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Original scientific paper

The Influence of the Number of Layers and the Raster Angle on the Mechanical Properties of 3D Printed Materials

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Abstract: 3D printing represents one of the newer production technologies which are becoming more and more important. The widening range of materials used in 3D printing leads to the need to examine their mechanical properties. 3D printing parameters such as infill pattern, building orientation, layer thickness, number of layers in the wall and air gap have a great influence on the mechanical properties. In this study, the mechanical properties were examined from the perspective of the influence of the raster angle and the change in the number of layers in the wall. Three different materials were tested, PLA, PETG and ABS. The results showed that the highest tensile strength was obtained with PETG material, and the lowest with ABS. From the aspect of the influence of the printing parameters, we can conclude that the building orientation and the number of layers in the wall have influence on mechanical properties of the material.

Keywords: 3D printing; mechanical properties; raster angle; tensile strength; wall layers

1 INTRODUCTION

3D printing represents one of the increasingly common technologies in the world of manufacturing [1-3]. In 3D printing, layers are added on top of each other to create a model that is created in CAD software before the actual printing process. In contrast to CAM technology, where the required geometry is obtained by removing material, in 3D printing material is added by different processes, printing technologies and different materials that can be used. Some of the most common technologies are Stereolithography, Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM) and one of the most widespread and most frequently used is Fused Deposition Modeling (FDM). This technology is most often used, first of all, due to low production costs, accessibility of equipment, and rapid prototyping. This process was developed by the company called MarkForged.

With FDM technique, the model is produced by extruding small beads of material which harden to form layers. A thermoplastic filament or wire that is wound into a coil is unwounded to supply material to an extrusion nozzle head (Fig. 1). Usually 1.75 - 3 mm wire thickness is used. During 3D printing, the material in the form of wire is melted by passing a 0.4 mm diameter nozzle and the production is carried out by axial movement [4, 5].

There are many parameters in the FDM printing process that affect the quality, geometric and mechanical properties such as build orientation, printing speed, layer thickness, raster angle, infill pattern, infill density, raster width, etc. Many researchers deal with the influence of different printing parameters on mechanical properties of printed parts.

Ashtankar et al. [7] investigated the effect of build orientation of ABS 3D-printed parts made by Fused Deposition Modeling, and results indicated that the tensile strength decreased when the orientation of the samples was aligned from 0° to 90°.

Montero et al. [8] in their study investigated printing process parameters and their influence on properties of parts produced by Fused Deposition Modeling. Air gap and raster orientation had greater effects on tensile strength than printing temperature, raster width, and filament color. Another conclusion is that the tensile strength would increase in the case when the air gap was negative.

Gunasekaran et al. [9] in their study showed that the specimens printed with 100% infill density have improved mechanical properties in terms of tensile strength, hardness, flexural strength and impact strength.

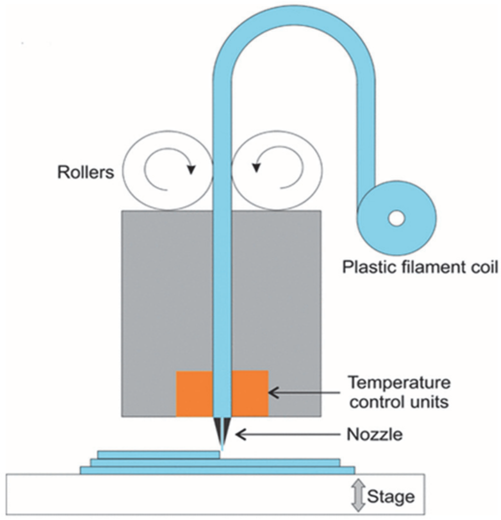


Figure 1 Process of fused deposition modeling [3]

Dawoud et al. [10] in their study investigated the effect of process parameters on the mechanical behavior of 3D printed ABS, specifically different combination of air gap and raster angles in printing layers of Fused Deposition Modeling technology. Results show that with FDM technology and with certain parameters, mechanical properties can be comparable to those of injection molded parts.

Chacon et al. [11] investigated the influence of layer height and build orientation on the mechanical properties of PLA specimen fabricated with Fused Deposition Modeling technique. They found that high tensile strength resulted due to small layer height, and the tensile strength varies significantly for the specimen with flat orientation.

According to A. Gebisa et al. [12] the tensile properties of ULTEM polyetherimide showed that compared to other printing parameters like air gap, raster width and raster angle, number of layers in wall had low influence on the mechanical properties.

Y. Liu et al. [13] in their study investigated the influence of printing parameters (number of walls, printing direction and infill patterns) on the mechanical properties of parts printed with onyx material. They found that two wall layers, flat printing and triangular pattern are the optimal parameters.

Mishra and Mahapatra [14] studied the influence of wall layers and other parameters on the tensile strength of Fused Deposition Modeling specimens. They concluded that the tensile strength of FDM parts enhances when the wall layer increases.

Rodriguez-Panes A. et al. [15] concluded that layer orientation, layer height and infill density have great influence on mechanical properties of 3D printed parts. They also noted that PLA has better mechanical properties than ABS.

Study by Dwiyati S.T. et al. [16] showed that greater tensile strength and maximum force were presented in specimens with thicker layers. Compared to the other direction, the highest tensile strength and forces were seen in the axial direction of 3D printed specimens.

Nikiema et al. [17] investigated the influence of layers in wall on mechanical properties. They found that with higher number of walls, specimen was found to be the mechanically strongest. However, as the number of walls increases, the global strain of the specimens decreased, with 70% reduction in deformation between a specimen with 1 layer in wall and specimen with 10 layers in wall.

Eryildiz [18] in his experimental study investigated the effect of 100% infill density and maximum wall number on flexural strength. He concluded that addition of maximum number of walls to the build parts increases the strength by shifting the stress concentration zone from outer edges to the center of the specimen due to avoidance of premature failure of the build parts.

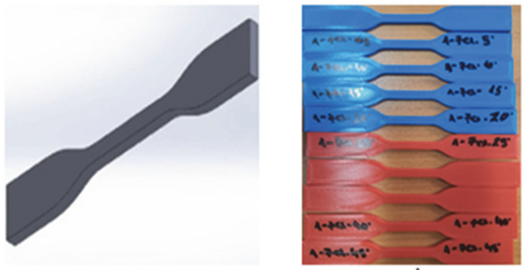
In another study by Eryildiz [19], tensile strength decreased when the build orientation of the parts was aligned from flat to upright direction and 0° to 90° raster angle. For upright build orientation, 36% less tensile strength was obtained compared to the flat ones because of the loading direction and fracture mode. It is also observed that the build orientation had a big influence on the mechanical properties.

Cwikla et al. [20] in their study showed that the best set of parameters is 2 - 3 layers in wall, a honeycomb pattern with infill density of about 40 - 50%. If the maximum strength is the priority, number of layers in wall should be increased.

Based on the review of literature and research related to press parameters and their impact on mechanical properties, it can be concluded that the papers mainly deal with research of 3D printing of PLA and ABS materials individually. There are no research papers comparing the impact characteristics of 3D printing of a number of different materials on mechanical characteristics. The aim of this paper is to investigate the influence of the printing conditions, that is, the raster angle and number of layers in wall on tensile strength.

2 MATERIAL AND METHOD AND EQUIPMENT

In this research, Solidworks 2015 CAD software was used for modeling dog bone specimen (Fig. 2a) and specimen after printing was given in Fig. 2b. ASTM D638 standard [22] specimen type IV was adopted in order to evaluate tensile strength. The ASTM standard is the most commonly used standard in research so far in the field of testing the mechanical properties of printed specimens, which enables an easier comparison of the measured results. The dimensions of the tensile test specimens are shown in Fig. 3.



a b

Figure 2 Specimen in CAD software (a) and after printing (b)

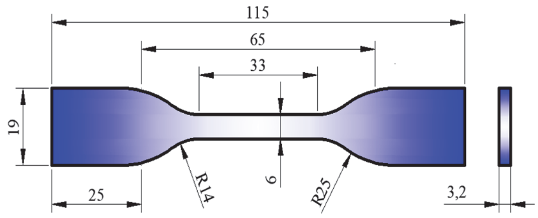
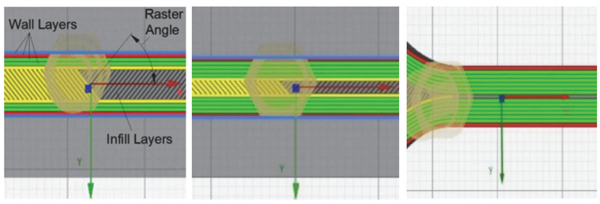


Figure 3 ASTM D638 Type-IV standard specimen dimensions [21]

3D CAD model was saved in STL file and imported to Ultimaker Cura software, where changes to print parameters were made. The number of wall layers varied from the standard setting to 3, 5 and 7 layers in the wall for specimens made with PLA, and 5 and 7 layers in wall for specimens made from ABS and PETG, while the raster angle was changed from 0° to 45° and infill pattern were lines for all specimens, build orientation of specimens was on flat, in the *XY* plane. Fig. 4 shows the infill of the central part of the specimens with 3 layers in the wall (Fig. 4a), 5 layers in the wall (Fig. 4b) and 7 layers in the wall (Fig. 4c). In Fig. 5 are presented changes of raster angles on printer build plate.



a b c

Figure 4 Central part of specimens with 3, 5, 7 layers in wall

Parameters of printing for all specimens are given in Tab. 1. The selected parameters are the recommended parameters for printed specimens.

Tensile strength specimens were printed on Creality 10 printer, which is located at the Faculty of Technical Sciences in Kosovska Mitrovica. Characteristics of the printer are: Build area of 300 × 300 × 400 mm, nozzle diameter 0.4 mm, print speed normal 60 mm/s max 100 mm/s, and a wide range of materials like PLA, PETG, TPU, ABS. 70 different specimens were sliced and then printed with three different materials, ABS, PLA and PETG. Each specimen was printed in 3 copies with the same parameters. The reproducibility of the measurement results was performed on several samples and proved to be good. As no significant difference was observed in the measured data, standard deviation was not derived. Fig. 5 shows the change of raster angle on 3D printer build plate.

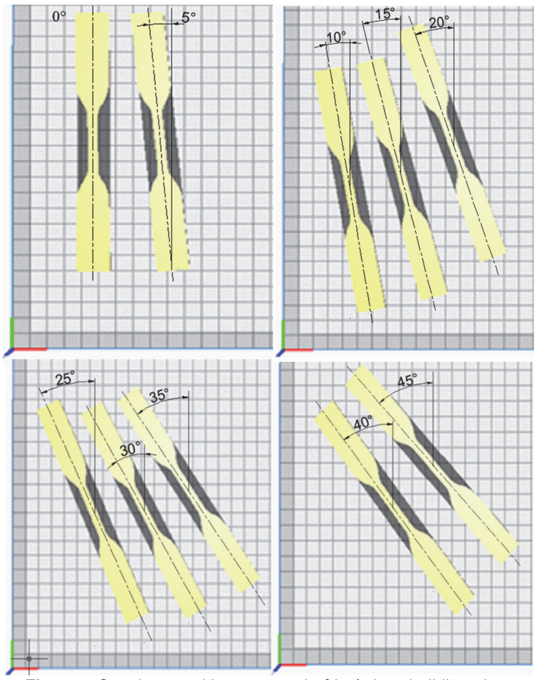


Figure 5 Specimens with raster angle 0°- 45° on building plate

Table 1 Printing parameters

Filament material	PLA			ABS		PETG	
Layer Heights, mm	0,2						
Wall Line Count (Wall Layers)	3	5	7	5	7	5	7
Infill Density / %	100						
Infill Pattern Type	Lines						
Printing Temperature / ºC	200			230		230	
Build Plate Temperature / ºC	50			80		70	
Printing Speed, mm/s	60			60		60	
Number of Specimens	10	10	10	10	10	10	10
Raster Angle / º	0, 5, 10, 15, 20, 25, 30, 35, 40, 45						

The tensile strength tests on the specimens to determine their mechanical properties were performed on a Shimadzu type EHF EV101K3-070-0A servo-hydraulic testing machine made by Shimadzu Corporation, Tokyo, Japan (Fig. 6) with a force of ±100 kN and a stroke of ±100 mm, which is located at the Faculty of Engineering, University of Kragujevac. The tensile strength was tested at a speed of testing of 5 mm/min. In Fig. 7 can be seen the procedure for tensile strength testing.

In order to examine the reproducibility of measurements during tensile testing, due to the large number of samples, tensile testing of all 3 specimens printed in the same conditions was performed on several specimens where deviations of less than 3% were obtained, which is a measurement error.

Figure 6 Shimadzu type EHF EV101K3-070-0A

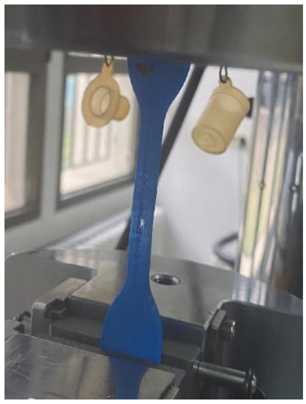


Figure 7 Tensile strength testing servo-hydraulic testing machine

3 RESULTS AND DISCUSSION

For specimens made of PLA material, shown in Fig. 8, 3 layers (3L PLA) in the wall give the highest tensile strength with the lowest raster angle of 0° (50 MPa), while the specimens with the largest raster angle (40° - 45°) have the lowest tensile strength (45.5 MPa). For specimens with 5 layers in the wall (5L PLA), it can be seen that the raster angle has no significant influence on the tensile strength and the highest is 47.2 MPa, while the lowest is 43.5 MPa. For 7 layers in the wall (7L PLA), it can be seen that the raster angle also has a small influence on tensile strength, while with an increase in the raster angle, the tensile strength has a slight drop. The highest tensile strength is 54.2 MPa, while the lowest is 52.8 MPa.

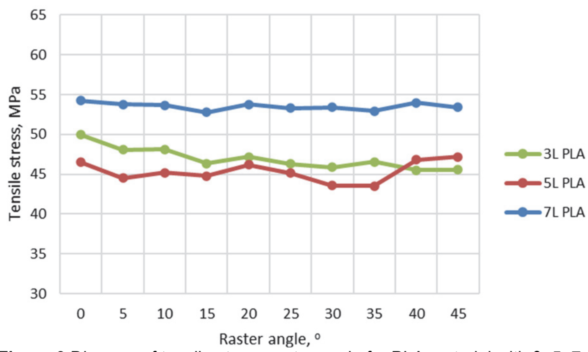


Figure 8 Diagram of tensile stress-raster angle for PLA material with 3, 5, 7 layers in the wall

For PETG specimens (Fig. 9) it can be seen that with 5 layers in the wall, the highest tensile strength is with raster angle of 0° (60.702 MPa), while the lowest is with raster angle of 45° (52.804 MPa). In case of 7 layers in wall, the highest tensile strength is with raster angle of 0° (58.839MPa) and the lowest one with raster angle of 20° (53.849 MPa).

In the case of ABS specimens (Fig. 10) it can be seen that with 5 layers in the wall (5L ABS) the tensile strength ranges from the limits of 32.5 MPa to 35.3 MPa and trend of change cannot be observed. With 7 layers in wall (7L ABS), the tensile strength slightly decreases with increasing raster angle and ranges from 35.9 MPa for the smallest raster angles to the smallest values 34.2 to 35 MPa.

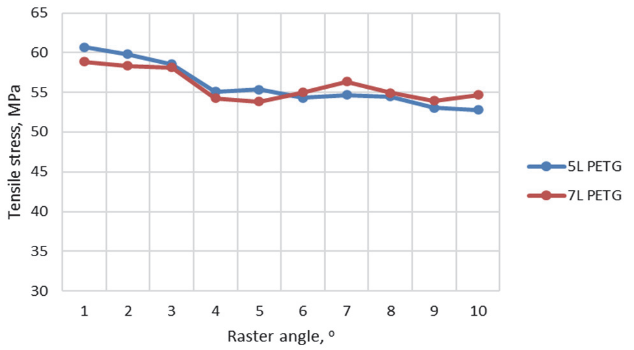


Figure 9 Diagram of tensile stress-raster angle for PETG material with 5 and 7 layers in the wall

Fig. 11 shows the force-elongation diagram of a specimen made of PLA material with 3 layers with a change in the raster angle from 0° to 45°. From the diagram, it can be seen that the change of the raster angle does not affect the elongation of the specimens, while it slightly affects the change in tensile strength.

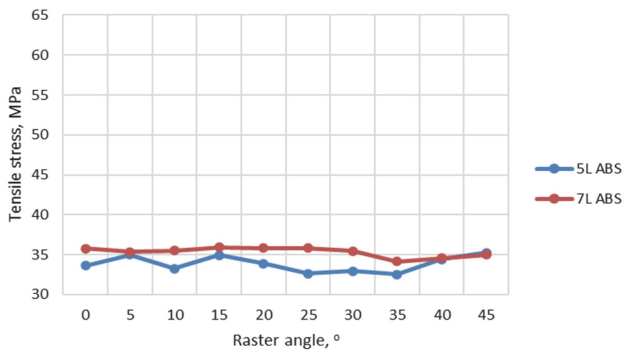


Figure 10 Diagram of tensile stress-raster angle for ABS material with 5 and 7 layers in the wall

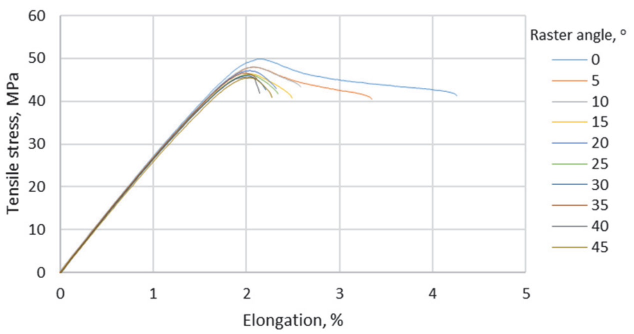


Figure 11 PLA 3L force-elongation diagram

Fig. 12 shows the force-elongation diagrams of specimens made of all materials with 5 layers in wall and raster angle of 0º. From the diagram, it can be seen the behavior of the specimens during stretching as well as the influence of the number of wall layers on the elongation. In specimens with 5 wall layers, PLA specimens showed the highest elongation, followed by PETG, while the lowest elongation was in specimens made of ABS material. A similar trend was shown in specimens with 7 layers (Fig. 13), with the difference that specimens made of PETG material showed the highest elongation, followed by PLA specimens while specimens made of ABS material again showed the lowest elongation. Elongation in PETG and PLA specimens is significantly higher, while in ABS specimens it is approximately the same compared to specimens with 5 layers.

From the results, it can be seen that the average value of the tensile strength of ABS material compared to PETG is 39.4% lower for specimens with 5 layers in wall, while for specimens with 7 layers in wall it is 36.7% lower. The average tensile strength for specimens made from PLA material is lower than PETG by 54.6% with five layers in wall and 46.5% lower for specimens with 7 layers. The average tensile strength of ABS material is 25.3% lower for specimens with 5 layers in wall and 34% lower for specimens with 7 layers in wall compared to PLA material. Fig. 14 represents the tensile strength for all materials.

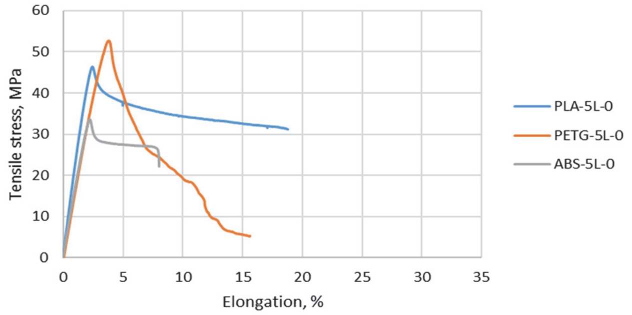


Figure 12 5L force-elongation diagram

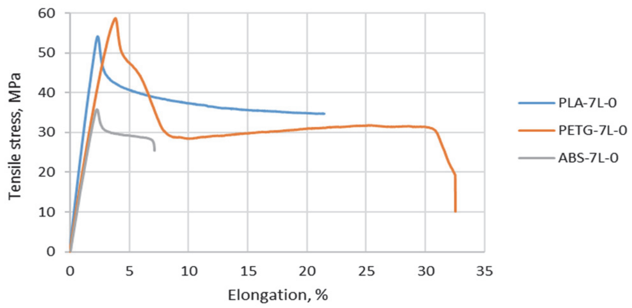


Figure 13 7L force-elongation diagram

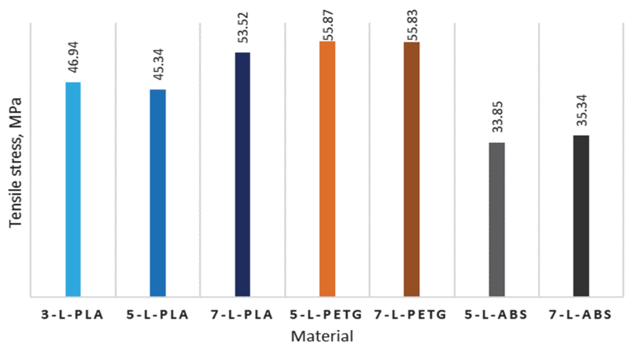
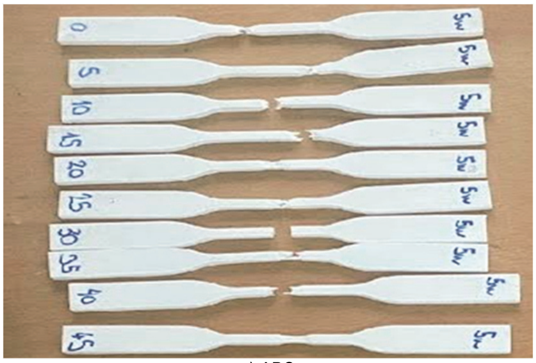


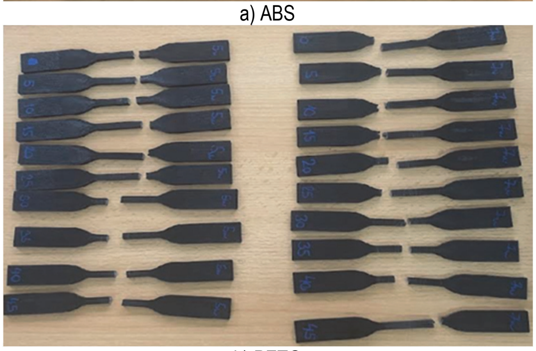
Figure14 Average tensile stress for all specimens

Fig. 15 shows all the specimens after tensile testing. The specimens made of ABS material are mostly torn in one part, while there are also a certain number of specimens that have become delaminated and elongated (Fig. 15a). All PETG specimens were torn in the central part closer to one of the jaws of the tensile test machine (Fig. 15b). In the case of the largest number of PLA specimens, there was no tearing, but there was delamination and elongation (Fig. 15c).

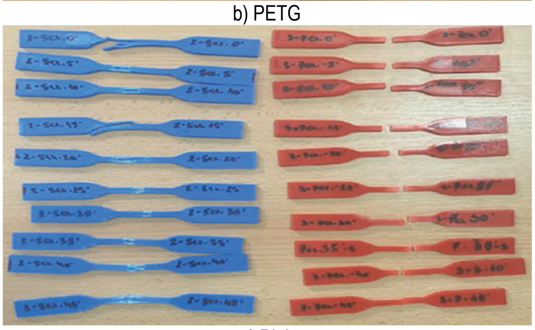
In terms of materials, PETG material had the highest tensile strength. Slightly lower tensile strength was achieved with PLA material, while ABS material had the lowest tensile strength.



a) ABS



b) PETG

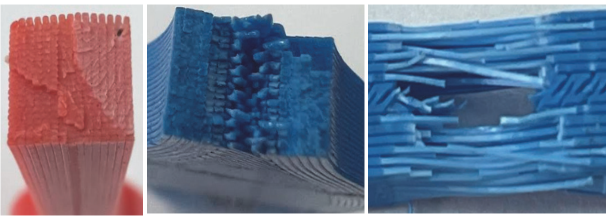


c) PLA

Figure 15 Specimens after testing

One of the reasons for these results is that the 7 - layer specimens were filled with layers in the wall in the central part (Fig. 16a). The longitudinal layers are connected by a greater adhesion force, so specimens were compactly filled in cross-sectional area and maximum tensile strength (53.52 MPa) was obtained.

In the case of specimens with 5 layers, the space for filling was insufficient, so that a good mutual connection between the inner filling and the layers in the wall was not achieved. A non-compact cross-section was obtained during testing, which led to delamination of both the longitudinal and the filling layers. This resulted in the lowest tensile strength (45.34 MPa) (Fig. 16c).



a b c

Figure 16 PLA specimen with 7 layers after tensile test (a), 3 layers (b), 5 layers (c)

In the specimens with 3 layers, there is enough space left in the central part to fill the space well with the inner layers (Fig. 16b). Good adhesion bond was formed between the longitudinal layers and the filling layers, which gave good cross-sectional compactness. The diagram shows a higher value of tensile strength (46.94 MPa) compared to the specimens with 5 layers.

4 CONCLUSION

The aim of this paper was to show the influence of printing parameters on the mechanical properties of the materials for 3D printing parts. Three different materials were used, PLA, ABS and PETG, and in terms of parameters, the number of layers in the wall and the raster angle were varied. After analysis of the obtained results, we came to the following conclusions:

- Regarding the material, the PETG material showed the highest tensile strength; it was slightly lower in the case of the PLA material, but was significantly lower in the case of the ABS material.
- From the aspect of the raster angle, it can be concluded that in the case of PETG and PLA materials, increase of the raster angle slightly reduces the tensile strength, while there is no significant difference in the case of ABS specimens.
- With a greater number of layers in the wall, the tensile strength increases.
- Changing of raster angle does not affect the change in the value of the elongation of the specimens during the tensile test.
- The number of layers in the wall increases the elongation of the specimens. This is pronounced in specimens made of PLA and PETG materials.
- In the case where the specimens are printed with PLA material, the effect of changing the number of layers in the wall can be seen, because 3 layers in the wall leave enough space for infill layers, 7 layers in the wall fill the central part and give greater tensile strength, while with 5 layers in the wall there is not enough space for filling and the layers are not well glued.
- The effect of filling with PLA material for specimens with 5 layers in the wall is significantly higher than for specimens with 5 layers in the wall made of ABS and PETG materials, i.e. delamination occurs, i.e. reduction of athesia between the layers.

The reasons for the observed differences between the tensile strengths can be found in the fact that the tested specimens were made from different materials, which certainly has an impact on adhesion between the layers.

These results represent part of the preliminary research and indicate the direction in which future research should continue.

Further research should take into account the influence of different materials, 3D printing parameters such as nozzle diameter, raster angle, number of wall layers, print speed, temperature, etc., in order to obtain a model that could more accurately predict their effect on athesia between layers. The available information (databases) of previous research should be included in order to obtain a more precise model.

5 REFERENCES

[1] Tripathy, C. R., Sharma, R. K., & Rattan, V. K. (2022). Effect of printing parameters on the mechanical behaviour of

the thermoplastic polymer processed by FDM technique: A research review. *Advances in Production Engineering & Management, 17*(3), 279-294. https://doi.org/10.14743/apem2022.2.427

[2] Curkovic, P. & Cubric, G. (2021). Fused Deposition Modelling for 3D Printing of Soft Anthropomorphic Actuators. *International Journal of Simulation Modelling, 20*(2), 303-314. https://doi.org/10.2507/IJSIMM20-2-560

[3] Neuenfeldt-Junior, A., Cheiram, M., Eckhardt, M., Scheuer, C., Siluk, J., & Francescatto, M. (2021). Additive and Subtractive Rapid Prototyping Techniques: A Comparative Analysis of FDM & CNC Processes. *International Journal of Industrial Engineering and Management, 12*(4), 262-273. https://doi.org/10.24867/IJIEM-2021-4-293

[4] Çabuk, N. & Çabuk, S. (2018).3D Printers and Application Fields. *1. International technological sciences and design symposium*, *Giresun/Turkey*, 349-356.

[5] Radojičić, S., Konjatić, P., Katinić, M., & Kačmarčik, J. (2023). The Influence of Material Storage on Mechanical Properties and Deterioration of Composite Materials. *Tehnički vjesnik, 30*, 1645-1651. https://doi.org/10.17559/TV-20230308000422

[6] Avinc, O., Yildirim, F., Yavas, A., & Kalayci, E. (2017). 3D printing technology and it influences on the textile industry. *International Journal of Industrial Electronics and Electrical Engineering, 5*(7), 37-43.

[7] Ashtankar, K. M., Kuthe, A. M., & Rathour, B. S. (2013). Effect of build orientation on mechanical properties of rapid prototyping (Fused Deposition Modeling) made Acrylonitrile Butadiene Styrene (ABS) Parts. *ASME 2013 International Mechanical Engineering Congress and Exposition, 11*, 1-7.https://doi.org/10.1115/IMECE2013-63146

[8] Montero, M., Roundy, S., Odell, D., Sunghoon, A., & Wright, P. (2001). Material characterization of fused deposition modeling (FDM) ABS by designed experiments. *Society of Manufacturing Engineers.*

[9] Gunasekaran, K. N., Aravinth, V., Kumaran, C. M., Madhankumar, K., & Kumar, S. P. (2021). Investigation of mechanical properties of PLA printed materials under varying infill density. *Materials Today: Proceedings, 45*(2), 1849-1856. https://doi.org/10.1016/j.matpr.2020.09.041

[10] Dawoud, M., Taha, I., & Ebeid, S. J. (2016). Mechanical behaviour of ABS: An experimental study using FDM and injection moulding techniques. *Journal of Manufacturing Processes, 21,* 39-45. https://doi.org/10.1016/j.jmapro.2015.11.002

[11] Chacon, J. M., Caminero, M. A., Garcia-Plaza, E., & Nunez, P. J. (2017). Additive manufacturing of PLA structures using fused deposition modelling: effect of process parameters on mechanical properties and their optimal selection. *Material & Design, 124*, 143-157 https://doi.org/10.1016/j.matdes.2017.03.065

[12] Gebisa, A. W. & Lemu, H. G. (2018). Investigating Effects of Fused-Deposition Modeling (FDM) Processing Parameters on Flexural Properties of ULTEM 9085 Using Designed Experiment. *Materials, 11*(4).

[13] Liu, Y., Jiang W., Hu, W., Ren, L., Deng, E., Wang, Y., Song, C., & Feng, Q. (2023). Compressive strength and energy absorption characteristics of the negative stiffness honeycomb cell structure. *Materials Today Communications, 35*(22). https://doi.org/10.1016/j.mtcomm.2023.105498

[14] Mishra, S. B. & Mahapatra, S. S. (2014). Improvement in Tensile Strength of FDM Built Parts by Parametric Control. *Applied Mechanics and Materials 592-594*, 1075-1079. https://doi.org/10.4028/www.scientific.net/AMM.592-594.1075

[15] Rodríguez-Panes, A., Claver, J., & Camacho, A. M. (2018). The influence of manufacturing parameters on the mechanical behaviour of PLA and ABS pieces manufactured by FDM: a comparative analysis. *Materials, 11*(8), 1333. https://doi.org/10.3390/ma11081333

[16] Dwiyati, S. T., Kholil, A., Riyadi, R., & Putra, S. E (2019). Influence of layer thickness and 3D printing direction on tensile properties of ABS material. *Journal of Physics Conference Series*, 1402. https://doi.org/10.1088/1742-6596/1402/6/066014

[17] Nikiema, D., Awa Sène, N., Balland, P., & Sergent, A. (2023). Study of walls' influence on the mechanical properties of 3D printed onyx parts: Experimental, analytical and numerical investigations. *Heliyon, 9*. https://doi.org/10.1016/j.heliyon.2023.e19187

[18] Eryldz, M. (2022). Comparison of Maximum Number of Walls and 100% Infill Density Parameters on Flexural Strength to Obtain FDM Build 3D Solid Parts. *1st International Conference on Engineering and Applied Natural Sciences ICEANS, Konya, Turkey.*

[19] Eryldz, M. (2021). Effect of Build Orientation on Mechanical Behaviour and Build Time of FDM 3D-Printed PLA Parts: An Experimental Investigation. *European Mechanical Science, 5*(3), 116-120. https://doi.org/10.26701/ems.881254

[20] Ćwikła, G., Grabowik, C., Kalinowski, K., Paprocka, I., & Ociepka, P. (2017). The influence of printing parameters on selected mechanical properties of FDM/FFF 3D-printed parts. *IOP Conference Series Materials Science and Engineering, 227.* https://doi.org/10.1088/1757-899X/227/1/012033

[21] Moradi, M., Hashemi, R., & Kasaeian-Naeini, M. (2023). Experimental investigation of parameters in fused filament fabrication 3D printing process of ABS plus using response surface methodology. *The International Journal of Advanced Manufacturing Technology*. https://doi.org/10.1007/s00170-023-11468-0

[22] ASTM D638-14. (2022). *Standard Test Method for Tensile Properties of Plastics*. https://www.astm.org/d0638-14.html

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