



Experimental Investigation Of Fdm Process Parameters To Enhance Tensile And Impact Strength Of Abs Material

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Abstract: Fused Deposition Modeling (FDM) is a widely used additive manufacturing process for producing thermoplastic components, but the mechanical properties of printed parts are highly dependent on process parameters, especially infill pattern geometry. This study examines the influence of three infill patterns—gyroid, concentric, and tri-hexagonal—on the tensile and impact strength of ABS material. Test specimens were fabricated at a constant 80% infill density under identical printing conditions to isolate the effect of infill geometry, while maintaining consistent print speed, layer thickness, and nozzle temperature. Mechanical testing demonstrated that the gyroid infill pattern achieved the highest tensile strength and impact resistance due to its continuous three-dimensional architecture and uniform stress distribution. The concentric pattern exhibited moderate performance, whereas the tri-hexagonal pattern showed comparatively lower strength because of stress concentration at junction points. The results highlight the importance of infill pattern selection in enhancing the structural performance of FDM-printed ABS parts.

KEY WORDS - FDM, ABS Material, Tensile Strength, Impact Strength, Process Optimization, Infill Pattern.

I. INTRODUCTION

Fused Deposition Modeling (FDM) is a widely used additive manufacturing technique that fabricates components by depositing thermoplastic material layer by layer. Acrylonitrile Butadiene Styrene (ABS) is commonly employed in FDM due to its good toughness, impact resistance, and thermal stability, making it suitable for functional and load-bearing applications. However, FDM-printed ABS parts often exhibit inferior mechanical properties compared to conventionally manufactured components, mainly due to weak interlayer bonding, internal voids, and anisotropic behavior. The mechanical performance of FDM parts is strongly influenced by process parameters such as layer thickness, raster angle, infill density, build orientation, printing speed, and extrusion temperature. Improper parameter selection can significantly reduce tensile and impact strength. Therefore, systematic experimental investigation and optimization of FDM process parameters are essential. This study focuses on analyzing the combined influence of key FDM parameters on the tensile and impact strength of ABS material to enhance part performance, reliability, and applicability in functional engineering applications.

K. Raney et al., [1] Studied examines tensile strength of FDM-printed ABS, analyzing infill density and build orientation. Solid infill performed best; vertical orientation weakest due to interlayer bonding limitations. **U. K. Roopavath et al., [2]** It should be optimizes extrusion-based 3D printing of clinically approved hydroxyapatite scaffolds, developing low-cost ceramic ink for accurate fabrication of complex porous bone structures. **M. Saini, et al., [3]** Studied on optimizes FDM parameters using the Taguchi method to improve tensile strength of ABS, PETG, and bi-material prints by varying infill density and nozzle temperature. **M. F. Marwah et al., [4]** study should be investigate and analyzes ABS shrinkage in desktop FDM using DOE. Bed temperature was most influential; optimized parameters minimized shrinkage with 2.56% prediction deviation. **Nagaraj et al., [5]** Then the study uses Taguchi L9 to optimize FDM parameters for ABS tensile strength. Maximum 24.86 MPa achieved at 80% infill, 100 mm/min speed, 0.2 mm thickness. **C. Abeykoon et al., [6]** This study evaluates FDM parameters affecting ABS mechanical performance. Infill density and interlayer bonding significantly influence strength; optimized settings improve tensile strength and dimensional stability.

M. A. Fountas et al., [7] Studied the performs multi-objective optimization of FDM ABS parts using Taguchi L9 and metaheuristic algorithms, reducing fabrication time and dimensional error through optimal parameter selection. **N. Žur et al., [8]** This study optimizes FDM parameters for ABS tensile strength and stiffness. Higher infill increases strength; 25% infill balances strength, weight reduction, and printing time effectively. **M. Sumalatha et al., [9]** optimizes FDM parameters using Taguchi L9 to improve ABS impact strength, surface roughness, and build time, validated through ASTM D256 testing and ANOVA analysis. **F. R a c h m a n , et al., [10]** It uses Taguchi L9 to optimize FDM parameters for ABS tensile strength. Layer height and infill pattern significantly affect strength; optimal settings were 0.2 mm, line pattern, 230 °C. **K. M. Agarwal et al., [11]** This study evaluates FDM parameters affecting ABS dimensional accuracy using RSM. Layer thickness and print speed were most significant; lower thickness and higher speed improved accuracy and reliability. **A. P. Agrawal, et al., [13]** This study evaluates infill pattern, density, and layer thickness on FFF ABS strength. Concentric pattern with 80% density and 100 µm thickness achieved highest tensile and impact strength. **M. Mani et al., [14]** This study optimizes FDM parameters for ABS dimensional accuracy using Taguchi L9. Build orientation most significant; best accuracy at 90°, 0.33 mm layer thickness, 60% infill density. **M. Delic et al., [15]** This study evaluates FDM parameters on ABS compressive properties. Rectangular infill showed higher strength than hexagonal, and increased infill density improved load-bearing capacity significantly. **M. Moradi, J et al., [16]** This study optimizes ABS FDM parameters using ANN and RSM. Contour number most significant; ANN outperformed RSM in predicting tensile strength and elastic modulus accurately. **Ramiah, et al., [17]** study optimizes FDM ABS strength using Taguchi L18 and hybrid Decision Tree–FAHP–COPRAS methods. Raster angle, width, and layer thickness most significantly improved mechanical properties. **Prof. Amit Bankar, et al., [18]** This study analyzes print speed, infill pattern, and density effects on ABS tensile strength. Gyroid infill pattern showed highest strength among tested FDM configurations. **K. L. Alvarez C., et al., [19]** The review analyzes FDM parameter optimization, detailing effects on mechanical properties, surface quality, and accuracy, while addressing challenges, limitations, and future research directions for industrial applications. **D. R. Unune and R. K. Mali, et al., [20]** It should be evaluates infill percentage effects on ABS FDM parts. Strength and impact resistance increased, peaking at 100% infill, which also showed lowest printing time.

This project investigates the influence of different FDM infill patterns—gyroid, concentric, and tri-hexagonal—on the mechanical performance of ABS components fabricated using fused deposition modeling. Standard test specimens were printed under controlled process parameters to ensure consistency. Experimental results reveal that the gyroid infill pattern provides superior strength and energy absorption due to its continuous and interconnected structure, while concentric and tri-hexagonal patterns show moderate performance. The study demonstrates that infill pattern selection plays a critical role in

determining part strength, material utilization, and functional reliability. These findings support optimized FDM pattern selection for engineering and industrial applications.

3. METHODOLOGY:

The methodology of 3D printing ABS material and the corresponding process parameters are explained as follows.

3.1. SELECTION OF MATERIAL :

Acrylonitrile Butadiene Styrene (ABS) was selected for this study due to its excellent mechanical properties, including high tensile strength, good impact resistance, and toughness. ABS is widely used in FDM 3D printing because of its good layer adhesion, thermal stability, and ease of processing. Its industrial relevance in automotive, consumer, and engineering applications makes ABS suitable for evaluating the effect of FDM process parameter optimization on tensile and impact strength.

3.2 .DESIGN OF TEST SPECIMENS IN AUTO CAD (2D & 3D MODELING)

The test specimens used for tensile and impact testing were designed using AutoCAD software in both 2D and 3D formats. The 2D drawings were prepared according to relevant ASTM standards to define accurate dimensions and tolerances, ensuring uniformity in specimen geometry. Based on these drawings, 3D solid models were developed to visualize the specimen shape and facilitate error-free fabrication. The 3D models were exported in STL format and used as input files for the FDM printer slicing software. Accurate CAD modeling ensured dimensional consistency, repeatability, and reliable comparison of mechanical test results. Standardized test specimens are designed in accordance with ASTM testing standards to ensure consistency and comparability of results.

3.2.1. TENSILE TEST SPECIMEN

Tensile test specimens are designed based on ASTM D638 Type I standard. The specimen geometry includes a uniform gauge length, shoulder radius, and grip sections to ensure uniform stress distribution during tensile loading. The specimen models are created using computer-aided design (CAD) software and exported in STL format for slicing and printing.

3.2.2. IMPACT TEST SPECIMEN

Impact test specimens are designed following ASTM D256 standard for Izod impact testing. The specimens include a standardized V-notch to initiate fracture during impact loading. The notch dimensions are precisely maintained to reduce variability in impact strength measurements.

3.3. SELECTION OF FDM PROCESS PARAMETERS

To evaluate their effect on mechanical properties, key FDM process parameters are selected based on literature review and preliminary trials. The selected parameters and their working ranges are listed below:

Layer Thickness: Determines the height of each deposited layer and influences surface finish and interlayer adhesion.

Infill Density: Controls the amount of material deposited inside the specimen and affects strength and stiffness.

Infill Pattern: Influences internal load distribution and energy absorption.

Extrusion Temperature: Affects filament melting, flow, and bonding quality.

3.4. SPECIMEN FABRICATION USING FDM

The STL files of the tensile and impact specimens are imported into slicing software to generate G-code. The slicing software is configured with the selected process parameters. The build platform is leveled prior to printing, and a consistent nozzle diameter is maintained throughout the experiments. During printing, parameters such as print speed, bed temperature, and cooling conditions are kept constant. Printed specimens are allowed to cool naturally to room temperature before removal from the build platform to prevent warping or residual stress development. After printing, specimens are visually inspected for defects such as elimination, voids, or incomplete layers. Defective specimens are discarded to ensure test accuracy.

3.5. TENSILE TESTING PROCEDURE

Tensile testing is conducted using a universal testing machine (UTM) in accordance with ASTM D638 standard. The specimens are mounted securely in the grips of the testing machine, ensuring proper alignment to avoid bending stresses. The test is performed at a constant crosshead speed as specified by the standard. During testing, tensile load and elongation data are recorded continuously until specimen failure. The ultimate tensile strength is calculated by dividing the maximum load by the original cross-sectional area of the specimen. Multiple specimens are tested for each parameter set, and the average tensile strength values are reported to improve result accuracy.

3.6. IMPACT TESTING PROCEDURE

Impact strength is evaluated using an Izod impact testing machine in accordance with ASTM D256 standard. The notched specimen is mounted vertically in the impact tester, with the notch facing the striking edge of the pendulum. The pendulum is released from a specified height to strike the specimen and fracture it.

4. EXPERIMENTATION

The effect of infill patterns on ABS material and its process parameters is explained as follows.

4.1 Selection of FDM Process Parameters

Table -1: Tensile Test Parameters

TENSILE TEST	INFILL DENSITY	PRINT SPEED	PATTERN	LAYER THICKNESS	NOZZLE TEMPERATURE
SAMPLE - 1	80%	60	HEXAGONAL	0.2mm	230
SAMPLE - 2	80%	60	CONCENTRIC	0.2mm	230
SAMPLE - 3	80%	60	GRID	0.2mm	230

Table - 2 : Impact Test Parameters

IMPACT TEST	INFILL DENSITY	PRINT SPEED	PATTERN	LAYER THICKNESS	NOZEL TEMPERATURE
SAMPLE - 1	80%	60	HEXAGONAL	0.2mm	230
SAMPLE - 2	80%	60	CONCENTRIC	0.2mm	230
SAMPLE - 3	80%	60	GRID	0.2mm	230

The design of test specimens was carried out using AutoCAD 3D modeling to ensure accuracy and standard compliance for FDM printing Parameters as describes that the Tables - 1 & 2. Tensile specimens were modeled according to ASTM D638 Type I dimensions, while impact specimens followed the ASTM D256 (Izod) standard. Precise geometric features such as gauge length, thickness, width, and notch dimensions were carefully defined in the 3D environment to minimize dimensional deviations. The models were created as solid bodies and oriented to suit FDM printing requirements, enabling consistent layer deposition and build direction control. These Auto CAD-designed specimens were exported in STL format, ensuring compatibility with slicing software.

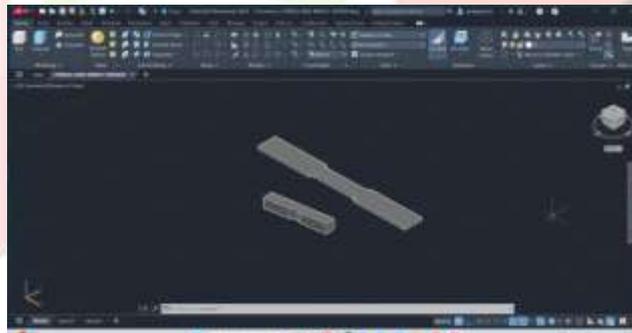


Fig.4.1 Design of specimens in Auto cad software (3D modeling)

Figure 4.1 illustrates the use of AutoCAD Mechanical 2022/2023, a widely used CAD software developed by Autodesk, for designing tensile and impact test specimens. Initially, 2D drawings were created in accordance with ASTM standards to ensure accurate dimensions and standardization. These drawings were then converted into 3D solid models using extrusion tools to verify geometry and thickness. The finalized models were exported in STL format for FDM printing, ensuring uniformity and reliable mechanical testing.

4.2. FDM 3D Printing Process

Specimens were fabricated using an FDM 3D printer equipped with a 0.4 mm nozzle under controlled room temperature conditions, with bed temperature maintained at 90–100 °C. Figures 4.3 illustrate the FDM process, where ABS filament is melted, extruded layer by layer onto a heated build platform, and incrementally deposited in the vertical direction to form the final three-dimensional part.

5. RESULT AND DISCUSSION

we discuss about the results of all the patterns w.r.t tensile and impact strength has been determined and the performance of ABS materials are given below.

5.1. IMPACT TEST RESULTS :

Table 5 presents the impact strength of ABS specimens fabricated using FDM with concentric, tri-hexagonal, and gyroid infill patterns at a constant infill density of 80%. The gyroid pattern exhibits the highest impact strength of 8.66 kJ/m² due to its continuous, interconnected geometry that promotes uniform stress distribution and efficient energy absorption. The concentric pattern shows moderate impact strength (7.53 kJ/m²

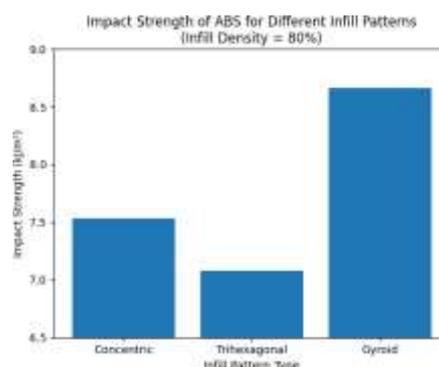
Table - 5 Impact Test Result

S.No	sample	Pattern Types	Infill density (%)	Impact Strength (kJ/m)
1	S-1	CONCENTRIC	80	7.53
2	S-2	TRIHESAGONAL	80	7.08
3	S-3	GYROID	80	8.66

Impact Test Graph Results

Graph 5.1 illustrates the impact strength of FDM-printed ABS specimens with concentric, tri-hexagonal, and gyroid infill patterns at a constant infill density of 80%. All other printing parameters were kept constant. The results show that infill pattern geometry significantly influences impact strength, with the gyroid pattern exhibiting the highest value, followed by concentric, while the tri-hexagonal pattern shows the lowest impact resistance.

Impact Strength test Graph -5.1



5.2. TENSILE TEST TABLE RESULT:

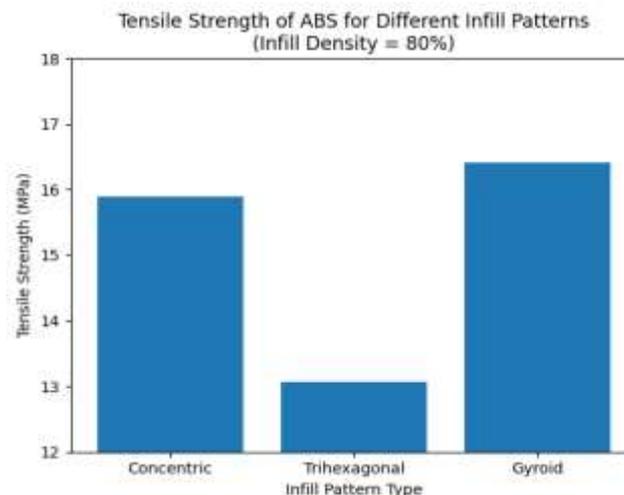
Table 6 presents the tensile properties of ABS specimens fabricated using FDM with different infill patterns at a constant infill density of 80%. Tensile testing was conducted under identical printing conditions to evaluate tensile strength and elastic modulus. The results show that infill pattern significantly influences tensile behavior. The gyroid pattern exhibited the highest tensile strength (16.41 MPa) and elastic modulus (586.7 MPa), indicating superior strength and stiffness. The concentric pattern showed moderate values, while the trihexagonal pattern recorded the lowest tensile strength (13.07 MPa) and elastic modulus (544.0 MPa).

Table - 6 Tensile Test Result

S.No	Pattern Types	Infill density (%)	Tensile Strength(MPa)	Elastic Modulus (MPa)
1	CONCENTRIC	80	15.89	567.5
2	TRIHEXAGONL	80	13.07	544.0
3	GYROID	80	16.41	586.7

5.4 TENSILE TEST GRAPH RESULT:

The Graph - 5 is Says that illustrates the **tensile strength of ABS specimens fabricated using Fused Deposition Modeling (FDM) with three different infill patterns**—Concentric, Trihexagonal, and Gyroid—while maintaining a **constant infill density of 80%**. Other printing parameters such as layer thickness, print speed, and nozzle temperature were kept constant to ensure that the observed variations in tensile strength are solely due to the change in infill geometry.



Tensile Test Result Graph - 5.2

The mechanical test results of FDM-printed ABS specimens fabricated at a constant infill density of 80% demonstrate a significant influence of infill pattern on both impact and tensile properties. Among the three patterns studied, the gyroid infill pattern exhibited the highest impact strength of 8.66 kJ/m, indicating superior energy absorption and resistance to sudden loading. It also showed the maximum tensile strength of 16.41 MPa and elastic modulus of 586.7 MPa, reflecting improved stiffness and load-bearing capability. The concentric pattern displayed moderate performance, with an impact strength of 7.53 kJ/m and tensile strength of 15.89 MPa. In contrast, the trihexagonal pattern recorded the lowest values in both impact (7.08 kJ/m) and tensile strength (13.07 MPa). Overall, the gyroid infill pattern is identified as the best configuration for achieving enhanced mechanical performance in FDM-printed ABS components.

The overall results demonstrate that FDM process parameter optimization can significantly enhance the mechanical performance of ABS material. Improved tensile and impact strength are primarily associated with enhanced inter layer adhesion and reduced internal defects such as voids and poor fusion. The optimized parameters promoted uniform material deposition and effective thermal bonding, resulting in stronger and tougher printed parts. The findings align well with previously reported studies, which highlight the dominant influence of nozzle temperature and layer thickness on the mechanical properties of FDM-fabricated ABS. The study confirms that careful selection of process parameters can tailor mechanical properties to meet specific application requirements. Therefore, the optimized FDM settings obtained in this work are suitable for producing ABS components requiring improved load-bearing capacity and impact resistance in functional and engineering applications.

CONCLUSION

This experimental study investigated the effect of infill pattern geometry on the tensile and impact strength of ABS parts fabricated using the Fused Deposition Modeling (FDM) process. All specimens were printed at a constant **infill density of 80%, layer thickness of 0.2 mm, print speed of 60 mm/s, and nozzle temperature of 230°C** to ensure consistency. To ensure consistency, all specimens were printed with a constant infill density of 80% while maintaining identical printing parameters. Mechanical performance was evaluated using standardized tensile and impact tests. Results showed that **the gyroid infill pattern achieved the highest impact strength (8.66 kJ/m²) and tensile strength (16.41 MPa)**, demonstrating superior energy absorption and load-bearing capability. The concentric pattern exhibited moderate performance, whereas the tri-hexagonal pattern showed the lowest strength due to higher stress concentration and weaker load transfer. Comparative analysis confirmed that the gyroid pattern consistently outperformed the other patterns in both tensile and impact properties. The findings highlight that infill pattern selection significantly influences mechanical performance, even at constant infill density. Overall, the gyroid infill pattern is identified as the most suitable choice for functional and load-bearing FDM-printed ABS applications.

REFERENCES

- 1) K. Raney, E. Lani, and D. K. Kalla, "Experimental characterization of the tensile strength of ABS parts manufactured by fused deposition modeling process," *Materials Today: Proceedings*, vol. 4, pp. 7956–7961, 2017.
- 2) U. K. Roopavath, S. Malferrari, A. V. Haver, F. Verstreken, S. N. Rath, and D. M. Kalaskar, "Optimization of extrusion based ceramic 3D printing process for complex bony designs," *Materials & Design*, vol. 162, pp. 263–270, 2019.
- 3) M. Saini, "Optimization the process parameter of FDM 3D printer using Taguchi method for improving the tensile strength," *International Journal of All Research Education and Scientific Methods (IJARESM)*, vol. 7, no. 4, Apr. 2019.
- 4) O.N.M. F. Marwah et al., "Investigation For Shrinkage Deformation In The Desktop 3D Printer Process By Using DOE Approach Of The ABS Materials," *Journal of Physics: Conference Series*, vol. 1150, p p. 012038, 2019.
- 5) C. Nagaraj, D. Mishra, and T. Tirupati, "Optimization of the FDM Process Parameters to Attain the Desired Strength of ABS Specimens," *International Journal of Recent Technology and Engineering (IJRTE)*, vol. 8, no. 4, Nov. 2019.
- 6) C. Abeykoon, P. Sri-Amphorn, and A. Fernando, "Optimization of fused deposition modeling parameters for improved PLA and ABS 3D printed structures," *International Journal of Lightweight Materials and Manufacture*, vol. 3, pp. 284–297, 2020.
- 7) N. A. Fountas, J. D. Kechagias, A. C. Tsiolikas, and N. M. Vaxevanidis, "Multi-objective optimization of printing time and shape accuracy for FDM-fabricated ABS parts," *Metaheuristic Computing and Applications*, vol. 1, no. 2, pp. 115–129, 2020.
- 8) 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, pp. 44–51, Mar. 2020.
- 9) M. Sumalatha, J. N. M. Rao, and B. S. Reddy, "Optimization Of Process Parameters In 3d Printing-Fused Deposition Modeling Using Taguchi Method," *IOP Conference Series: Materials Science and Engineering*, vol. 1112, pp. 012009, 2021.
- 10) M. S. N. M. Shaikh and B. B. Ahuja, "Optimization of electroless nickel tungsten composite coating on 3D-printed ABS substrate for maximum tungsten content," Springer, India, 2020.
- 11) F. Rachman, B. W. Kurniawan, and M. T. Yoningtias, "Optimization of 3D Printing Process Parameters on Tensile Strength of ABS Filament Material Product using Taguchi Method," presented at the 6th International Conference on Marine Technology, Surabaya, Indonesia, 2021.

- 12) K. M. Agarwal et al., "Analyzing the Impact of Print Parameters on Dimensional Variation of ABS specimens printed using Fused Deposition Modelling (FDM)," *Sensors International*, vol. 3, pp. 100149, 2022.
- 13) A. P. Agrawal, V. Kumar, J. Kumar, P. Paramasivam, S. Dhanasekarand, and L. Prasad, "An investigation of combined effect of infill pattern, density, and layer thickness on mechanical properties of 3D printed ABS by fused filament fabrication," *Heliyon*, vol. 9, no. 6, pp. e16531, Jun. 2023.
- 14) A. Singh, T. Bhardwaj, P. K. Singh, and D. K. Singh, "Investigation on FDM process parameters for the dimensional accuracy with ABS polymer part," *Engineering Research Express*, vol. 6, no. 2, pp. 025553, Jun. 2024.
- 15) P. M. Angelopoulos, G. Kenanakis, Z. Viskadourakis, and P. Tsakiridis, "Manufacturing of ABS/expanded perlite filament for 3D printing of lightweight components through fused deposition modeling," *Materials Today: Proceedings*, Science Direct, Greece, 2022.
- 16) Delic, V. Mandica, S. Aleksandrovica, and D. Arsica, "Influence of FDM printing parameters on the compressive mechanical properties and fracture of ABS material," *Procedia Structural Integrity*, Elsevier, Europe, 2024.
- 17) M. Moradi, R. Beygi, N. M. Yusof, A. Amiri, L. F. M. da Silva, and S. Sharif, "3D Printing of Acrylonitrile Butadiene Styrene by Fused Deposition Modeling: Artificial Neural Network and Response Surface Method Analyses," *Journal of Materials Engineering and Performance (JMEPEG)*, vol. 32, pp. 2016-2028, Aug. 2023.
- 18) A. Bankar, A. M. Sonekar, A. R. Kashyap, A. A. Pathan, and R. S. Ansari, "Effect of Print Speed, Infill Pattern and Infill Density on Tensile Strength of Part Produced by ABS Filament Using FDM 3D Printing Technology," *International Journal on Theoretical and Applied Research in Mechanical Engineering*, vol. 14, no. 1, 2025.
- 19) A. Dey and N. Yodo, "A Systematic Survey of FDM Process Parameter Optimization and Their Influence on Part Characteristics," *Journal of Manufacturing and Materials Processing*, vol. 3, no. 3, pp. 64, Jul. 2019.
- 20) K. L. Alvarez C., R. F. Lagos C., and M. Aizpun, "Investigating the influence of infill percentage on the mechanical properties of fused deposition modelled ABS parts," *Ingeniería e Investigación*, vol. 36, no. 3, pp. 110-116, Dec. 2016.