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Posted Date: 11 October 2023

doi: 10.20944/preprints202310.0656.v1

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Effects of 3D Printing Parameters on Mechanical Properties of ABS Samples

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Abstract: The most modern technique utilized to create intricate manufactured parts for a variety of applications is called additive manufacturing (AM). Fused deposition modeling (FDM) has acknowledged the greatest consideration in the development and industrial sectors. The main objective of this study was to investigate how printing factors affected the mechanical characteristics of printed samples. Samples were produced via an FDM 3D printer in compliance with ASTM D638 using a variety of input settings, including orientation, layer thickness, speed, and infill pattern. On the printed samples, tensile tests and morphological analysis using a scanning electron microscope (SEM) were done. The results of this study demonstrate that factors including layer thickness, printing speed, and orientation significantly affect the tensile strength of ABS printed samples. Discovering the parameter settings that could lead to greater mechanical and physical characteristics would undoubtedly assist designers and manufacturers worldwide as the FDM 3D printer becomes more and more crucial in manufacturing engineering parts.

Keywords: fused deposition modeling (FDM); additive manufacturing (AM); acrylonitrile butadiene styrene (ABS); mechanical properties; 3D printing parameters

1. Introduction

The process of synthesizing layers of materials to produce precise parts or finished goods is known as additive manufacturing (AM) [1]. A computer-aided design (CAD) model serves as the blueprint for the additive manufacturing process, which entails building three-dimensional parts by gradually integrating material in the form of layers [2]. The process of additive manufacturing may create parts with decent precision and a small amount of waste [3]. The ability of AM technology to get a product to market more quickly than traditional techniques has caused its use to explode over the past few decades [4]. According to Forbes, 95% of manufacturing firms believe that 3D printing technology offers a sizable competitive edge. 57% of worldwide companies made investments in 3D printing research and development. Additionally, research demonstrates that 47% of 3D printing companies have had greater success than in past years [5]. According to estimates, the AM industry will increase by an average of 24%, or 35 billion US dollars, during the next five years [6]. The AM sector expanded by 7.5%, or roughly $12.8 billion US dollars, in 2020. AM is currently an area of interest for bio-printing and is employed in a wide range of industries, comprising the ceramic, polymer, biomedical, and industrial of composite materials [7–9]. Powder bed fusion, direct energy deposition, material extrusion, binder jetting, material jetting, sheet lamination, and VAT photopolymerization are some of the various types of AM technology [10].

Polymers are used as a filament in fused deposition modeling (FDM), sometimes referred to as the material extrusion AM technology. Typically, the filament is heated until it becomes molten, at which point it is extruded through the machine's nozzle. A significant reduction in processing time can be achieved by using lightweight materials to create complex shapes with the FDM technique

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[11,12]. In contrast to other AM methods that make use of various laser systems, powders, and resins. It stands out as a widely used technology that extrudes semi-solid thermoplastic material via a nozzle [13]. FDM, also referred to as fused filament fabrication (FFF), was a popular technique for extruding materials. After being drawn through a nozzle and heated there, hot layers of material are then deposited. Due to its simplicity, adaptability, speed of processing, cheap cost, dependability, low waste, range of materials, and ability to deal with new materials, FDM is also among the most extensively used methods. The FDM technology was created in 1989 by Stratasys, Ltd., one of the leading participants in the global marketplace for 3D printing. FDM technology makes up over 40% of the global market. The most widely used AM technology is FDM because of its speed production, accessibility, cost-effectiveness, wide range of material versatility, and capacity to create complicated parts. [14]. The most comprehensively researched thermoplastic polymer materials used in the FDM method consist of acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polypropylene (PP), polyethylene terephthalate (PET), and high-density polyethylene (HDPE) [15,16].

Numerous earlier scholars investigated the effect of the FDM 3D printer's printing parameters. They researched variables such as printing speed, layer thickness, orientation, raster angle, and pattern infill [17–20]. ABS material was utilized by Sharma et al. [21] and Vicente et al. [22] to examine the influence of layer thickness on mechanical behavior. The FDM factors that received the greatest attention throughout the research were build orientation, layer thickness, raster orientation, air gap, infill density, and raster width. The most significant variables affecting the product's mechanical properties, dimensional accuracy, and surface roughness, according to previous studies, are thickness and orientation. The support material and fabrication time optimization on FDM were examined by Pavan Kumar and Regalla et al. [23] using the DOE approach. According to the analysis of variance (ANOVA) results, the sample's orientation was determined to be essential for minimizing build time, and build time is reduced when the raster angle, raster width, layer thickness, and contour width rise. According to Nancharaiah et al.'s ANOVA analysis [24], the raster width and layer thickness had a substantial impact on the product's part accuracy and surface finish. In order to prepare the sample and conduct mechanical experiments, research organizations used ASTM-established standards. For instance, practically all research organizations that tested for tensile testing employed ASTM D638 [25].

A high percentage of studies indicated that the process variables primarily influence the part's tensile strength, elongation, and elastic modulus. Furthermore, mechanical performance was shown to depend on printing conditions in almost all of the research published [26]. The part orientation and the inadequate interlayer bonding have the biggest impacts on the sample's tensile strength. Additionally, both parallel and longitudinal materials can produce materials that have elevated tensile in the printing direction [27]. Hossain et al. [28] investigated methods to manipulate the contour width, air gap, build orientation, and raster angle in order to increase Young's modulus, ultimate tensile strength, and tensile strain. The evaluation has been conducted using the default, visual response, and insight methods. The results showed that by employing the insight approach to optimize process parameters, a greater UTS could be achieved. The mechanical characteristics and microstructure of the FDM-printed ABS parts at various raster angle orientations were investigated by Fatimatuzahraa et al. [29]. The results demonstrated that constructions with a cross-sectional angle of 45° have greater performance for impact, flexural, and deflection tests.

Researchers frequently used the scanning electron microscope (SEM) technology in their research. It is an accurate and efficient approach to evaluate a material's surface morphology. The samples' fractured surfaces underwent morphological examination by Atakok et al. [30]. The test parts' resistance to deformation was decreased by their porous structure and the significant surface voids that they had created. The parallel layers created by the FDM process are clearly visible in the cross-section of the fracture test parts. According to Lyu et al. [31], the interlayer bonding of the three samples had similarities as seen in the SEM images. The number of pores and adhesion between the filaments were greatly influenced by the 3D printing parameters, which in turn affected the samples' yield strength. For SEM microscopy investigation, the samples with the finest fracture were chosen

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[32]. The outcome demonstrates that when the infill percentage declined, the amount of the infill voids grew larger. Therefore, the characteristics dropped as the size of the voids increased and the interaction between the layers became weaker. Based on the literature, there had been less research conducted regarding the effects of parameters for the FDM 3D printer (model Up Plus 2) using ABS filament. In order to better understand how 3D printing factors, affect important mechanical characteristics including tensile strength and tensile modulus of ABS material produced by an FDM 3D printer, this study will investigate those effects.

2. Materials and Methods

2.1. Filaments and printing parameters

We bought ABS filament from eSUN in Shenzhen, China. The ideal printing temperature and the optimal printing bed temperature were 245°C and 80°C, respectively. The nozzle diameter was 0.4 mm, whereas the filaments had a 1.75 mm diameter. An experimental setup flow chart for this work is shown in Figure 1. Catia V9 software was used to create the CAD model in accordance with ASTM D638 standards. Then, this model was transferred to Slicing UP Studio 3 software. The samples were then printed using the generated G-code on an FDM 3D printer.

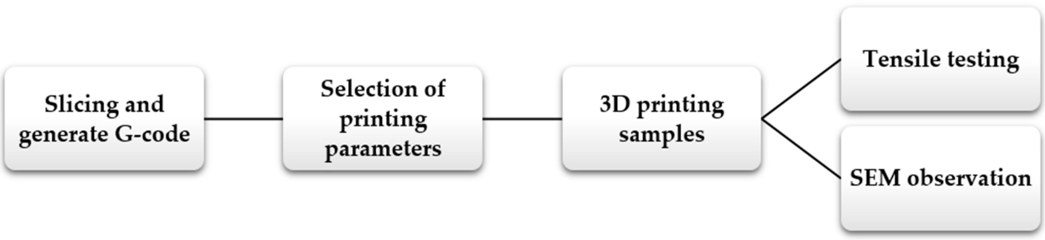

Figure 1. Flow chart of experimental setup for the ABS printed samples

Table 1 shows infill pattern, orientation, layer thickness, and printing speed have been selected as printing parameters used to produce the samples. To determine the impact these factors had on the mechanical characteristics, the specimens were created using three different infill patterns (loose, solid, and hollow), layer thicknesses (0.2, 0.3, and 0.4mm), orientations (0, 45, and 90°), and speeds (fine, normal, and fast). Compared to other types of samples, those that had lower layer thicknesses and faster printing speeds took less time to print. The 3D printer, UP Plus 2, Beijing, China was used to print the specimens. Right after the printing method, all samples undergo tensile testing and SEM examination.

Table 1. Printing parameters for ABS printed samples

No.	Infill pattern	Orientation (°)	Thickness (mm)	Speed (cm^3/h)
1	Loose	0°	0.2	Fine
2		45°	0.3	Normal
3		90°	0.4	Fast
4	Solid	0°	0.2	Fine
5		45°	0.3	Normal
6		90°	0.4	Fast
7	Hollow	0°	0.2	Fine
8		45°	0.3	Normal
9		90°	0.4	Fast

2.2. Tensile testing

Tensile strength is a measurement of how much a material can be stretched before breaking or how far it can be stretched before cracking. An extensometer was fastened to the sample at its focus

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point in order to perform the tensile test. A universal testing machine (Instron 5969, MA, United States) with a 50 kN load cell and a constant crosshead speed of 5 mm/min was used to measure the tensile strength, modulus, and elongation. For tensile and modulus properties, the testing was done in accordance with ASTM D638 [33]. The tensile test setup for ABS-printed samples is shown in Figure 2. In addition, the ductile modulus, rigidity, and elongation at the breaking point, among other tensile parameters, were identified. Calculating elasticity and modulus is done using Equations 1 and 2, where σ indicates the tensile strength at yielding; A denotes the cross-section area; F represents the applied load (kN); E stands for the elastic modulus (MPa), and ϵ for the sample's strain (mm/mm).

$$\sigma = \frac{F}{A} \quad (1)$$

$$E = \frac{\sigma}{\epsilon} \quad (2)$$

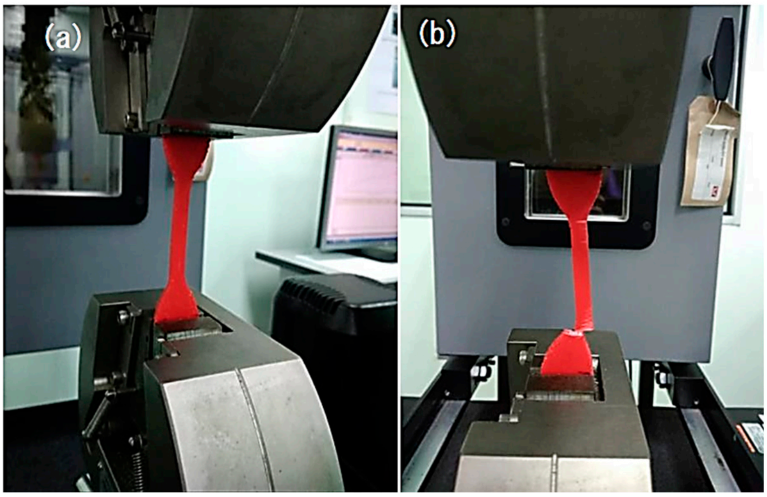

Figure 2. Tensile testing setup using an universal testing machine (Instron 5969) (a) underformed and (b) deformed

2.3. Scanning electron microscope (SEM)

Scanner electron microscopy (SEM) analysis was performed in order to examine the top surface of the fracture morphology with a 20 kV acceleration voltage, the JEOL JSM-6010PLUS/LV (Tokyo, Japan). Prior to the experiment, all samples had been trimmed to a uniform size and coated with platinum. After inspection, all test specimens were sealed in zip-top plastic bags.

2.3. Analysis of variance (ANOVA)

With regard to mechanical characteristics, a one-way ANOVA was employed to assess the significance and comparative importance of the primary variables. One-way ANOVA was performed by Ahmad et al. [34] to analyze the mechanical characteristics of oil palm fiber composite for FDM-3D printer and assess the impact of each mean value (*p- value* less than 0.05).

3. Results and discussion

3.1. Mechanical properties

Figure 3 shows the result of tensile strength and tensile modulus of ABS printed samples. The influence of FDM-3D printing parameters towards tensile strength and Young's modulus resulted the similar pattern. The result shows that the parameters were set to 45° orientation, 0.3 mm thickness and normal speed had contributed the highest value of tensile strength (34.5 MPa) and tensile modulus (2.3 GPa). These significant results were contributed by sample no. 2, 5 and 8. Otherwise, parameter setting (sample no. 1, 4 and 7) with 0° orientation, 0.2 mm thickness and fine speed were

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contributed the lower tensile strength and tensile modulus, which is 19.5 MPa and 1.4 GPa respectively. This is in accordance with a study by Rankouhi et al. [35] that examined how layer thickness affected the mechanical characteristics of ABS parts. As indicated by the study, samples with thinner layer heights exhibited superior mechanical capabilities over those with thicker layer heights. Similar findings by Shergill et al. [36] and Ahmad et al. [34], they found that printing the parts using ABS filament with lower layer thickness had achived a good result of tensile strength. Additionally, Shashikumar [37] reported that Significant improvements in tensile strength were seen after implementing the technique known as FDM technological advances, especially when employing thinner layer thicknesses.

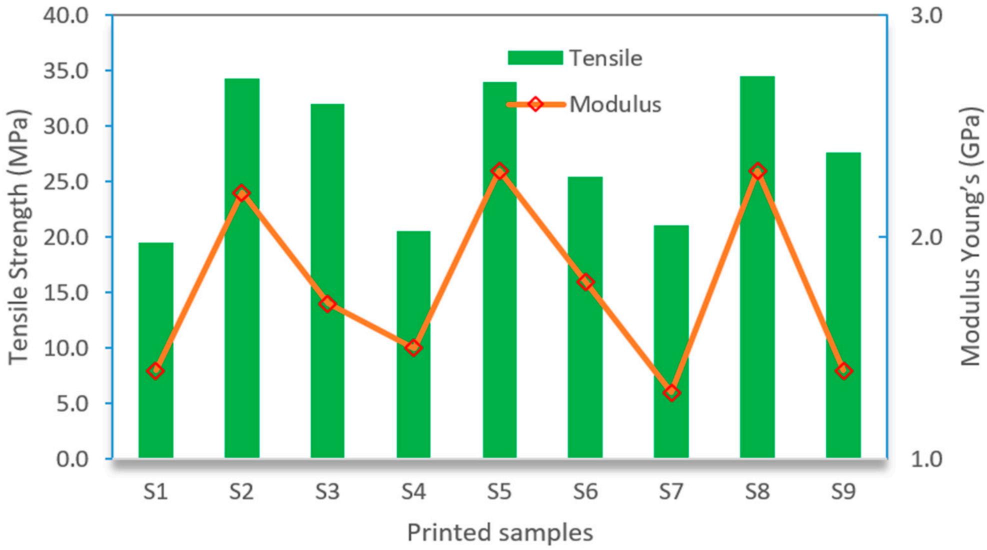

Figure 3. Result of tensile strength and Young's modulus of ABS printed samples

Figure 4 shows a graph of S-N curve of nine printed samples of ABS. By measuring the area under the S-N curve, tensile toughness was identified. The results analysis showed that the ABS samples had ductile fracture behavior. According to the results, sample no. 3 and 9 (90° orientation, 0.4 mm thickness, fast speed) perform better in terms of elongation than the others. The alteration in intermolecular interaction and segmental chain mobility in those samples could have been the cause of the higher elongation [38]. Beyond the yield point, the stress values in the situation of ABS material gradually rise till ultimate tensile strength then decrease until the breaking point. The stress-strain behavior of ABS, an amorphous copolymer, exhibits necking after the UTS. Owolabi et al. [39], who printed the component parts using a 3D printer, reported a similar S-N behavior in ABS.

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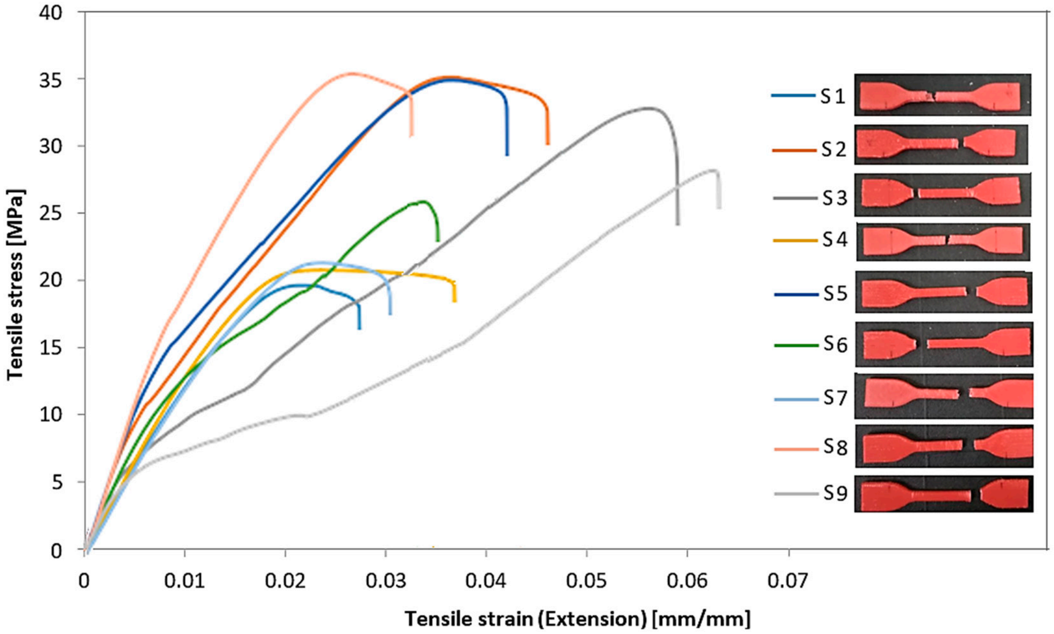

Figure 4. Graph of S-N curve of ABS printed samples

3.2. Morphological analysis

The scanning electron microscope (SEM) method used in this research is a precise and quick way to examine the microscopic topology and surface morphology of a material. The printed samples' fracture surfaces showed a ductile particular type of fracture. The material was stretched and then re-oriented, which is ultimately caused the distortion. Figure 5 depicts the SEM images of nine ABS-printed samples that have undergone a tensile test. The fractured samples' surface morphology also shows a distinct fracture pattern. In comparison to other samples, the result demonstrates that samples S2 and S5 have a robust packed structure and high structural integrity. Then, it led to higher tensile strength and Young's modulus values. Therefore, samples printed at a normal speed and with a 45° orientation setting could produce tough structures. In the meanwhile, bigger voids were discovered in samples S6, S7, and S9. It implies that samples with 0 and 90° orientations would have an inferior structure and more voids. Due to the weak adhesion between layers, the voids between layers grew, which ultimately reduced the strength of the ABS samples. The same finding was reported by Casavola et al. [40], ABS samples with setting 0° orientation show the presence of voids between beads. It results from a decrease in the component's net segment and density as well as from the existence of a cavity at the interface between the beads. Thus, to enhance the specimen's microstructure, the build orientation and printing speed must be properly selected. In summary, there was a clear relationship between the experimental results and the structure morphological investigation.

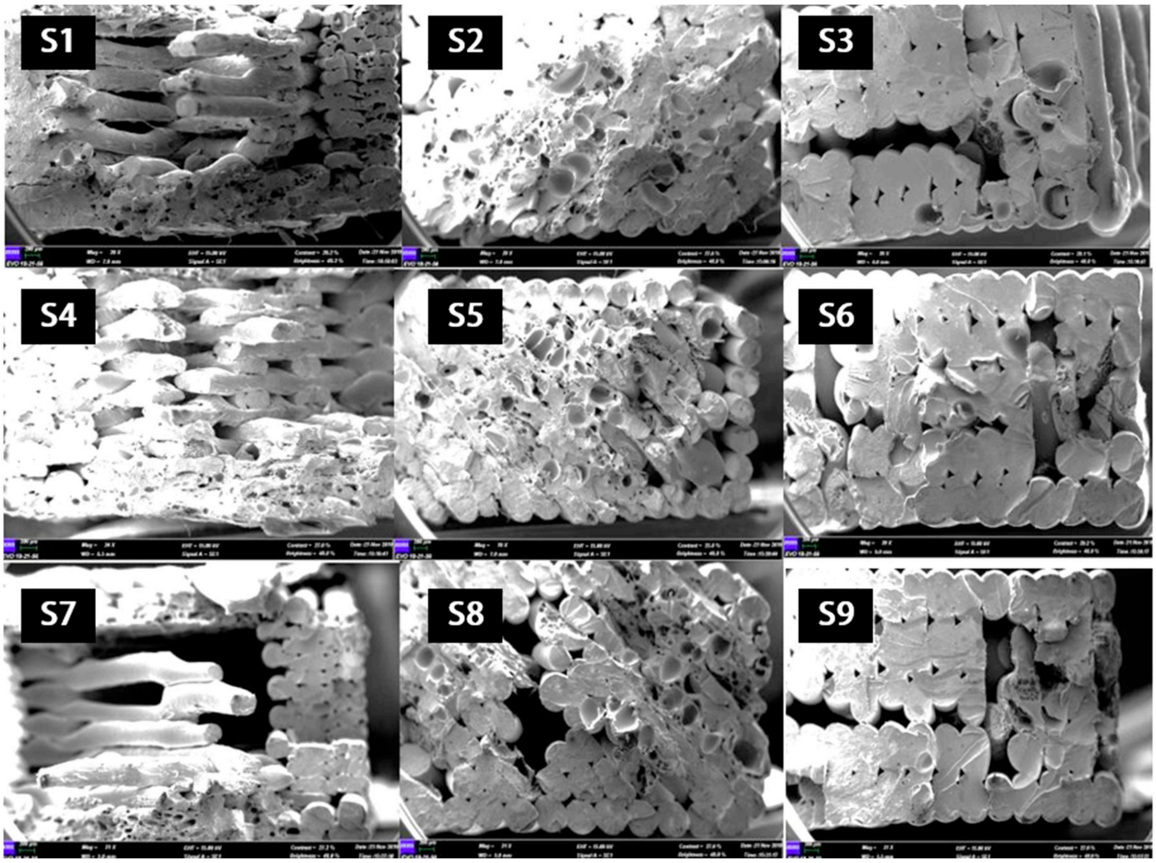

Figure 5. SEM images of fractured ABS samples (S1-S9) with 20x magnifications

3.3. Analysis of variance (ANOVA)

ANOVA is a statistical technique that classifies experimental findings into groups based on a common parameter and a function with objective characteristics or responses [41]. It is used for optimizing process parameters. An ANOVA with a confidence interval of 95% was used to examine the main effects of input parameters on each response. Table 2 exhibits the results of a one-way ANOVA for tensile strength and Young's modulus. The *p-value* calculated the results' significance or how much a parameter influences the objective function. In regard to responses, the parameter is significant if the *p-value* is less than 0.05. In this study, orientation had the greatest impact on the value of tensile strength. It has been proved, that the SEM morphological analysis has demonstrated that printing samples at a 45° orientation results in strong structures. *P-values* larger than 0.05 indicated that the remaining variables, such as infill, thickness, and speed, were not significant. In addition, with a *p-value* less than 0.05, orientation had the greatest influence on the Young's modulus response. The build orientation has the largest influence on mechanical properties, according to Hikmat et al. [16], who also found the same result.

Table 2. One-way ANOVA for tensile strength and Young's modulus

Response	Source	DF	SS	MS	*F-value*	*P-value*	Significant (Yes/No)
Tensile strength	Infill	2	5.5	2.8	0.05	0.948	No
	Orientation	2	290.83	145.41	36.17	0.000	Yes
	Thickness	2	10.2	5.1	0.10	0.906	No
	Speed	2	8.4	4.2	0,08	0.922	No
	Error	6	24.12	4.02			
	Total	8	314.95				
Young's modulus	Infill	2	0.05	0.03	0.13	0.880	No
	Orientation	2	1.19	0.60	32.06	0.001	Yes

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Thickness	2	0.03	0.01	0.07	0.937	No
Speed	2	0.03	0.02	0.07	0.935	No
Error	6	1.25	0.21			
Total	8	1.31				

* *p-value* < 0.05 is significant; DF is degree of freedom; SS is sum of square; MS is mean square.

4. Conclusions

In this work, the effect of printing parameters on the mechanical characteristics of ABS-printed samples using FDM was examined. The samples were examined in accordance with ASTM D638 standards. The study found that the tensile strength of ABS printed samples was significantly affected by the parameters of 45° orientation, 0.3 mm thickness, and normal speed. In contrast, the results for Young's modulus demonstrate that samples with a 90° orientation, 0.4 mm thickness, and fast speed exhibit greater elongation performance than other samples. SEM results for microscopic inspection reveal that samples S2 and S5 have a solid-packed structure and strong structural integrity. It proves that those samples have a greater mechanical strength value. The findings of the experimental data and the structure morphological investigations were shown to have a good relationship. This study offers sufficient data on FDM-3D printing using ABS filament in the polymer, automobile parts, and consumer product industries.

Author Contributions: Conceptualization—M.N.A.; Methodology—M.N.A. and A.Y.; Validation—M.N.A.; Original draft preparation—M.N.A. and A.Y.; Review and editing—M.N.A.; Supervision—M.N.A.; Project administration—M.N.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data will be made available on request.

Acknowledgments: The authors wish to thank Universiti Teknikal Malaysia Melaka for supporting this research. Special appreciation and gratitude to Centre of Research and Innovation Management and Faculty of Industrial and Manufacturing Technology and Engineering for giving the full cooperation towards this research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Parandoush, P.; Lin, D. A review on additive manufacturing of polymer-fiber composites. Compos. Struct. 2017, 182, 36–53
2. G. Liu, et al., ''Additive manufacturing of structural materials,'' Materials Science and Engineering R: Reports, vol. 145. Elsevier Ltd, Jul. 01, 2021.
3. M. Javaid, A. Haleem, R. P. Singh, R. Suman, and S. Rab, ''Role of additive manufacturing applications towards environmental sustainability,'' Advanced Industrial and Engineering Polymer Research, vol. 4, no. 4. KeAi Communications Co., pp. 312–322, Oct. 01, 2021.
4. Wang X, Jiang M, Zhou Z, Gou J, Hui D (2017) 3D printing of polymer matrix composites: a review and prospective. Compos Part B Eng 110:442–458.
5. Bai X, Wu J, Liu Y, Xu Y, Yang D (2020) Exploring the characteristics of 3D printing global industry chain and value chain innovation network. Inf Dev 36(4):559–575.
6. Vialva T (2020) 3D hubs 3D Printing trends report forecasts 24% growth in 3D printing industry over 5 years - 3D printing industry. https:// 3dprinting industry. com/ news/ 3d- hubs- 3d- printing- trends- report-forecasts- 24- growth- in- 3d- printing industry- over-5- years-167998
7. Jain, A.; Mathur, T.; Pandian, N.K.; Selahi, A. Organ-on-a-chip and 3D printing as preclinical models for medical research and practice. In Precision Medicine for Investigators, Practitioners and Providers; Chapter 9; Elsevier Ltd.: Duxford, UK, 2020; pp. 83–95.
8. Durfee, K.; Iaizzo, P.A. Medical Applications of 3D Printing. In Engineering in Medicine; Chapter 21; Elsevier Ltd.: Duxford, UK, 2019; pp. 495–509.
9. Rouf, S.; Malik, A.; Singh, N.; Raina, A.; Naveed, N.; Siddiqui, M.I.H.; Haq, M.I.U. Additive manufacturing technologies: Industrial and medical applications. Sustain. Oper. Comput. 2022, 3, 258–274.

10. Ahmad, M. N., Ishak, M. R., Mohammad Taha, M., Mustapha, F., & Leman, Z. (2023). A Review of Natural Fiber-Based Filaments for 3D Printing: Filament Fabrication and Characterization. Materials, 16(11), 4052.
11. Jayawardane H, Davies IJ, Leadbeater G, John M, Biswas WK (2021) 'Techno-eco-efficiency' performance of 3D printed impellers: an application of life cycle assessment. International Journal of Sustainable Manufacturing.
12. Maguluri N, Suresh G, Rao KV (2023) Assessing the effect of FDM processing parameters on mechanical properties of PLA parts using Taguchi method. Journal of Thermoplastic Composite Materials 36: 1472-1488
13. Jayawardane H, Davies IJ, Gamage JR, John M, Biswas WK (2022) Investigating the 'techno-eco-efficiency' performance of pump impellers: metal 3D printing vs. CNC machining. The International Journal of Advanced Manufacturing Technology 121: 6811-6836
14. Kumaresan, R.; Samykano, M.; Kadirgama, K.; Sharuzi, W.; Harun, W.; Rahman, M. Fused deposition modeling: Process, materials, parameters, properties, and applications. Int. J. Adv. Manuf. Technol. 2022, 120, 1531–1570
15. Sabil M, Prabhakar DAP (2022) Optimisation of Extrusion Temperature and Infill Density of PLA material by using L16 Orthogonal Array. Australian Journal of Mechanical Engineering: 1-17
16. Hikmat M, Rostam S, Ahmed YM (2021) Investigation of tensile property-based Taguchi method of PLA parts fabricated by FDM 3D printing technology. Results in Engineering 11: 100264
17. Ahmad, M. N., Tarmeze, A. A., & Rasib, A. H. A. (2020). Capability of 3D printing technology in producing molar teeth prototype. Int. J. Eng. Appl, 8, 64.
18. Ahmad, M. N., & Mohamad, A. R. (2021). Analysis on dimensional accuracy of 3D printed parts by Taguchi approach. In Advances in Mechatronics, Manufacturing, and Mechanical Engineering: Selected articles from MUCET 2019 (pp. 219-231). Springer Singapore.
19. M. Heidari-Rarani, N. Ezati, P. Sadeghi, Badrossamay M. (2020) Optimization of FDM process parameters for tensile properties of polylactic acid specimens using Taguchi design of experiment method: Journal of Thermoplastic Composite Materials. pp. 2435-2452.
20. K. E. Aslani, D. Chaidas, J. Kechagias et al. (2020) Quality Performance Evaluation of Thin Walled PLA 3D Printed Parts Using the Taguchi Method and Grey Relational Analysis: J. Manuf. Mater. Process. 2020, 4, 47.
21. Sharma M, Sharma V, Kala P (2019) Optimization of process variables to improve the mechanical properties of FDM structures. J Phys: Conf Ser 1240:012061
22. Vicente C, Martins T, Leite M, Ribeiro A, Reis L (2019) Influence of fused deposition modeling parameters on the mechanical properties of ABS parts. Polym Adv Technol 31(3):501–507
23. Gurrala PK, Regalla SP (2012) Optimization of support material and build time in fused deposition modeling (FDM). Appl Mech Mater 110–116:2245–2251
24. Nancharaiah T, Raju DR, Raju VR (2010) An experimental investigation on surface quality and dimensional accuracy of FDM components. Int J Emerg Technol 1(2):106–111
25. Nabipour M, Akhoundi B, Bagheri Saed A (2019) Manufacturing of polymer/metal composites by fused deposition modeling process with polyethylene. J Appl Polym Sci 48717:1–9.
26. Letcher T, Waytashek M (2016) Material property testing of 3D-printed specimen in PLA on an entry-level 3D printer. InASME International Mechanical Engineering Congress and Exposition pp. 1–8
27. Türk DA, Brenni F, Zogg M, Meboldt M (2017) Mechanical characterization of 3D printed polymers for fiber reinforced polymers processing. Mater Des 118:256–265.
28. Shojib Hossain M, Espalin D, Ramos J, Perez M, Wicker R (2014) Improved mechanical properties of fused deposition modeling-manufactured parts through build parameter modifications. J. Manuf. Sci. Eng. Trans. ASME 136(6)
29. Fatimatuzahraa AW, Farahaina B, Yusoff WA (2011) The effect of employing different raster orientations on the mechanical properties and microstructure of Fused Deposition Modeling parts. 2011 IEEE Symposium on Business, Engineering and Industrial Applications (ISBEIA 2011).
30. Atakok, G., Kam, M., & Koc, H. B. (2022). Tensile, three-point bending and impact strength of 3D printed parts using PLA and recycled PLA filaments: A statistical investigation. Journal of Materials Research and Technology, 18, 1542-1554.
31. Lyu, Y., Zhao, H., Wen, X., Lin, L., Schlarb, A. K., & Shi, X. (2021). Optimization of 3D printing parameters for high-performance biodegradable materials. Journal of Applied Polymer Science, 138(32), 50782.

 doi:10.20944/preprints202310.0656.v1

32. Retolaza, J., Gondra, K., Ansola, R., & Allue, A. (2022). Mechanical research to optimize parameter selection for PPS material processed by FDM. Materials and Manufacturing Processes, 37(11), 1332-1338.
33. ASTM D638 (2003) Standard test method for tensile properties of plastics. ASTM International, West Conshohocken, PA.
34. Ahmad, M. N., Ishak, M. R., Mohammad Taha, M., Mustapha, F., Leman, Z., Anak Lukista, D. D. & Ghazali, I. (2022). Application of taguchi method to optimize the parameter of fused deposition modeling (FDM) using oil palm fiber reinforced thermoplastic composites. Polymers, 14(11), 2140.
35. Rankouhi B, Javadpour S, Delfanian F, Letcher T (2016) Failure analysis and mechanical characterization of 3D printed ABS with respect to layer thickness and orientation. J Fail Anal Prev 16(3):467–481
36. Shergill, K., Chen, Y., & Bull, S. (2023). An investigation into the layer thickness effect on the mechanical properties of additively manufactured polymers: PLA and ABS. The International Journal of Advanced Manufacturing Technology, 126(7-8), 3651-3665.
37. Shashikumar, S., & Sreekanth, M. S. (2023). The effect of printing parameters on tensile properties of thermoplastics prepared by fused deposition modeling (FDM) based additive manufacturing technique. Materials Today: Proceedings.
38. A. Galeski, strength and toughness of crystalline polymer systems, Progress In Polymer Science (Oxford) 28(12) (Dec.2003)1643–1699
39. G. Owolabi et al., ‘‘Dynamic response of acrylonitrile butadiene styrene under impact loading”, International Journal of Mechanical and Materials, Engineering 11 (1) (2016)
40. Casavola, C., Cazzato, A., Moramarco, V., & Renna, G. (2019). Mechanical behaviour of ABS-Fused Filament Fabrication compounds under impact tensile loadings. Materials, 12(8), 1295.
41. Chen, W. H., Uribe, M. C., Kwon, E. E., Lin, K. Y. A., Park, Y. K., Ding, L., & Saw, L. H. (2022). A comprehensive review of thermoelectric generation optimization by statistical approach: Taguchi method, analysis of variance (ANOVA), and response surface methodology (RSM). Renewable and Sustainable Energy Reviews, 169, 112917.