ISSN 3047-5473
Innovation in Engineering, Volume 1, Nomor 2, 2024, pp. 125-133

Exploring how 3D printing parameters affect the flexural strength of ABS materials

Diki Anggara, Rifelino*, Zainal Abadi and Andril Arafat

Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Padang, **Indonesia**

*Corresponding Author: rifelino@ft.unp.ac.id

DOI: https://doi.org/10.58712/ie.v1i2.16

Abstract: This research focuses on testing the flexural strength of Acrylonitrile Butadiene Styrene (ABS) materials used in 3D printing by the Fused Deposition Modeling (FDM) method. The objective of this study was to evaluate the mechanical strength of ABS using a full factorial experimental design, applying three main factors such as layer height, infill density and infill pattern. Flexural testing was conducted following ASTM D790 standards. A total of 27 specimens were made by varying the layer height, infill density and infill pattern. The results showed that layer height was the most influential factor on flexural strength, with the highest value of 41.815 Mpa at 0.2 mm layer height, 100% infill density, and line infill pattern. ANOVA analysis supported this conclusion with p values <0.05 for layer height, while infill pattern and infill density showed no significant effect. This study provides guidelines for the use of optimal parameters in ABS-based 3D printing processes.

Keywords: Ultimaker Cura Software; Future manufacture; STL; g-code

1. Introduction

Advances in science and technology, particularly in the field of 3D printing, have seen significant growth in recent years [1], [2], [3], [4]. Fused Deposition Modelling (FDM) technology as one of the most commonly used 3D printing methods, is known for its ease of use, affordability, and environmental sustainability [5], [6], [7], [8]. This method is widely chosen because of its efficiency in identifying the optimal combination of controllable factors while still considering the lowest cost and fulfilling expectations [9]. 3D printing is used to print a wide range of products such as educational aids, jewellery accessories, medical devices, product designs, children's toys, and other necessities [10].

Acrylonitrile Butadiene Styrene (ABS) material has a yield strength of 31.19 MPa and a tensile strength of 50.96 MPa [11]. Parameter settings with 45° orientation, 0.3 mm

Received: June 21, 2024. **Revised**: August 29, 2024. **Accepted**: September 15, 2024

thickness, and normal speed have a significant impact on the tensile strength of samples printed using ABS filament [12]. The moulding temperature did not affect the tensile strength, but the use of full infill (100%) increased the tensile strength by 51% and the infill pattern using a honeycomb shape had a higher tensile strength than the lattice infill pattern [13]. The use of ABS as a filament in 3D printing has the potential to be further investigated, including the parameters of layer thickness, infill percentage, and infill pattern on mechanical, thermal, and electrical characteristics [14]. Comprehensively, no one has reported the effect of layer thickness, infill density and infill pattern on the use of ABS filament on the mechanical properties of 3D printing results.

This research aims to explore the effect of printing settings in terms of layer height, infill density and infill pattern on the flexural strength of ABS materials used in the 3D printing process. By conducting an in-depth analysis of these variables, this research is expected to not only provide a better understanding of the mechanical characteristics of ABS 3D prints but also make a significant contribution to the development of new methods and techniques in ABS filament utilisation. The results obtained are expected to be an important reference for future research, which can improve the efficiency and effectiveness of ABS utilisation in industrial and technological applications, and open up opportunities for innovation in the design and production of 3D printing-based components.

2. Material and methods

Making specimen designs using SolidWorks Research 2021 License Universitas Negeri Padang. The dimensions of the specimens follow the ASTM D790 standard. Furthermore, to create of G-code as a command language for 3D printing is done using Ultimaker Cura Software (open source). The printing process uses Anet A8 Plus 3D printing. The type of filament material used in this research is ABS with a diameter of 2.85 mm and a density of 1.04 g/cm^3. ABS-type filaments are widely used due to their heat resistance and chemical stability [15], [16].

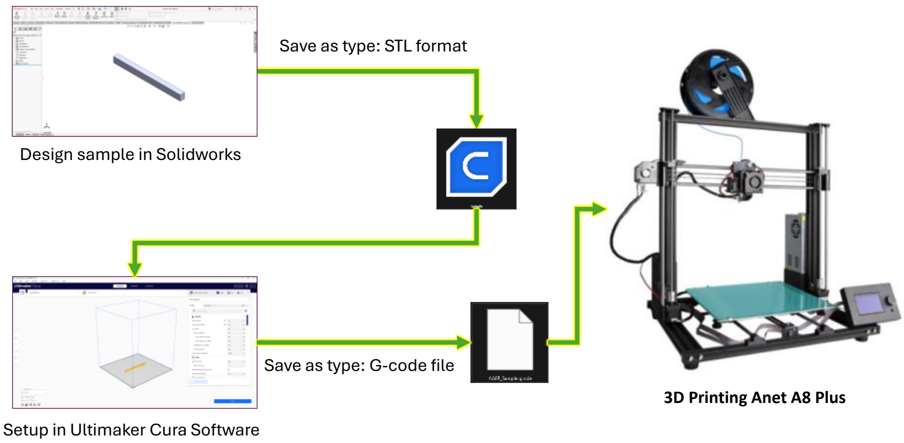

Figure 1: The specimen preparation process

A total of 27 specimens were printed (table 1) by varying the layer height (0.1 mm, 0.2 mm and 0.3 mm), infill density ((20%, 60% and 100%) and infill pattern (line, tri hexagon and grid). The difference settings are set in the print settings of the Ultimaker Cura software. Other print settings are presented in Table 2. The different shapes of infill density and infill patterns are presented in Figure 2.

Table 1: Specimen differences

Specimens	Factors		
	Layer Height	Infill density	Infill Pattern
1	0.1 mm	20%	Lines
2			Tri Hexagone
3			Grid
4		60%	Lines
5			Tri Hexagone
6			Grid
7		100%	Lines
8			Tri Hexagone
9			Grid
10	0.2 mm	20%	Lines
11			Tri Hexagone
12			Grid
13		60%	Lines
14			Tri Hexagone
15			Grid
16		100%	Lines
17			Tri Hexagone
18			Grid
19	0.3 mm	20%	Lines
20			Tri Hexagone
21			Grid
22		60%	Lines
23			Tri Hexagone
24			Grid
25		100%	Lines
26			Tri Hexagone
27			Grid

Table 2: Printing settings

Printing temperature	240 ° C - 260 ° C
Build plate temperature	100 ° C
Print Speed	20-60 mm/s

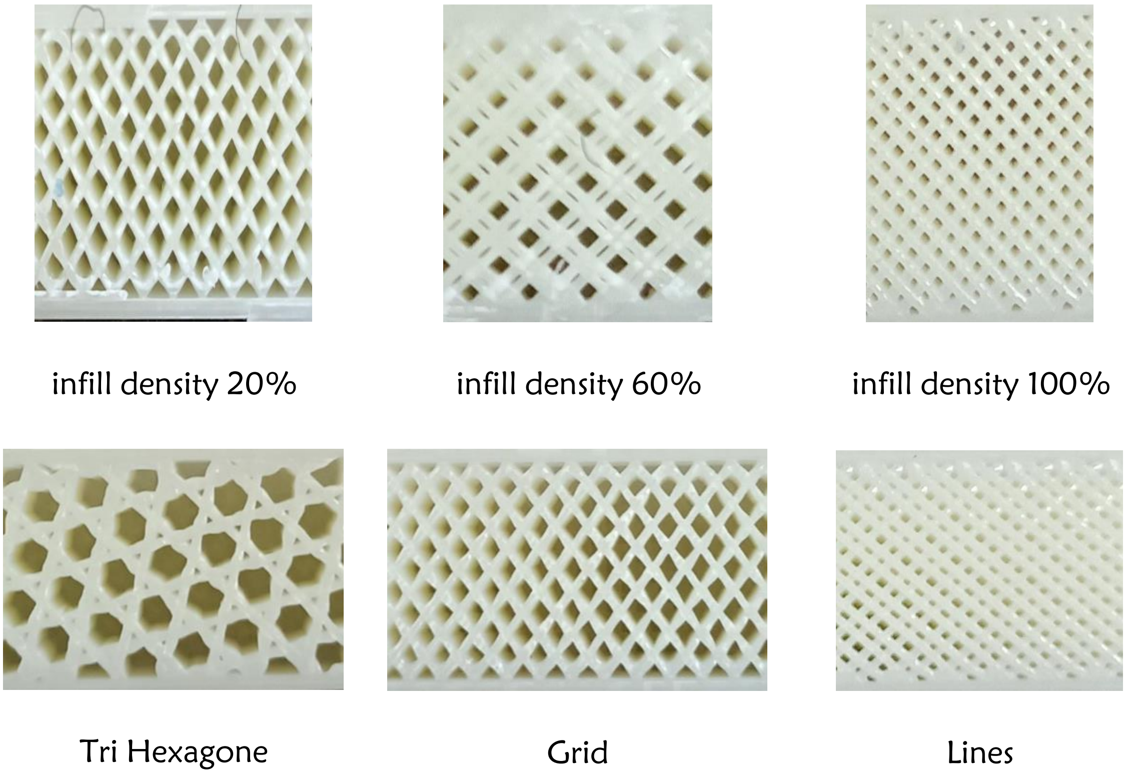

Figure 2: Differences in infill density and infill pattern shape

Flexural testing was conducted using a three-point flexural test. The testing process used a UTM HT 2402 machine. The test procedure refers to the ASTM D790 standard. The testing process and the results of the tested specimens are presented in Figure 3.

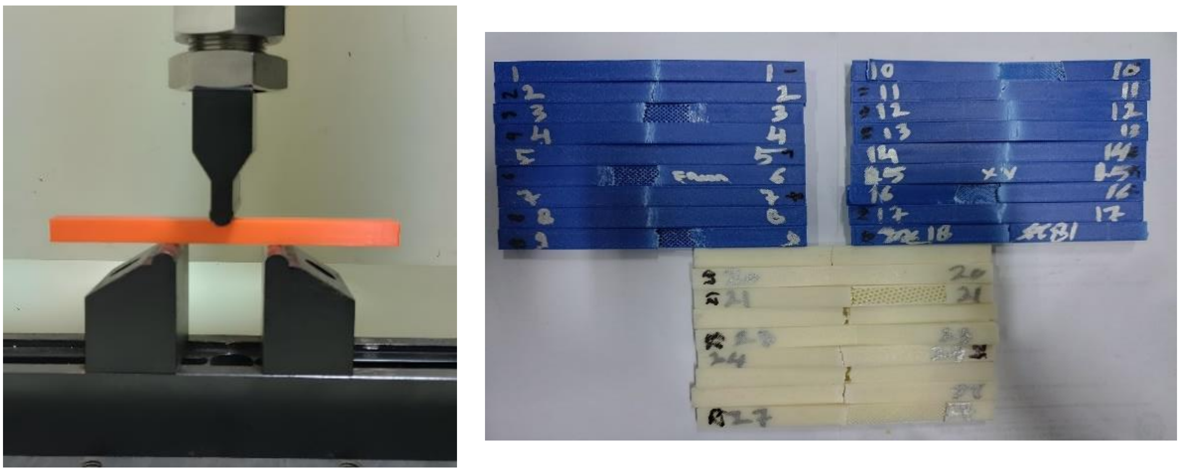

Figure 3: Flexural testing used UTM HT 2402

Data were analysed using the analysis of variance (ANOVA) technique. The purpose of this analysis was to compare the effect of various moulding parameter factors on flexural strength.

3. Results and discussion

Based on the test results that have been conducted (Figure 4), the print setting parameter that has the highest flexural strength is in specimen 16 at 41.815 MPa, with a print setting of layer height 0.2 mm, infill density 100%, and an infill pattern using a line pattern. The lowest moulding setting was specimen 5, where the flexural strength was 26.106 MPa with a moulding setting of layer heights of 0.1 mm, infill density of 60%, and an infill pattern using a tri hexagon pattern.

Figure 4: Flexural strength comparison

ANOVA analysis was conducted to compare and test the factors of the print setting parameters by analysing the resulting variation values. The results of ANOVA analysis on the flexion strength data of each specimen are presented in Table 3.

Table 3: One-way ANOVA for flexural strength

Source	DF*	SS*	MS*	F-Value	P-Value	Significant (Yes/No)
Layer heights	2	91196958	45598479	5.79	0.01	Yes
Infill density	2	20595981	10297990	1.31	0.293	No
Infill pattern	2	48547936	24273968	3.08	0.068	No
Error	20	157498327	7874916			
Total	26	317839201				

* *P*-value < 0.05 is significant; DF is the degree of freedom; SS is the sum of squares; MS is the mean square

Based on the results of ANOVA analysis, the layer height parameter significantly affects the flexural strength of 3D printing results using ABS filament. In Figure 5, it can be seen that the most significant influence on flexural strength is layer heights of 0.2 mm. The use of PLA material also shows that the layer height has a much greater influence on the tensile strength [17]. Other studies have also revealed that at an infill height of 0.2 mm, the optimal use of PLA filaments is [18]. In terms of the infill density parameter, the most significant influence is 100% infill density and the infill pattern parameter is the grid pattern.

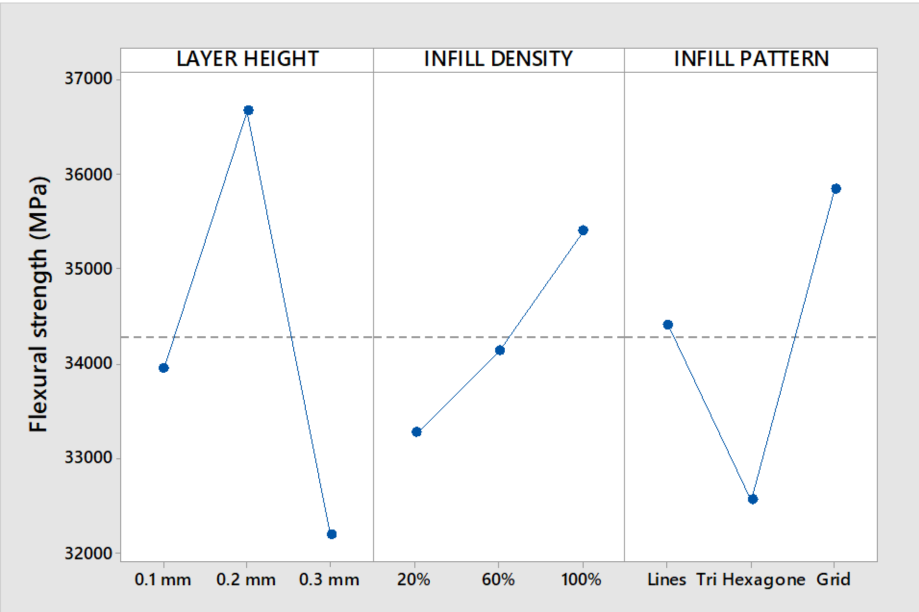

Figure 5: Main effect plot flexural strength

4. Conclusion

In 3D printing, there are many options for print settings before printing. In this study, 27 specimens were made with different print settings based on layer height, infill density and infill pattern. The test results show that there is a difference in the flexural strength value of each specimen. This shows that the print settings affect the quality of 3D printing results. Based on the test results, the highest flexural strength value is in the specimen with layer height 0.2 mm, infill density 100% and infill pattern using a Grid pattern.

Acknowledgements

The authors would like to thank the Manufacturing Laboratory of the Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Padang for allowing and providing facilities for this research.

Declarations

Author contribution

Diki Anggara: Conceptualization, Methodology, Project management, Supervision, Reviewing and Editing. Rifelino: Conceptualization, Methodology, Formal Analysis, Reviewing and Editing. Zainal Abadi and Andril Arafat: Conceptualization, Methodology Investigation, Validation, Visualization, Manuscript Writing, Reviewing and Editing.

Funding statement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors declare no conflict of interest in this research and publication.

Ethical Clearance

This research does not involve human subjects.

References

[1] D. Nurfaedah, R. Rifelino, P. Purwantono, and F. Prasetya, "Optimalisasi Kekuatan Bending Hasil 3D Printing Menggunakan Metode Response Surface Pada Filamen Pla (Poly Lactic Acid) [Optimisation of Bending Strength of 3D Printing Results Using Response Surface Method on Pla (Poly Lactic Acid) Filament]," *Jurnal Vokasi Mekanika (VoMek)*, vol. 3, no. 3, pp. 58–66, 2021, https://doi.org/10.24036/vomek.v3i3.217

[2] R. Sharma, P. Chandra Nath, T. Kumar Hazarika, A. Ojha, P. Kumar Nayak, and K. Sridhar, "Recent advances in 3D printing properties of natural food gels:

Application of innovative food additives," *Food Chem*, vol. 432, p. 137196, Jan. 2024, https://doi.org/10.1016/j.foodchem.2023.137196

[3] S. F. Iftekar, A. Aabid, A. Amir, and M. Baig, "Advancements and Limitations in 3D Printing Materials and Technologies: A Critical Review," *Polymers (Basel)*, vol. 15, no. 11, p. 2519, May 2023, https://doi.org/10.3390/polym15112519

[4] S. Siddiqui, S. Surananai, K. Sainath, M. Zubair Khan, R. Raja Pandiyan Kuppusamy, and Y. Kempaiah Suneetha, "Emerging trends in development and application of 3D printed nanocomposite polymers for sustainable environmental solutions," *Eur Polym J*, vol. 196, p. 112298, Sep. 2023, https://doi.org/10.1016/j.eurpolymj.2023.112298

[5] K. Rajan, M. Samykano, K. Kadirgama, W. S. W. Harun, and M. M. Rahman, *Fused deposition modeling: process, materials, parameters, properties, and applications*, vol. 120, no. 3–4. Springer London, 2022. https://doi.org/10.1007/s00170-022-08860-7

[6] N. R. Madhu, H. Erfani, S. Jadoun, M. Amir, Y. Thiagarajan, and N. P. S. Chauhan, "Fused deposition modelling approach using 3D printing and recycled industrial materials for a sustainable environment: a review," *The International Journal of Advanced Manufacturing Technology*, vol. 122, no. 5–6, pp. 2125–2138, Sep. 2022, https://doi.org/10.1007/s00170-022-10048-y

[7] M. Rahmati, J. J. Blaker, S. P. Lyngstadaas, J. F. Mano, and H. J. Haugen, " Designing multigradient biomaterials for skin regeneration," *Mater Today Adv*, vol. 5, p. 100051, Mar. 2020, https://doi.org/10.1016/j.mtadv.2019.100051

[8] A. Cano-Vicent *et al.*, "Fused deposition modelling: Current status, methodology, applications and future prospects," *Addit Manuf*, vol. 47, p. 102378, Nov. 2021, https://doi.org/10.1016/j.addma.2021.102378

[9] D. G. Zisopol, A. I. Portoaca, I. Nae, and I. Ramadan, "A Statistical Approach of the Flexural Strength of PLA and ABS 3D Printed Parts," *Engineering, Technology and Applied Science Research*, vol. 12, no. 2, pp. 8248–8252, 2022, https://doi.org/10.48084/etasr.4739

[10] M. N. M. Azlin *et al.*, "3D Printing and Shaping Polymers, Composites, and Nanocomposites: A Review," *Polymers (Basel)*, vol. 14, no. 1, 2022, https://doi.org/10.3390/polym14010180

[11] N. Sathishkumar, B. Vincent, N. Arunkumar, K. M. Kumar, and P. L. Sudharsan, " Study of compressive behaviour on 3D printed ABS polymer lattice structures infilled with epoxy and polyester resins," *IOP Conf Ser Mater Sci Eng*, vol. 923, p. 012044, Oct. 2020, https://doi.org/10.1088/1757-899X/923/1/012044

[12] M. N. Ahmad and A. Yahya, "Effects of 3D Printing Parameters on Mechanical Properties of ABS Samples," *Designs (Basel)*, vol. 7, no. 6, p. 136, Nov. 2023, https://doi.org/10.3390/designs7060136

[13] P. Żur, A. Kołodziej, A. Baier, and G. Kokot, "Optimization of Abs 3D-Printing Method and Parameters," *European Journal of Engineering Science and Technology*, vol. 3, no. 1, 1970, https://doi.org/10.33422/ejest.v3i1.160

[14] L. Sandanamsamy *et al.*, "A comprehensive review on fused deposition modelling of polylactic acid," *Progress in Additive Manufacturing*, vol. 8, no. 5, pp. 775–799, Oct. 2023, https://doi.org/10.1007/s40964-022-00356-w
[15] Y. Li and Y. Lou, "Tensile and Bending Strength Improvements in PEEK Parts Using Fused Deposition Modelling 3D Printing Considering Multi-Factor Coupling," *Polymers (Basel)*, vol. 12, no. 11, p. 2497, Oct. 2020, https://doi.org/10.3390/polym12112497
[16] S. Prajapati, J. K. Sharma, S. Kumar, S. Pandey, and M. K. Pandey, "A review on comparison of physical and mechanical properties of PLA, ABS, TPU, and PETG manufactured engineering components by using fused deposition modelling," *Mater Today Proc*, May 2024, https://doi.org/10.1016/j.matpr.2024.05.018
[17] J. R. Stojković *et al.*, "An Experimental Study on the Impact of Layer Height and Annealing Parameters on the Tensile Strength and Dimensional Accuracy of FDM 3D Printed Parts," *Materials*, vol. 16, no. 13, p. 4574, Jun. 2023, https://doi.org/10.3390/ma16134574
[18] N. S. Mohd Tamizi, N. Zainon, M. Md Deros, and A. A. Basri, "Investigation on the Effect of Printing Parameters on Flexural properties of 3D Printed Polymeric Scaffolds," *J Phys Conf Ser*, vol. 2169, no. 1, p. 012027, Jan. 2022, https://doi.org/10.1088/1742-6596/2169/1/012027