, and the results are shown in the diagrams using Microsoft Excel software.

3. EXPERIMENTAL RESULTS AND ANALYSIS

The following figures (Figure 3-Figure 8) show the results of the surface roughness with variable machining parameters.

Surface roughness was exspressed trough the average arithmetic roughness Ra. After analyzing the results, it can be seen from the diagrams that the best machinability is with the materials that gave the lowest surface roughness. With some materials, we can see that the results deviate from the expected ones due to measurement error or sticking of the material to the tool, so it is necessary to repeat the measurements and machining process.

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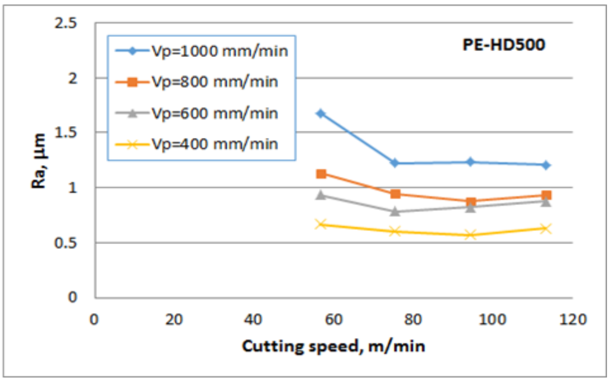

Fig.3. Specimen A-HD500 polyethylene

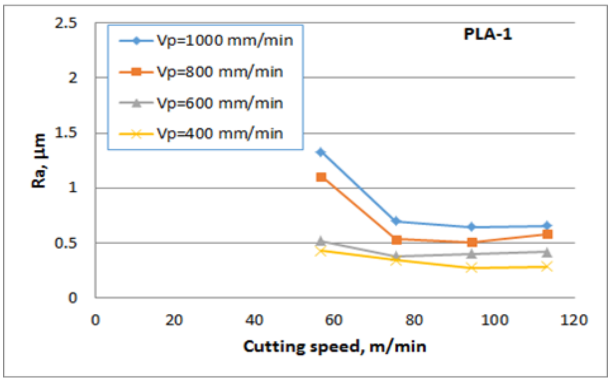

Fig.4. Specimen B-3D printed PLA-1

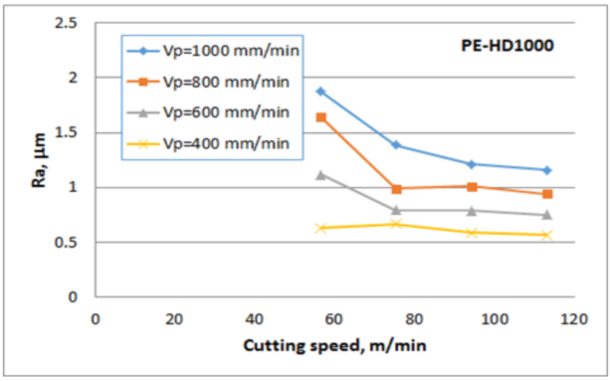

Fig.5. Specimen C- HD1000 polyethylene

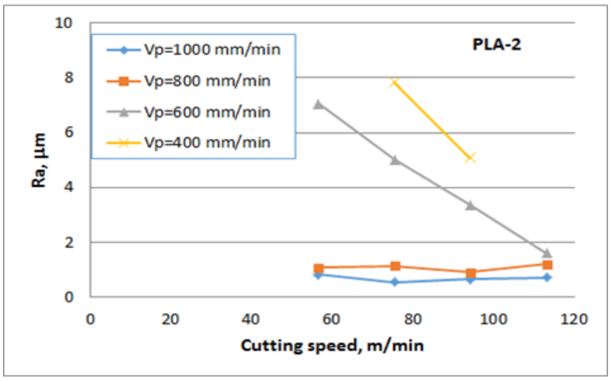

Fig.6. Specimen D-3D printed PLA-2

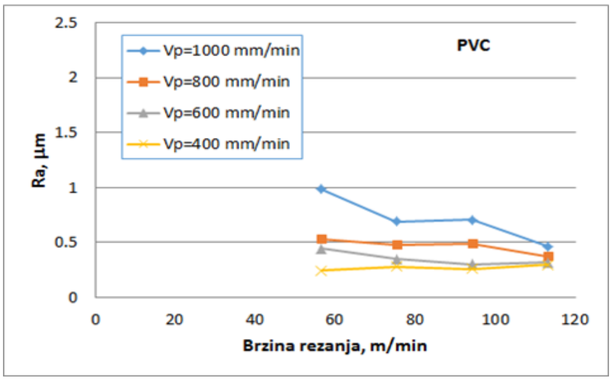

Fig.7. Specimen E- PVC

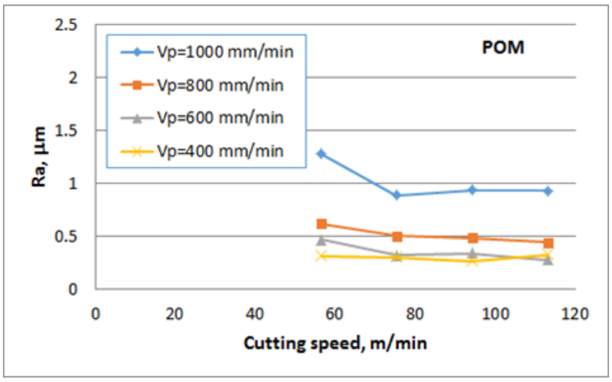

Fig.8. Specimen F- POM – Polyoxymethylene

4. CONCLUSION

This paper shows the effects of changing machining parameters from the aspect of surface roughness. Plastic specimens which were used were obtained through traditional methods as well as 3D printing. Parameters such as cutting speed, depth of cut, feed can have a great influence on the machining process as well as on the quality of the machined surfaces.

These are preliminary results that require further research to reduce surface roughness. The measurements should be repeated and justified, and it should be determined how the errors shown in the experimental part occurred.

REFERENCES

[1] https://www.industrija.rs/vesti/clanak/3dstampa accessed: 02.09.2023

[2] Botao, H., Guomin, L (2020) *3D Printing Technology and Its Application in Industrial Manufacturing*. IOP Conf. Series: Materials Science and Engineering

[3] https://www.stratasysdirect.com/technologies/cnc-machining/cnc-machining-3d-printed-parts accessed: 02.09.2023

[4] https://www.sculpteo.com/blog/2019/10/23/3d-printing-and-machining-how-to-combine-them-for-your-benefits/ accessed: 02.09.2023

[5] Kulkarni, P., Dutta D (2000) *On the integration of layered manufacturing and material removal process*. Journal of Manufacturing Science and Engineering, volume (122), pp 100-108

TOC

[6] Noorani, R (2018) *3D Printing, Technology, Applications and Selection*, CRC Press, Boca Ratón, Florida (US)

[7] Boschetto, A., Bottini, L., Veniali, F (2016) *Finishing of Fused Deposition Modeling parts by CNC machining*, Robotics and Computer-Integrated Manufacturing, volume (41), pp. 92–101

[8] Adeniji, D., Schoop, J., Gunawardena, S., Hanson, C., Jahan, M (2020) *Characterization and Modeling of Surface Roughness and Burr Formation in Slot Milling of Polycarbonate*, J. Manuf. Mater. Process. pp. 1-22

[9] Wang, H., Sun, J., Zhang, D., Guo, K., Li, J (2016) *The effect of cutting temperature in milling of carbon fiber reinforced polymer composites,* Compos. Part A Appl. Sci. Manuf. 91 pp. 380–387

[10] Keresztes, R., Kalacska, G., Zsidai, L., Dobrocsi, Z (2011) *Machinability of engineering polymers*, Sustainable Construction and Design, pp. 106-114

[11] Jenarthanan, M.P., Jeyapaul, R (2013) *Optimisation of machining parameters on milling of GFRP composites by desirability function analysis using Taguchi method,* International Journal of Engineering, Science and Technology, Vol. 5, No. 4, pp. 23-36

[12] Ramulu, M., Arola, D., Colligan, K (1994) *Preliminary investigation of effects on the surface integrity of fiber reinforced plastics*, Engineering Systems Design and Analysis, pp. 93–101

[13] Hussain, S.A., Pandurangadu, V., Kumar, K (2011) *Machinability of glass fiber reinforced plastic (GFRP) composite materials*, International Journal of Engineering, Science and Technology, Vol. 3, No. 4, pp. 103-118