The Effect of Nozzle Temperature, Infill Geometry, Layer Height and Fan Speed on Roughness Surface in PETG Filament

Doohan Taqdissillah, Aris Zainul Mutaqqin, Mahros Darsin*, Dedi Dwilaksana, Nasrul Ilminnafik

Department of Mechanical Engineering, Faculty of Engineering, University of Jember, Jl. Kalimantan 37, Jember, 68121, Indonesia
**Corresponding author: mahros.teknik@unej.ac.id*

Article history:
Received: 28 July 2022 / Received in revised form: 13 September 2022 / Accepted: 24 September 2022

ABSTRACT

3D printing is a process of making three-dimensional solid objects from a digital file process created by laying down successive layers of material until the object is created. Many filaments can be used in 3D printing, one of which is PETG (PolyEthylene Terephthalate Glycol). PETG is a modification of PET (PolyEthylene Terephthalate) with added glycol at a molecular level to offer different chemical properties that provide significant chemical resistance, durability, and excellent formability for manufacturing. This study aims to find the most optimal parameter of surface roughness of PETG with different parameters of nozzle temperature, infill geometry, layer height and fan speed. Taguchi L16 (44), with four levels for each parameter, was used to determine the effect of each parameter. Each experiment was repeated five times to minimize the occurrence of errors. Based on the result, the effect of each parameter is nozzle temperature at 4.9%, infill geometry at 5.9%, layer height at 82.3%, and fan speed at 4.6%. Layer height has the highest effect on surface roughness, and other parameters have a low effect, under 7%. Research shows that the optimal combination of parameters is a nozzle temperature of 220 °C, infill geometry zig-zag, layer height of 0.12 mm, and a fan speed of 80 %.

Keywords: *3D printing, PETG filament, printing parameter, Taguchi, surface roughness*

I. Introduction

In this massive industry era, many industries try to satisfy the customer with their product, and one factor that can satisfy the customer is customization. Customization can make the customer choose the design based on what they want, and because of that customer will satisfy with the product [1]-[3]. One of the manufacturing techniques for customization is 3D printing because 3D printing uses a building system so the product can be built up to the design the customer desires. Many filaments can be used as a base material for 3D printing, such as ABS, PLA, PC, PEKK, dan PETG, etc. [4], [5].

PETG is a kind of filament in 3D printing with the market name polyester plastic with the addition of glycol modification [6]. The advantage of PETG material is its excellent chemical resistance, high impact resistance, low shrinkage, and good interlayer bonding [7]-[9]. The popularity of PETG is in the food industry (food-safe plastic containers), the medical sector can be created for medical use (rigid structures that withstand rigorous sterilization processes, implants) and body accessories customization [10]-[13]. In body accessories customization, one product is a necklace. In body accessories customization,

DOI: 10.17977/um016v6i22022p074

surface roughness is the factor that affects in quality of PETG because the smooth surface of accessories can provide comfort to the user. Because of that, smoother surface roughness can improve the material's quality [14]-[16].

Che Mat et al. [17] studied that layer height affects surface roughness; the smoothest surface roughness was Ra 4.2, with a parameter layer thickness of 0.1 mm and infill density of 50%. Pramanik et al. [18] conclude that the parameter that has the most effect on surface roughness is printing speed (58.15%), followed by extruder temperature (23.79%), infill density (15.64%), layer height (7.11%) and bed temperature (0.924%). In this research, printing speed has the most extensive domination, above 50%, while other parameters are under 25%. Priyadarsini et al. [19] conclude that surface roughness has a linear relationship with a layer thickness parameter. As the layer thickness increase, the surface roughness can be rougher. Barrios et al. [20] conclude that the parameter with the most decisive influence on surface roughness is printing acceleration (PA) and flow rate (F). PA contributes to a surface roughness of 23.00 %, and F contributes to a surface roughness of 43.74 %.

From the previous research, there is no research on the surface roughness of PETG with the parameter of infill geometry, and this research wants to use the parameter of infill geometry to find out the effect of this parameter on the surface roughness of 3D printing specimens. This research aimed to obtain the most affected combination of surface roughness parameters from 4 parameters (nozzle temperature, infill geometry, layer height and fan speed).

II. Material and Methods

In this study, the material used is PETG filament (Esun brand), and the tools used are 3D printing creality 3 V2 and surface roughness tester TR220.

Table 1. PETG filament specification

Material	PETG
Filament diameter (mm)	1.75
Printing temperature (°C)	200-220
Tolerance (mm)	0.02
Printing speed (mm/s)	50-100
Bed temperature (°C)	60-80
Net weight (kg)	1
Bruto (kg)	1.3
Filament length (m)	320
Melting process speed (gr/min)	61
Certificate	RoHS, REACH

The process parameter used in this study is independent parameters and control parameters. Independent parameters are nozzle temperature, infill geometry, layer height and fan speed. Furthermore, every parameter has four levels. The control parameters are Infill density 50%, bed temperature 80 °C and printing speed 50 mm/s. Table 2 shows the independent parameters and the levels in this study.

Table 2. Research independent parameters

Parameter	Level			
	1	2	3	4
Layer height (mm)	0.12	0.16	0.20	0.24
Infill geometry	Grid	Zig-zag	Gyroid	Triangles
Nozzle temperature (°C)	220	230	240	250
Fan speed (%)	20	40	60	80

In this study, Taguchi OA L16 (44) was used to minimize the number of experiments from 256 to 16 without reducing the data accuracy. In layer height, the reason for selecting the four levels is because 0.12 mm is the smoothest layer height, 0.24 mm is the roughest layer height, 0.16 mm and 0.20 mm are used as proof of the difference value between the smoothest and roughest. In infill geometry, the reason for selecting that four levels is because every level has a different foundation pattern and to prove which pattern has the best effect on surface roughness. Nozzle temperature is the reason for selecting those four levels because 220°C to 250°C are the temperature required for PETG filament. In fan speed, the reason for selecting that four levels is because every level has a different effect in hardening PETG filament. Each experiment was repeated five times to reduce data error. The Taguchi OA L16 table is obtained from the Minitab application. Table 3 shows the combination of each parameter and level in every experiment.

Table 3. Orthogonal array

Experiment	Layer height	Infill geometry	Nozzle temperature	Fan speed
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

The design of the specimen used in this study is a cube with an arch-shape on one side, the dimension of the cube is 25 mm, and the diameter of the arch-shape side is 25 mm. Five sides will be points of surface roughness measurement. There are 1 point on the right side, 1 point on the front side, 1 point on the left side, 1 point on the left side arch, and 1 point on the right side arch for measuring direction if toward the front from behind in every side of specimens. Figure 1(a) shows the specimen's design, and Figure 1(b) shows the specimen after being printed. Figure 2 shows the specimen with 16 different parameters.

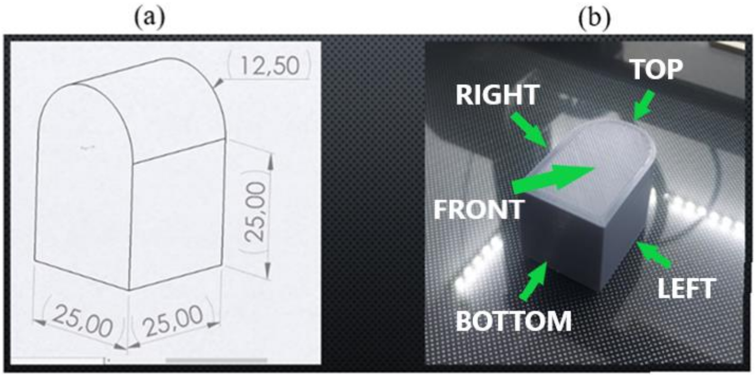

Fig. 1. Design of specimen (left) and specimen after printing (right)

Fig. 2. Specimens of this research

III. Results and Discussions

This study measured surface roughness in 16 specimens with surface roughness tester TR220. Table 4 shows the result of the surface roughness of 16 specimens in Ra score. Based on the Table 4, the specimen with the lowest surface roughness point is experiment 2 with a surface roughness point (Ra) 8.308, and the specimen with the highest surface roughness point is experiment 16 with a surface roughness point (Ra) 17.144. Based on this data specimen with the smoothest surface is in experiment 2, and the specimen with the roughest surface is in experiment 16.

Each experiment was repeated five times to calculate the signal-to-noise ratio or SNR. SNR is used to determine the parameters that affect the response. In this study is the surface roughness. Minitab application is used to analyze experimental data. The parameters are sorted from most to least influential and written in the main effect graph and response table. The surface roughness response of the specimen was analyzed using the smaller is better SNR method, or the lower the response value, the better result will be. The results of the SNR value is shown at Table 5. The formula for the smaller is better SNR method is below:

$$\text{Rasio S/N} = -10 \log \left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right]$$

Table 4. Surface roughness result

Exp	Surface roughness score (μm)						Standard deviation
	A	B	C	D	E	Average	
1	9.828	8.342	8.437	8.357	7.566	8.506	0.819
2	8.163	7.962	9.996	8.010	7.407	**8.308**	0.986
3	10.289	7.964	10.210	9.560	8.588	9.322	1.020
4	10.340	8.121	8.843	8.079	9.928	9.062	1.034
5	12.259	11.359	12.270	11.569	10.970	11.685	0.570
6	8.923	9.317	8.826	7.900	9.145	8.822	0.549
7	17.389	16.780	15.909	15.079	15.470	16.126	0.948
8	12.590	11.329	10.960	11.260	12.140	11.656	0.680
9	13.710	13.449	14.560	13.210	12.899	13.565	0.631
10	14.970	13.199	13.779	14.189	13.220	13.871	0.740
11	14.460	13.109	13.850	13.539	13.439	13.679	0.510
12	14.579	13.050	16.139	15.170	14.140	14.615	1.151
13	17.469	16.229	17.829	15.579	16.569	16.735	0.915
14	17.299	16.709	17.329	16.219	16.450	16.801	0.499
15	17.549	16.819	17.129	15.979	16.520	16.799	0.596
16	18.250	16.829	17.579	15.470	17.590	**17.144**	1.062

Table 5. SNR parameter response

Level	Layer Height (mm)	Infill Geometry	Nozzle Temperature (˚C)	Fan Speed
1	-18.92	-21.78	-21.24	-22.65
2	-21.45	-21.18	-21.91	-21.75
3	-22.89	-22.14	-21.99	-22.09
4	-24.55	-22.71	-22.67	-21.32
Delta	5.63	1.53	1.43	1.33
Rank	1	2	3	4

Based on Table 5, the level that affects the best score in surface roughness are layer height of 0.12 mm, infill geometry zig-zag, nozzle temperature 220˚C and the fan speed of 80%. Analysis of variance for the SNR table shows every parameter's contribution to the surface roughness response. The contribution can be determined by dividing the sequel sum of square (seq SS) by total SS and multiplying by 100%. Table 6 shows an analysis of parameter variance.

Based on Table 6, the confidence level used as a standard is $\alpha = 0.05$. If P-value has a lower score than α mean, the parameter gives more effect in surface roughness, and if P-value has a higher score than α mean, the parameter gives less effect in surface roughness. The data show that only layer height has a P-value lower than α and the rest of the parameters have a P-value higher than α. The P-value of the three parameters is higher than 0.20 because the three-parameter supports layer height and affects layer height. They have a common effect on surface roughness because they are indirectly related. The parameter with the highest contribution is layer height at 82.3 %, followed by infill geometry, nozzle temperature and fan speed under 7%. Bintara et al. [9] conclude that increasing layer height affected the distance between the valley and the peak. The higher the distance between the valley and the peak, the rougher the surface will be. Based on this, a lower layer height is used, and then a smoother surface of the specimen is made. Mayank et al.[19] conclude that layer height was the parameter with the highest contribution due to layer height being the score index (value) of the score of each layer. It may be because the lower layer height printing process can reduce the space or gap, making printing results perfect and spread evenly.

Table 6. Analysis of parameter variance

Source	DF	Seq SS	Adj	Adj MS	F	P	Contribution (%)
layer height (mm)	3	68.24	68.24	22.75	36.17	0.01	82.3
infill geometry	3	4.91	4.91	1.64	2.60	0.23	5.9
nozzle temperature (˚C)	3	4.09	4.09	1.36	2.17	0.27	4.9
fan speed (%)	3	3.81	3.80	1.27	2.02	0.29	4.6
residual error	3	1.89	1.89	0.62			
total	15	82.94					

In this study, analysis of variance (ANOVA) was used to prove the relationship between independent and dependent variables. There are two treatments in ANOVA, normality test and homogeneity test. Figure 3 shows the normality test results, and Table 7 shows the decision of the normality test. Figure 4 shows the homogeneity test results, and Table 8 shows the decision of the homogeneity test.

Based on Figures 3-4 and Tables 7-8, the result of ANOVA is H_0 rejected in the normality and homogeneity tests, meaning the data was normally distributed and homogenous. Soejanto [16] indicates that the normality test determines whether the data spread on a variable has been normally distributed. The homogeneity test is used to prove whether the data that has been used has variations in two or more distributions was the same or not.

Table 7. The decision of normality test

response	P-value	test results
surface roughness	0.076	H_0 rejected

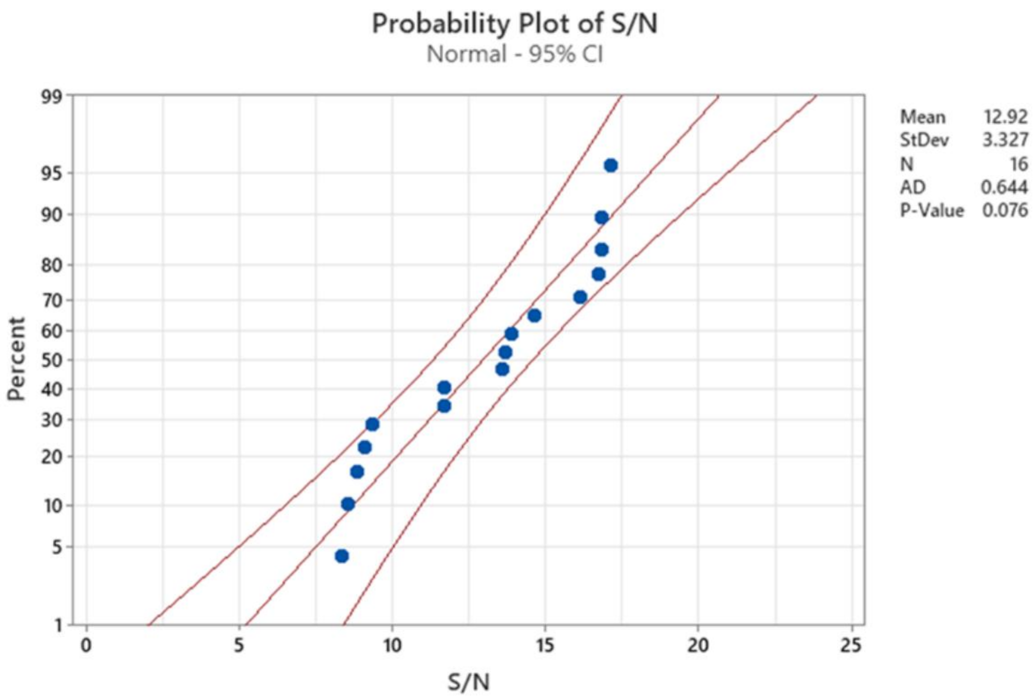

Fig. 3. Result of the normality test

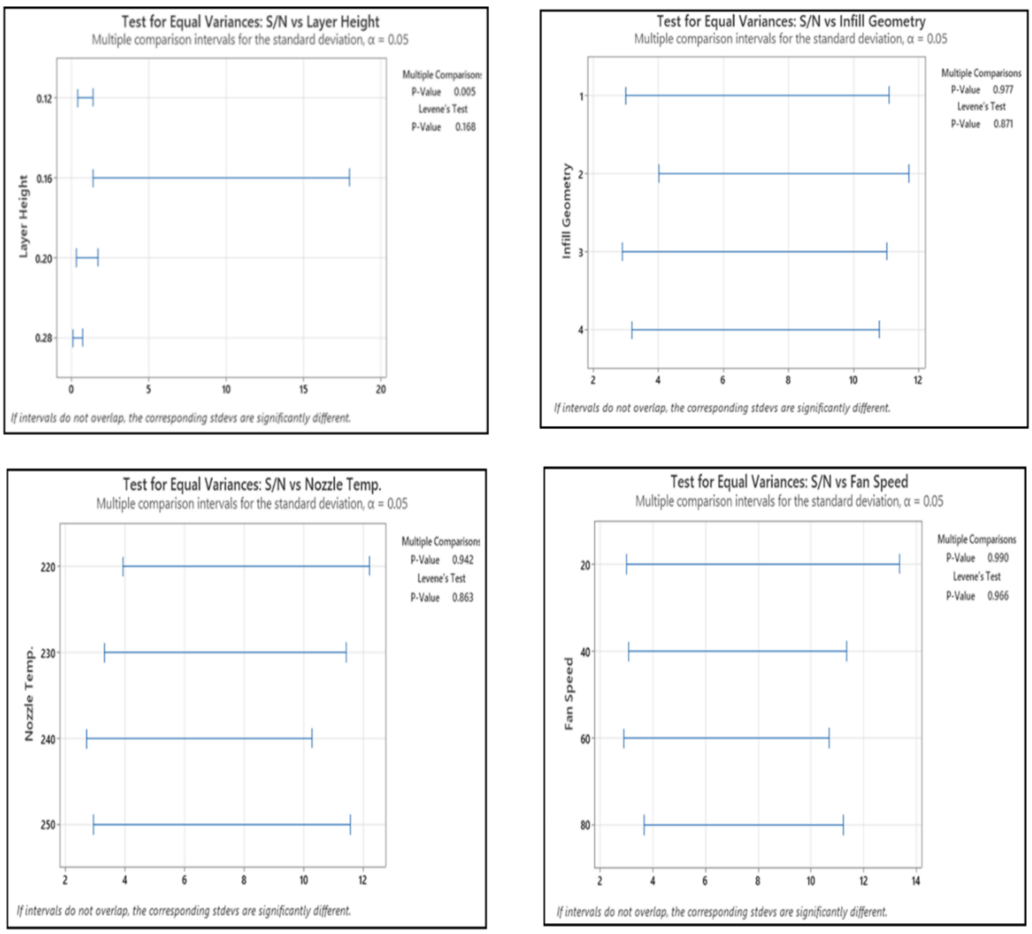

Fig. 4. Result of the homogeneity test

Table 8. The decision of the homogeneity test

Parameter	P-value	test results
Layer Height	0.168	H_0 rejected
Infill Geometry	0.871	H_0 rejected
Nozzle Temperature	0.863	H_0 rejected
Fan Speed	0.966	H_0 rejected

In this study, the most optimal parameters for surface roughness are layer height of 0.12 mm, infill geometry zig-zag, nozzle temperature 220˚C and a fan speed of 80%. Figure 5 shows the graph of the confirmation test of the most optimal parameter combination for surface roughness (symbolized with CT), and Table 9 shows a comparison between the confirmation test and the specimen with the smoothest surface (experiment 2).

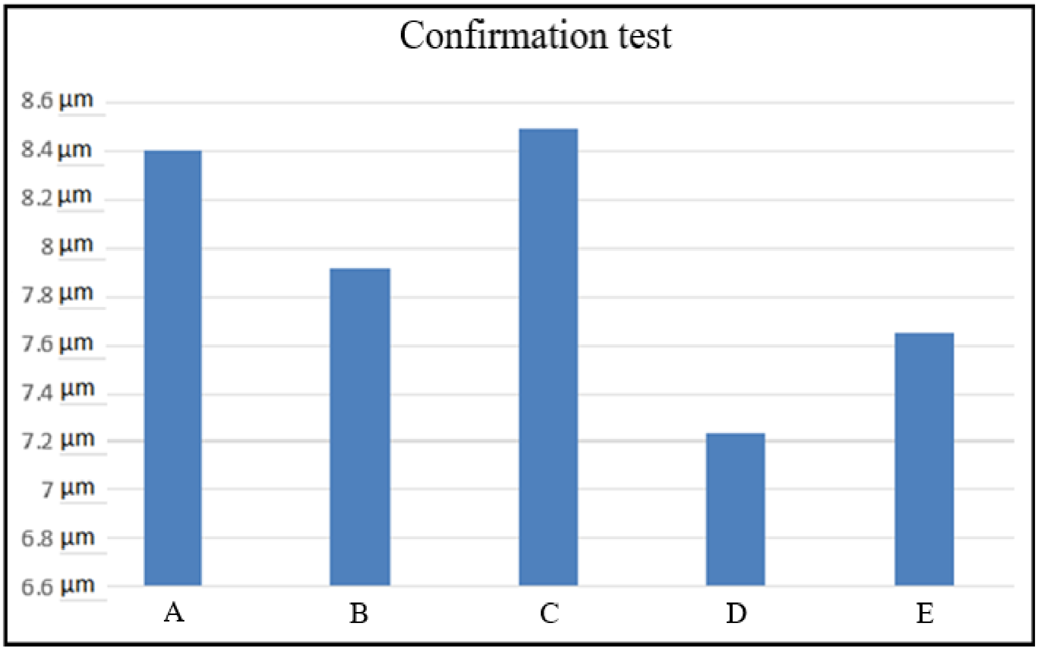

Fig. 5. Confirmation test graph

Table 9. Comparison of confirmation test and experiment 2

Exp	Surface roughness score (µm)						standard deviation
	A	B	C	D	E	average	
CT	8.4049	7.919	8.489	7.242	7.650	**7.941**	0.522
2	8.163	7.962	9.996	8.010	7.407	**8.308**	0.986

Based on Table 9, the confirmation test result is smoother than experiment 2, with a different point of 0.367. The combination parameter of the confirmation test is proven to be the most optimum combination parameter for surface roughness.

The difference between this research and previous research is the parameter used. Infill geometry is a parameter that is rarely used in surface roughness research. In this research, infill geometry is used as a parameter to find out the effect of this parameter on surface roughness. Infill geometry functions as the foundation of an outer layer, so infill geometry can help the outer layer stabilize its form. Different patterns of infill geometry can have different effects on the stability of the outer layer.

IV. Conclusions

Two conclusions can be drawn from this research. First, The layer height parameter contributes to the surface roughness by as much as 82.3 %, which is the most considerable contribution to the surface roughness value. The infill geometry, the nozzle temperature, and the fan speed contribute to the surface roughness by 5.9%, 4.9 %, and 4.6 %, respectively. Second, the parameters that produce the smoothest surface roughness values are a layer height of 0.12 mm, infill geometry zig-zag, nozzle temperature of 220˚C and fan speed of 80%.

For future research, the author has recommended research. Application of some parameters that are rarely used in surface roughness can be used to find another effect of the parameter in surface roughness. Some parameters are rarely used in surface roughness because those parameters have little effect on surface roughness. However, if those parameters are combined, that can have a more significant effect on surface roughness.

Acknowledgement

The authors would like to appreciate the Universitas Jember, which provides the facilities to conduct the research. We also thank Mas Abduh, the technician of the material test laboratory.

References

[1] M. Attaran, "The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing," *Bus Horiz*, vol. 60, no. 5, pp. 677–688, Sep. 2017, doi: 10.1016/j.bushor.2017.05.011.

[2] O. A. Mohamed, S. H. Masood, and J. L. Bhowmik, "Optimization of fused deposition modeling process parameters for dimensional accuracy using I-optimality criterion," *Measurement (Lond)*, vol. 81, pp. 174–196, Mar. 2016, doi: 10.1016/j.measurement.2015.12.011.

[3] R. Srinivasan, P. Prathap, A. Raj, S. A. Kannan, and V. Deepak, "Influence of fused deposition modeling process parameters on the mechanical properties of PETG parts," in *Materials Today: Proceedings*, Jan. 2020, vol. 27, pp. 1877–1883. doi: 10.1016/j.matpr.2020.03.809.

[4] J. Banks, "Adding value in additive manufacturing: Researchers in the United Kingdom and Europe look to 3D printing for customization," *IEEE Pulse*, vol. 4, no. 6, pp. 22–26, 2013, doi: 10.1109/MPUL.2013.2279617.

[5] X. Wu, Q. Lian, D. Lia, X. He *et al.*, "Influence of boundary masks on dimensions and surface roughness using segmented exposure in ceramic 3D printing," *Ceram Int*, vol. 45, no. 3, pp. 3687–3697, Feb. 2019, doi: 10.1016/j.ceramint.2018.11.031.

[6] M. R. Khosravani, P. Soltani, and T. Reinicke, "Fracture and structural performance of adhesively bonded 3D-printed PETG single lap joints under different printing parameters," *Theoretical and Applied Fracture Mechanics*, vol. 116, Dec. 2021, doi: 10.1016/j.tafmec.2021.103087.

[7] S. Guo, T. M. Choi, and S. H. Chung, "Self-design fun: Should 3D printing be employed in mass customization operations?," *Eur J Oper Res*, vol. 299, no. 3, pp. 883–897, Jun. 2022, doi: 10.1016/j.ejor.2021.07.009.

[8] D. Devsingh, A. D. Dev, B. Avala, R. Reddy, and S. Arjula, "Characterization of Additive Manufactured PETG and Carbon Fiber-PETG," *International Journal for Research in Engineering Application & Management (IJREAM)*, vol. 04, p. 2, 2018, doi: 10.18231/2454-9150.2018.0139.

[9] R. D. Bintara, D. Z. Lubis, and Y. R. Aji Pradana, "The effect of layer height on the surface roughness in 3D Printed Polylactic Acid (PLA) using FDM 3D printing," *IOP Conf Ser Mater Sci Eng*, vol. 1034, no. 1, p. 012096, Feb. 2021, doi: 10.1088/1757-899x/1034/1/012096.

[10] J. Hartcher-O'Brien, J. Evers, and E. Tempelman, "Surface roughness of 3D printed materials: Comparing physical measurements and human perception," *Mater Today Commun*, vol. 19, pp. 300–305, Jun. 2019, doi: 10.1016/j.mtcomm.2019.01.008.

[11] J. M. Mercado-Colmenero, M. Dolores La Rubia, E. Mata-Garcia, M. Rodriguez-Santiago, and C. Martin-Doñate, "Experimental and numerical analysis for the mechanical characterization of petg polymers manufactured with fdm technology under pure uniaxial compression stress states for architectural applications," *Polymers (Basel)*, vol. 12, no. 10, pp. 1–25, Oct. 2020, doi: 10.3390/polym12102202.

[12] K. Durgashyam, M. Indra Reddy, A. Balakrishna, and K. Satyanarayana, "Experimental investigation on mechanical properties of PETG material processed by fused deposition modeling method," in *Materials Today: Proceedings*, 2019, vol. 18, pp. 2052–2059. doi: 10.1016/j.matpr.2019.06.082.

[13] K. Kowsari, B. Zhang, S. Panjwani, Z. Chen et al., "Photopolymer formulation to minimize feature size, surface roughness, and stair-stepping in digital light processing-based three-dimensional printing," *Addit Manuf*, vol. 24, pp. 627–638, Dec. 2018, doi: 10.1016/j.addma.2018.10.037.

[14] P. Morampudi, V. S. N. V. Ramana, K. A. Prabha, S. Swetha, and A. N. Brahmeswara Rao, "3D-printing analysis of surface finish," in *Materials Today: Proceedings*, 2020, vol. 43, pp. 587–592. doi: 10.1016/j.matpr.2020.12.085.

[15] M. Revilla-León, D. Jordan, M. M. Methani, W. Piedra-Cascón, M. Özcan, and A. Zandinejad, "Influence of printing angulation on the surface roughness of additive manufactured clear silicone indices: An in vitro study." *J Prosthet Dent*, vol 125(3), pp. 462-468. 2021; doi: 10.1016/j.prosdent.2020.02.008.

[16] Soejanto, I. *Desain eksperimen dengan metode Taguchi* (1st ed., Vol. 1). Yogyakarta: Graha Ilmu. 2009.

[17] M.A. Che Mat, F. R. Ramli, M. R. Alkahari et al., "Influence of layer thickness and infill design on the surface roughness of PLA, PETG and metal copper materials," *Proceedings of Mechanical Engineering Research Day* 2020, pp. 64-66, December 2020.

[18] D. Pramanik, A. Mandal, and A. S. Kuar, "An experimental investigation on improvement of surface roughness of ABS on fused deposition modelling process," in *Materials Today: Proceedings*, 2019, vol. 26, pp. 860–863. doi: 10.1016/j.matpr.2020.01.054.

[19] B. Mayank and V. R.O., "Parameters affecting surface roughness of fused deposition modeling," *i-manager's Journal on Mechanical Engineering*, vol. 6, no. 1, p. 34, 2016, doi: 10.26634/jme.6.1.3739.

[20] J. M. Barrios and P. E. Romero, "Improvement of surface roughness and hydrophobicity in PETG parts manufactured via fused deposition modeling (FDM): An application in 3D printed self-cleaning parts," *Materials*, vol. 12, no. 15, Aug. 2019, doi: 10.3390/ma12152499.