

Optimization of 3D Printing Parameters on Mechanical Properties of Printed PETG Materials

Nurul Hayati Abdul Halim^a, Izdihar Tharazi^a, Farrahshaida Mohd Salleh^a, Abdul Hakim Abdullah^a, Mohamad Firhan Morni^a, Afeeqa Puteri Marzuki^a, Nur Diyana Mohamad Nasri^a, Muhammad Ilham Khalit^b & Thoufeili Taufek^c

^a*Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia*

^b*Department of Mechanical Engineering, School of Engineering, Bahrain Polytechnic, Isa Town 33349, Kingdom of Bahrain*

^c*Flexkey Sdn. Bhd., No.8, Jalan PJU 8/8A, Bandar Damansara Perdana, 47820 Petaling Jaya, Selangor, Malaysia*

*Corresponding author: izdihar92@uitm.edu.my

Received 10 January 2026, Received in revised form 19 June 2026
 Accepted 19 July 2026, Available online 30 September 2026

ABSTRACT

Polyethylene terephthalate glycol (PETG) is gaining popularity as a 3D printing material, replacing traditional polymers like PLA and ABS in various industries such as medical and automotive. Despite the growing popularity of PETG as a 3D printing material, the relationship between its mechanical properties and the specific printing parameters used has not been comprehensively studied. Therefore, this research aims to investigate the influence of 3D printing parameters, namely layer thickness, raster angle, and infill density, on the flexural and impact strength of 3D printed Polyethylene Terephthalate Glycol (PETG). Response Surface Methodology (RSM) was employed for experimental design through the Box-Behnken Design (BBD) method. The 3D modelling was created according to ASTM standards then sliced using Ultimaker Cura software. Subsequently, the models were printed and underwent mechanical testing to evaluate its flexural strength using a Universal Testing Machine (UTM) and impact strength using an Izod impact apparatus. The results through ANOVA analysis demonstrated that high layer thickness and infill density significantly enhance impact strength. Conversely, reducing layer thickness at high infill density improves flexural strength. Raster angles have less significant influence on both flexural and impact strength. The optimal printing settings for PETG obtained were layer thickness of 0.234 mm, an infill density of 80%, and a raster angle of 90 degrees. These parameter settings result in a 31.9 MPa in flexural strength and 39.4 MPa in impact strength. Confirmation runs validated the model with a low error rate of 10%. Therefore, this research contributes to the advancement of additive manufacturing by providing guidelines for optimizing PETG-based 3D printed objects, enhancing their reliability and durability for various industrial applications.

Keywords: 3D printing; polyethylene terephthalate glycol (PETG); mechanical properties; response surface methodology; optimization

INTRODUCTION

The notable popularization of 3D Printing is due to the increased pressure to adopt innovative techniques that can handle small quantities and rapid manufacturing faced by manufacturing industry (Hsueh et al. 2021). 3D Printing, that is also known as Fused Deposition Modelling (FDM) additive manufacturing, involves the direct production of three-dimensional parts using computer-aided design

software, building them layer by layer by extruding small beads of molten material which then harden to form the model (Shahrubudin et al. 2019). The technique was invented by S. Scott Crump in the late 1980s and was later developed by Stratasys in 1990 and this method has undergone tremendous growth in recent years as a versatile and efficient method (Durgashyam et al. 2019; Shahrubudin et al. 2019). 3D printing is an additive manufacturing method that enables the efficient production of intricate

shapes at a relatively low cost and within a short time frame as this process directly utilizes 3D digital models and does not require any fixtures or specialized tools. Consequently, it can rapidly create complex structures of functional prototypes and print with multiple materials, offering significant advantages over other technologies (Hsueh et al. 2021; Szykiedans et al. 2017).

3D Printing employs a wide variety of materials to produce 3D-printed items, with PETG being used as a substitute for conventional polymers like polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) and polyamide (PA) (Valvez et al. 2022). Conventional thermoplastics, ceramics, graphene-based materials, and metals are also now printable using 3D printing technology (Low et al. 2017; Shahrubudin et al. 2019). Polyethylene terephthalate glycol (PETG) is a thermoplastic polymer that is synthesized through the amalgamation of polyethylene terephthalate (PET) and ethylene glycol, and it has recently drawn an enormous amount of attention for its potential in FDM manufacturing (Guessasma et al. 2019; Sepahi et al. 2021). PETG is well-known for its strong tensile qualities, high ability to stretch, resilience to heat and chemical damage, and unlike PET, it does not show strain-induced crystallization. PETG's excellent toughness, transparency, and chemical resistance makes it possess the capacity to be utilized in several sectors such as defense, aviation, medical, food, and automotive industries (Sepahi et al. 2021; Yan et al. 2023). PETG modalities can be created using various manufacturing techniques such as injection molding, pressure molding, 3D printing, and thermoforming, with 3D printing techniques being particularly prominent (Tezel et al. 2021).

However, despite the growing popularity of PETG in 3D printing, there appears to be a lack of research on the

correlation between printing parameters and the mechanical behavior of 3D printed PETG. According to previous studies, certain process parameters have a direct impact on the strength of 3D-printed materials, notably influenced by factors such as infill density, infill pattern, and layer height (Johnson & French 2018; Panneerselvam et al. 2021; Suteja 2024). This study primarily investigates the variation of process parameters specifically layer thickness, raster angle, and infill density on flexural and impact strength. The aim is to analyze their respective outcomes and determine which parameter exerts the most significant influence compared to others through ANOVA analysis. By methodically optimizing the parameters of 3D printing for PETG materials, it is possible to enhance the mechanical properties of the printed objects.

METHODOLOGY

CAD MODEL

The Computer-Aided Design (CAD) models for both flexural and impact testing specimens were developed using SOLIDWORKS 2023 software following ASTM standards as in Figure 1. Given that most of the slicing software is compatible with .obj and .stl formats, the SolidWorks file was then transformed into .stl format after the creation of the CAD model. The .stl file was subsequently sent to the slicing program, ULTIMAKER CURA version 5.7.1 as in Figure 2. The process parameters were modified related to infill density, layer thickness, and raster angle. ULTIMAKER CURA then separated the model into layers and produce G-code instructions. Subsequently, the G-code was utilised by the 3D printer throughout the printing procedure and the ASTM standard specimens were created.

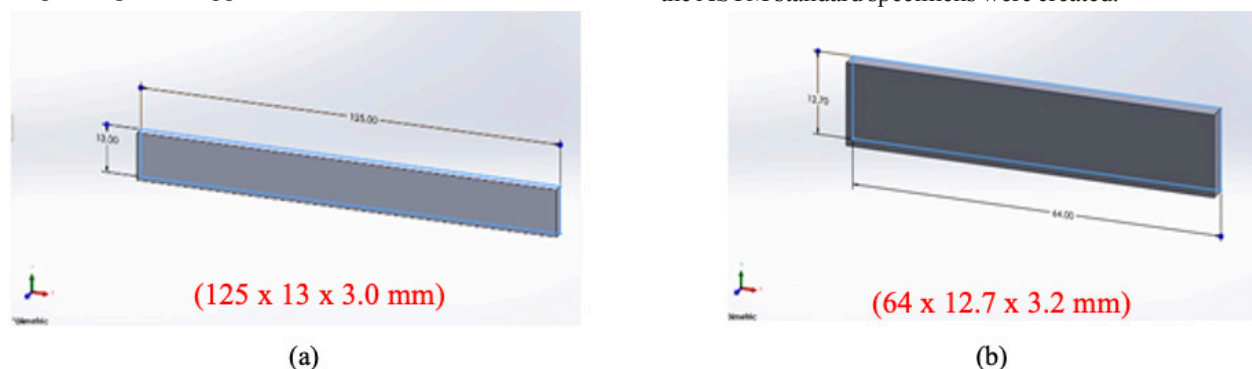


FIGURE 1. CAD Model (a) Flexural test and; (b) Impact test sample

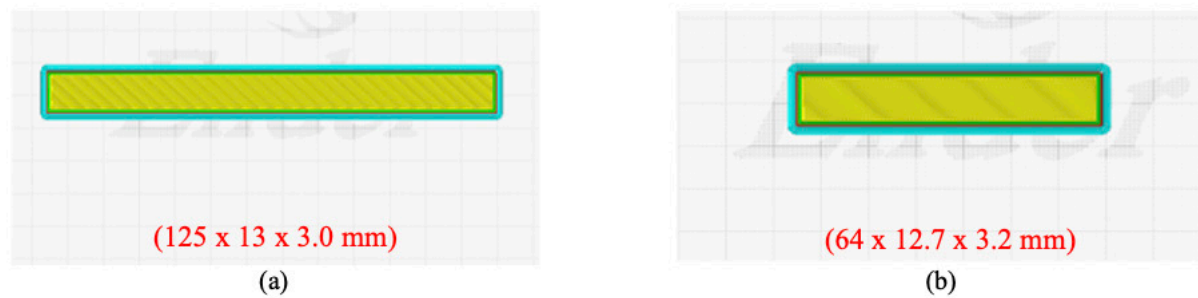


FIGURE 2. 3D Model in ULTIMAKER CURA; (a) Flexural test and; (b) Impact test sample

DESIGN OF EXPERIMENT (DOE) BASED ON BOX-BEHNKEN DESIGN

Design of Experiments (DOE) was utilized to determine the ideal parameter that has a significant impact on the mechanical characteristics of 3D-printed PETG material. This current study employed the Box-Behnken Design to optimize the 3D printing parameters for processing PETG material. Three controlling factors were selected for this study which were layer thickness, infill density and raster angle at three distinct levels as listed in Table 1. In total, 15 runs were generated that incorporated various combinations of the process parameters.

No.	Process Parameters	Levels		
		1	2	3
1	Layer Thickness (mm)	0.10	0.25	0.40
2	Infill Density (%)	40	60	80
3	Raster Angle (°)	0	45	90

ANOVA ANALYSIS

Then, experimental analysis was done by using ANOVA. This analysis enables simultaneous comparison of multiple groups to ascertain the presence of a relationship among them. ANOVA is employed to identify the most influential parameters, such as layer thickness, infill density, or raster angle, that significantly affected the mechanical characteristic of 3D printed PETG material. It also functions to facilitate comprehension of the interaction between those variables and their impact on the output, thereby facilitating the optimization of processes in a more efficient and effective manner.

3D PRINTING

Figure 3 shows Creality Ender-3 3D Printer and the test samples. A total of 15 runs were performed, with 3 repetitions of center points, yielding 45 samples each for both flexural and impact testing to assure reliable values of the test findings under the same conditions. Hence, a total of 90 PETG samples were fabricated and mechanically tested to analyse their flexural and impact properties.

This 3D printing process utilized the PETG filament that has a diameter of 1.75 ± 0.03 mm, using a Creality Ender-3 printer. The fixed parameter conditions were selected based on the recommendation of the printing setup, including a printing temperature of 240°C , a platform temperature of 85°C , a printing speed of 60 mm/s with a lines infill pattern.

FLEXURAL AND IMPACT TEST

To assess the influence of printing parameters, flexural and impact tests were conducted in compliance with ASTM standards. The samples for flexural strength were assessed by a three-point bending test using a Shimadzu Universal Testing Machine (UTM), conducted in accordance with ASTM D790 with dimensions of $125 * 13 * 3.0$ mm. The bending span utilized for the flexural test is 60 mm with a speed of 10 mm/min. Impact strength properties, on the other hand, were assessed using Izod Impact tester device in accordance with ASTM D256 specification with a notch angle of $45 \pm 1^{\circ}$ and radius of 0.2 ± 0.05 mm. The dimensions of the samples were at $64 * 12.70 * 3.2$ mm.

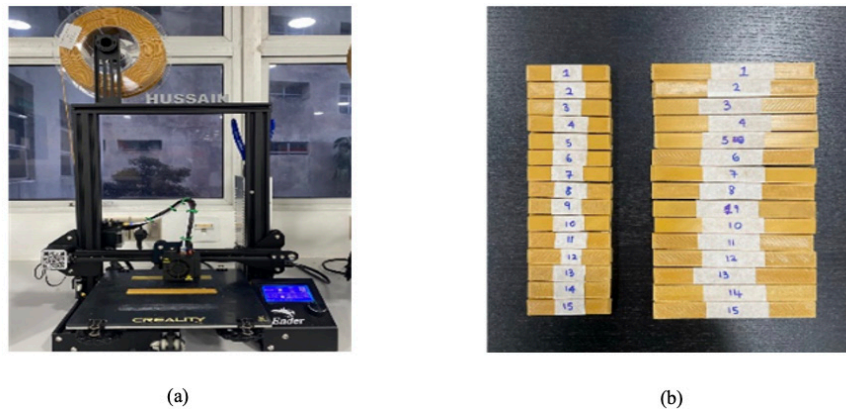


FIGURE 3. (a) Creality ender-3 3D Printer, (b) Fabricated flexural and impact test specimens

RESULTS AND DISCUSSION

EXPERIMENTAL RESULTS OF FLEXURAL AND IMPACT STRENGTH

Using the Box-Behnken Design, 15 runs with three replicates each were conducted for both flexural and Izod impact tests, incorporating various combinations of three factors (A: layer thickness, B: infill density, C: raster angle) at varying levels. A grand total of 90 specimens were produced using 3D printing and then subjected to both tests, and the response values of flexural strength and impact strength were derived by calculating the average of the results as depicted in Table 2.

As shown from Table 2, the flexural strength obtained ranged from a minimum of 24 MPa to maximum of 30.50 MPa. Meanwhile, the impact strength obtained ranged from 20.83 MPa up to maximum of 54.17 MPa. Thinner layer tend to increase flexural strength. This is evident in the runs with 0.25 mm and 0.1 mm layer thicknesses compared to 0.4 mm. Meanwhile, a higher infill density seems to correlate with increased flexural and impact strength. The raster angle appears to have a less significant influence on both flexural and impact strength. However, raster angle of either 45 or 90 degrees often results in higher strengths, especially for flexural. This result is also supported by Abbas et al. (2017) where a rectangular pattern with a 90° deposition angle shows that increasing infill density leads to an increase in mechanical strength. While this is a general trend, it's important to note that specific results may vary based on other factors of layer thickness and infill density. Even though it has a high infill density and a 45-degree raster angle, run 15 exhibits lower strengths than expected. In addition, a run with the lowest layer thickness and a 60% infill density, shows relatively low impact strengths. These could be due to variations in material properties or experimental errors (Almutairi et al. 2023). To strengthen

the conclusions, statistical ANOVA tests were conducted to determine the significance of the relationships between factors and responses.

ANOVA OF FLEXURAL STRENGTH

Table 3 shows the ANOVA for flexural strength which shows its F-value, p-value, residual, lack of fit and its fit statistics. The model F-value of 5.98 represents the ratio of the mean square of the model to the residual mean square, implying the model is significant. There is only a 1.01% probability that such a large F-value could arise due to random variation. P-values quantify the likelihood that the observed outcomes are a result of random variation. In this scenario, the result is less than 0.0500, implying that the model terms are statistically significant. The ANOVA analysis demonstrates that the factor AB and A² which are the layer thickness and infill density have a significant effect on the flexural strength of 3D printed PETG material as their p-values are less than 0.05. The Predicted R² value of 0.4005 is reasonably consistent with the Adjusted R² value of 0.5873, indicating that the discrepancy between the two values is less than 0.2. The Lack of Fit F-value in this test is not significant, with the value of 0.37, indicating that the model accurately fits the data. A Lack of Fit F-value of this magnitude is 87.38% likely to be caused by noise. The Equation (1) shown below is a regression equation for flexural strength. It is used to obtain anticipated values for the specimen based on the considered process factors.

TABLE 2. Data results of flexural and impact testing

Run	Factor 1 A: Layer Thickness (mm)	Factor 2 B: Infill Density (%)	Factor 3 C: Raster Angle (deg)	Response 1 Flexural Strength (MPa)	Response 2 Impact Strength (MPa)
1	0.25	80	0	30.50	33.33
2	0.25	40	90	27.50	28.13
3	0.1	80	45	29.98	37.5
4	0.25	40	0	28.70	39.58
5	0.1	60	0	29.00	31.25
6	0.25	60	45	30.00	20.83
7	0.1	60	90	28.00	23.96
8	0.25	80	90	30.00	41.67
9	0.4	60	90	27.50	54.17
10	0.1	40	45	24.00	28.13
11	0.25	60	45	26.50	43.75
12	0.4	40	45	28.50	50.00
13	0.25	60	45	27.00	45.83
14	0.4	60	0	25.00	43.75
15	0.4	80	45	24.50	54.17

TABLE 3. ANOVA table of flexural strength

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	42.44	4	10.61	5.98	<0.0101	significant
A-Layer Thickness	3.75	1	3.75	2.12	0.1764	
B-Infill Density	4.93	1	4.93	2.78	0.1265	
AB	24.90	1	24.90	14.04	0.0038	
A ²	8.85	1	8.85	4.99	0.0495	
Residual	17.74	10	1.77			
Lack of Fit	10.57	8	1.32	0.3688	0.8738	Not significant
Pure Error	7.17	2	3.58			
Cor Total	60.18	14				
Std. Dev.	1.33	R ²			0.7052	
Mean	27.78	Adjusted R ²			0.5873	
C.V. %	4.79	Predicted R ²			0.4005	
		Adeq Precision			8.5313	

$$\text{Flexural Strength} = 28.60 - 0.6850A + 0.7850B - 2.50AB - 1.54A^2 \quad (1)$$

Figure 4(a) illustrates the evidence that the data points are closely scattered around the red line, suggesting that the residuals in this model exhibit a normal distribution. It demonstrates the smallest variance between all unbiased estimators. Figure 4(b) displays a graphical representation of the model's predictive power by comparing predicted values to actual values. It is evident that the points closely

align with the diagonal line. However, there may be a few differences between the predicted and actual values, with certain points deviating from the perfect fit line. This suggests potential areas for improvement in the model. In Figure 4(c), none of the data points are regarded as outliers as all of them fall within the red lines, suggesting a precise model fit.

Figure 5 shows the 3D response surface plot visualizing the interaction among two variable factors that impact the flexural strength. Based on the figure, the surface

plot demonstrates a variation in color gradient. The blue gradient suggests a lower flexural strength of 24 MPa,

while the red gradient indicates the highest value of 30.5 MPa.

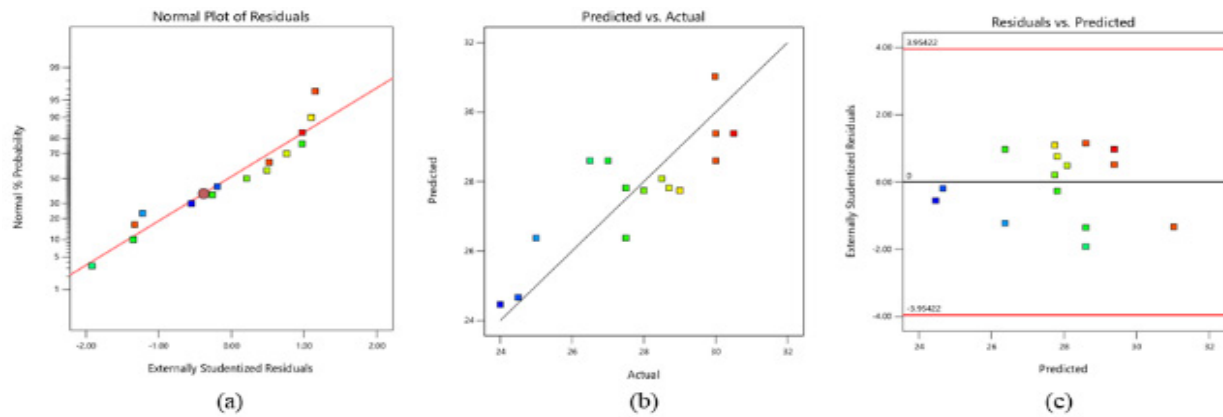


FIGURE 4. Plots for flexural strength (a) Normal Plot of Residuals; (b) Predicted vs. Actual and; (c) Residuals vs. Predicted

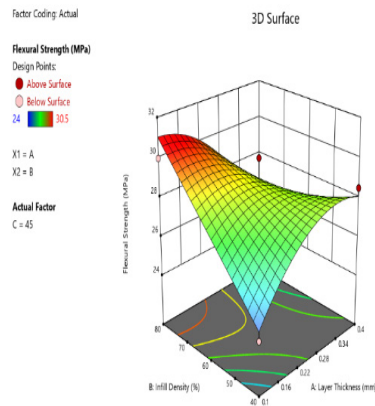


FIGURE 5. 3D Response surface plot of flexural strength

Based on the plot analysis, it appears that there is a notable interaction between the layer thickness and infill density. There is a significant relationship between layer thickness and infill density, and a corresponding increase in the strength of the material's flexibility. At around a layer thickness of 0.1 mm and an infill density between 70% and 80%, the flexural strength reaches its highest point, indicating that they are the parameters that maximize the flexural properties of 3D-printed PETG. According to the literature, it has been found that using smaller layer thicknesses can improve mechanical properties. This is because smaller layer thicknesses result in fewer interlayer gaps and air pores in the cross-section (Gao et al. 2022). As per Sousa et al. (2021) it has been observed that using lower layer heights results in improved mechanical properties as it is attributed to the increased cohesion between layers (Valvez et al. 2022). Therefore, the layer height has a more significant role in determining

the flexural strength of PETG material compared to the infill density and raster angle (Panneerselvam et al. 2021).

ANOVA OF IMPACT STRENGTH

Table 4 shows the ANOVA analysis for impact strength which shows its F-value, p-value, residual, lack of fit and its fit statistics. The model F-value of 3.83 represents the ratio of the mean square of the model to the residual mean square, implying the model is significant. There is only a 3.86% probability that such a large F-value could arise due to random variation. P-values quantify the likelihood that the observed outcomes are a result of random variation. In this scenario, the result is less than 0.05, implying that the model terms are statistically significant. The ANOVA analysis demonstrates that the factor A layer thickness has a significant effect on the impact strength of 3D printed PETG material because the P-value is less than 0.05. The

Predicted R^2 value of 0.2755 is reasonably consistent with the Adjusted R^2 value of 0.4473, indicating that the discrepancy between the two values is less than 0.2. The

Lack of Fit F-value in this test is not significant, with the value of 0.15, indicating that the model accurately fits the data. A Lack of Fit F-value of this magnitude is 98.00% likely to be caused by noise.

TABLE 4. ANOVA table of impact strength

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	945.48	4	236.37	3.83	<0.0386	significant
A-Layer Thickness	825.20	1	825.20	13.38	0.0044	
B-Infill Density	54.24	1	54.24	0.8793	0.3705	
C-Raster Angle	0	1	0.0000	8.106E-07	0.9993	
A ²	66.05	1	66.05	1.07	0.3251	
Residual	616.80	10	61.68			
Lack of Fit	231.91	8	28.99	0.1506	0.9800	not significant
Pure Error	384.88	2	192.44			
Cor Total	1562.28	14				
Std. Dev.	7.85		R^2		0.6052	
Mean	38.40		Adjusted R^2		0.4473	
C.V. %	20.45		Predicted R^2		0.2755	
			Adeq Precision		5.6282	

The Equation (2) shown below is a regression equation for impact strength. It is used to obtain anticipated values for the specimen based on the considered process factors.

$$\text{Impact Strength} = 36.16 + 10.16A + 2.60B + 0.0025C + 4.21A^2 \quad (2)$$

Figure 6(a) represents the differences between observed and predicted impact strength values. The points in this plot closely align with the red line, suggesting that the residuals follow a normal distribution. Consequently, this plot serves as a reliable indication that the model assumptions are valid, and the errors are random. Figure 6(b) demonstrates that the model generally fits well with the impact strength data of 3D-printed PETG materials. Most of the data points closely align with the line of perfect fit, although there are some deviations that suggest potential areas for improvement in the model.

Figure 6(c) demonstrated that the residuals were distributed in a moderately random manner around the horizontal line at zero. Furthermore, there were no data points that fell outside the boundaries of the outliers indicated by the red lines. This observation provides evidence in favor of the model's validity. The 3D response surface plot in Figure 7 is utilized for the purpose of visualizing the interaction of two variable factors, namely A: layer thickness and B: infill density on impact strength. Based on the plot surface, the impact strength is found to

be highest when the layer thickness is set to 0.4 mm and the infill density is set to 80%, as indicated by the red color gradient. However, the impact strength notably decreases, particularly when using lower infill densities and layer thicknesses.

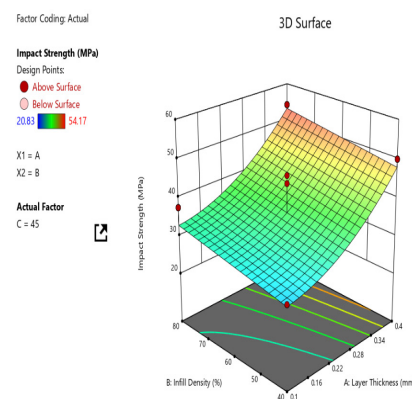


FIGURE 7. 3D Response surface plot of impact strength

This result is supported by Panneerselvam et al. (2021) who suggested that a higher layer height has the benefit of better load-bearing capacity and improved resistance to the separation of layered materials, due to its greater stiffness compared to other layer heights under consideration. When the layer height is small, the interlayer

bonding may become weaker and more prone to failure (Panneerselvam et al. 2021). The increase in impact strength at higher infill density as it is worth nothing, as a higher infill density leads to reduced porosity and, as a result, enhances the strength of the connections between adjacent filaments that are deposited (Carneiro et al. 2015). Alternatively, a lower infill density results in filaments

being deposited at a greater distance from each other, leading to weaker bonds and reduced mechanical strength. Literature also reported that the samples printed with higher infill percentages contain more material, leading to denser samples with increased bearing capacity (Valvez et al. 2022).

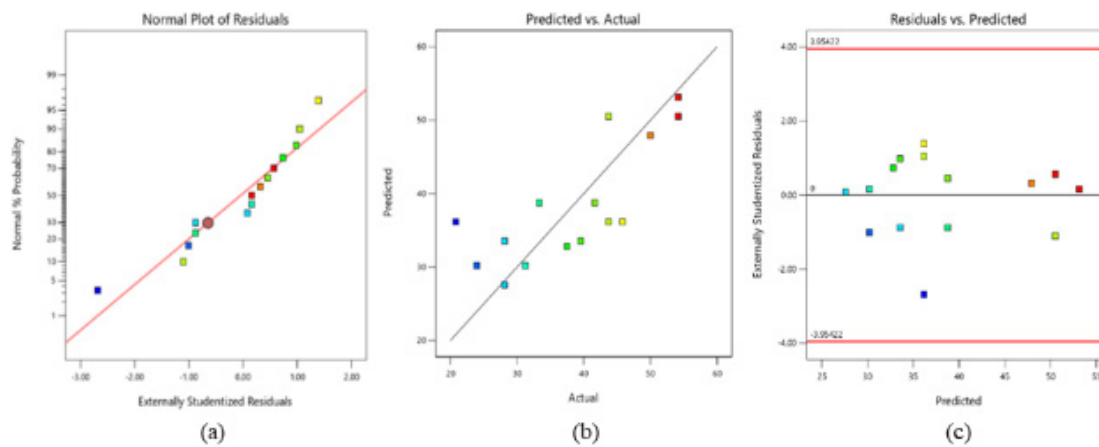


FIGURE 6. Plots for impact strength (a) Normal Plot of Residuals, (b) Predicted vs. Actual, (c) Residuals vs. Predicted

OPTIMIZATION PARAMETERS OF 3D PRINTING OF PETG

Table 5 is a critical component of the DOE optimization procedure as it offers a measurable metric that enables the making of well-informed judgments in the selection of the optimal combination of factor levels to attain the intended results. It directs the optimization process by defining the objectives, constraints, and significance of each factor and

response. Desirability functions are typically bounded by values ranging from 0 to 1. Undesirable responses are assigned a value of 0, while optimal performance for the factors under study is represented by a value of 1. Hence, a high score of 82.9% in this study indicates improved overall multi-objective optimization as it meets the given aims more precisely, making it the most favorable combination of conditions for the experiment.

TABLE 5. Desirability criteria

Number	Layer Thickness (mm)	Infill Density (%)	Raster Angle (°)	Flexural Strength	Impact Strength	Desirability
1	0.234	80	90	29.71	37.70	0.829

For this study, the overall desirability score is 0.829 when the printing parameters were set at layer thickness: 0.234 mm, infill density: 80% and raster angle: 90°. This combination effectively balances the requirements for both high flexural and impact strength in the printed parts. The results of this study are consistent with those reported by Kumar et al. (2023) and Kechagias & Vidakis (2022), which demonstrate that a lower layer thickness combined with high infill density enhances both flexural and impact strength. Selection of decreased printing layer thicknesses leads to better interlayer adhesion, smoother surface finish, and increased detail (Lužanin et al. 2014). For infill density,

higher infill density selection provides a more solid internal structure where a higher amount of plastic is incorporated into the specimen. Therefore, the load-bearing capacity is enhanced which result in higher values of strength and reduce the risk of failure as the specimen has fewer void spaces or porosity (Triawan et al. 2022). For raster angle, the 45-90 degree aligns the material's fibers in a way that is conducive to high strength, provides better resistance to perpendicular forces, and minimizes weak points (Almutairi et al. 2023). At a raster angle of 90 degrees, where the nozzle moves perpendicular to the layer's direction, can often lead to higher strength and stronger

bond due to more interlocking structure between layers created, enhancing adhesion and reducing the risk of delamination. Furthermore, the perpendicular printing movement allows for more efficient heat dissipation as the path is shortened, leading to faster cooling and reduced warping (Abbas et al. 2017). Thus, this balanced cooling helps prevent distortions that can weaken the material.

CONFIRMATION RUN

Confirmation runs were performed to ascertain the accuracy of the predictions. The purpose of these runs was to verify that no changes had occurred and that the response values closely corresponded to the predicted values (Tharazi et al. 2020). The optimal parameters setting was a layer

thickness 0.234 mm, an infill density of 80% and a raster angle of 90° with a desirability of 0.829. Table 6 presents the mechanical properties of printed PETG under optimal parameter settings, with a predicted flexural strength of 29.71 MPa and a predicted impact strength of 37.70 MPa. The values obtained from the confirmation run are presented in Table 6, with the flexural strength recorded at 31.90 MPa and the impact strength at 39.40 MPa. The analysis of the predicted mechanical properties and the actual values from the validation experiment indicates a percentage discrepancy of 6.87% for flexural strength and 4.29% for impact strength. As indicated by Halim et al. (2024) and Tharazi et al. (2024), an error of less than 10% is considered valid and acceptable.

TABLE 6. Confirmation run results with optimal parameter settings

Layer Thickness (mm)	Infill Density (%)	Raster Angle (°)	Flexural Strength (MPa)		Impact Strength (MPa)	
			Predicted	Actual	Predicted	Actual
0.234	80	90	29.71	31.90	37.71	39.40

CONCLUSION

The mechanical properties of Polyethylene Terephthalate Glycol (PETG) material have been thoroughly investigated by conducting flexural and impact tests, focusing on the influence of process parameters of layer thickness, infill density and raster angle. The primary goal was to enhance the flexural and impact properties of 3D-printed PETG specimens by optimizing these parameters. The optimum flexural strength was attained with lower layer thickness and a higher infill density of 80%. The ANOVA analysis for flexural strength demonstrated that both the interaction between layer thickness and infill density (AB) had a substantial impact on the flexural strength of PETG. The impact strength showed a positive response to higher layer thickness, with the response surface indicating the highest impact strength at a layer thickness of 0.4 mm and an infill density of 80%. As indicated by the ANOVA analysis, layer thickness is identified as the most influential factor affecting the impact strength. This study concluded that the most desirable combination of printing settings for high flexural and impact strength is a layer thickness of 0.234 mm, an infill density of 80%, and a raster angle of 90°. This implies that these factors collectively generate the optimal mechanical performance for 3D-printed PETG samples. The model's validity was confirmed by analyzing the results of confirmation runs, which showed discrepancies of 6.87% for flexural strength and 4.29% for impact strength. The findings contribute to the expanding knowledge base in additive manufacturing, and this optimization has the

potential to enhance the reliability and durability of 3D-printed objects. This is especially advantageous in many industrial settings.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the Faculty of Mechanical Engineering, Universiti Teknologi MARA for providing research facilities.

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

- Abbas, T., Othman, F. M., & Ali, H. B. 2017. Effect of infill Parameter on compression property in FDM Process. *Int. Journal of Engineering Research and Application* 7(10): 16-19.
- Almutairi, M. D., Mascarenhas, T. A., Alnahdi, S. S., He, F., & Khan, M. A. 2023. Modal response of hybrid raster orientation on material extrusion printed acrylonitrile butadiene styrene and polyethylene terephthalate glycol under thermo-mechanical loads. *Polymer Testing* 120: 107953.

- Carneiro, O. S., Silva, A. F., & Gomes, R. 2015. Fused deposition modeling with polypropylene. *Materials & Design* 83: 768-776.
- Durgashyam, K., Reddy, M. I., Balakrishna, A., & Satyanarayana, K. J. M. T. P. 2019. Experimental investigation on mechanical properties of PETG material processed by fused deposition modeling method. *Materials Today: Proceedings* 18: 2052-2059.
- Gao, G., Xu, F., Xu, J., Tang, G., & Liu, Z. 2022. A survey of the influence of process parameters on mechanical properties of fused deposition modeling parts. *Micromachines* 13(4): 553.
- Guessasma, S., Belhabib, S., & Nouri, H. 2019. Printability and tensile performance of 3D printed polyethylene terephthalate glycol using fused deposition modelling. *Polymers* 11(7): 1220.
- Halim, N. H. A., Tharazi, I., Salleh, F. M., Morni, M. F., Khalit, M. I., & Abdullah, M. A. A. 2024. Multi-objectives optimization of abrasive water jet machining (AJWM) on mild steel. *International Journal of Integrated Engineering* 16(5): 187-200.
- Hsueh, M. H., Lai, C. J., Wang, S. H., Zeng, Y. S., Hsieh, C. H., Pan, C. Y., & Huang, W. C. 2021. Effect of printing parameters on the thermal and mechanical properties of 3d-printed PLA and PETG, using fused deposition modeling. *Polymers* 13(11): 1758.
- Johnson, G. A., & French, J. J. 2018. Evaluation of infill effect on mechanical properties of consumer 3D printing materials. *Advance. Technology Innovations* 3(4): 179-184.
- Kechagias, J. D. & Vidakis, N. Parametric optimization of material extrusion 3D printing process: an assessment of Box-Behnken versus full-factorial experimental approach. *International Journal of Advances Manufacturing and Technology* 121: 3163-3172.
- Kumar, M. S., Farooq, M. U., Ross, N. S., Yang, C. H., Kavimani, V., & Adediran, A. A. 2023. Achieving effective interlayer bonding of PLA parts during the material extrusion process with enhanced mechanical properties. *Scientific Reports* 13(1): 6800.
- Low, Z. X., Chua, Y. T., Ray, B. M., Mattia, D., Metcalfe, I. S., & Patterson, D. A. 2017. Perspective on 3D printing of separation membranes and comparison to related unconventional fabrication techniques. *Journal of Membrane Science* 523: 596-613.
- Lužanin, O.; Movrin, D.; & Plančak, M. 2014. Effect of layer thickness, deposition angle, and infill on maximum flexural force in FDM-built specimens. *Journal for Technology of Plasticity* 39(1): 49-58.
- Panneerselvam, T., Raghuraman, S., & Vamsi Krishnan, N. 2021. Investigating mechanical properties of 3D-printed polyethylene terephthalate glycol material under fused deposition modeling. *Journal of The Institution of Engineers (India): Series C* 102: 375-387.
- Sepahi, M. T., Abusalma, H., Jovanovic, V., & Eisazadeh, H. 2021. Mechanical properties of 3D-printed parts made of polyethylene terephthalate glycol. *Journal of Materials Engineering and Performance* 30: 6851-6861.
- Shahrubudin, N., Lee, T. C., & Ramlan, R. J. P. M. 2019. An overview on 3D printing technology: Technological, materials, and applications. *Procedia Manufacturing* 35: 1286-1296.
- Sousa, A. M., Pinho, A. C., & Piedade, A. P. 2021. Mechanical properties of 3D printed mouthguards: Influence of layer height and device thickness. *Materials & Design* 203: 109624.
- Suteja, J. 2024. Experimental investigation of infill parameters influence on compressive strength-to-mass ratio of PLA 3D printed part. *Journal of Mechanical Engineering* 21(1): 45-59.
- Szykiedans, K., Credo, W., & Osiński, D. 2017. Selected mechanical properties of PETG 3-D prints. *Procedia Engineering* 177: 455-461.
- Tezel, T., Ozenc, M. m, & Kovan, V. 2021. Impact properties of 3D-printed engineering polymers. *Materials Today Communications* 26: 102161.
- Tharazi, I., Sulong, A. B., & Mohd Salleh, F. 2020. Application of response surface methodology for parameters optimization in hot pressing kenaf reinforced biocomposites. *Journal of Mechanical Engineering* 17(3): 131-144.
- Tharazi, I., Halim, N. H. A., Salleh, F., Manurung, Y. H., Sabtu, A. S., Zulkifli, Z., & Khalit, M. I. 2024. Sheet metal forming analysis of aluminium alloy AA6061 using Altair INSPIRE form simulation. *Jurnal Kejuruteraan* 36(3): 1237-1247.
- Triawan, F., Syefira, D., Rismalia, M., Suryani, I. O., Djamari, D. W., Budiman, B. A., & Nandiyanto, A. B. D. 2022. The influence of infill density and pattern on the mechanical and fracture behavior of 3D printed structure subjected to uniaxial tensile load. *Journal of Engineering Science and Technology* 17(5): 3254-3266.
- Valvez, S., Silva, A. P., & Reis, P. N. 2022. Optimization of printing parameters to maximize the mechanical properties of 3D-printed PETG-based parts. *Polymers* 14(13): 2564.
- Yan, C., Kleiner, C., Tabigue, A., Shah, V., Sacks, G., Shah, D., & DeStefano, V. 2023. PETG: applications in modern medicine. *Engineered Regeneration* 5(1): 45-55.