

A Study on the Influence of Printing Parameters and Part Orientation on the Compression Behavior of Additively Manufactured Parts Made of Acrylonitrile Styrene Acrylate

Dragos Gabriel Zisopol

Mechanical Engineering Department, Petroleum-Gas University Ploiesti, Romania
zisopold@upg-ploiesti.ro

Mihail Minescu

Mechanical Engineering Department, Petroleum-Gas University Ploiesti, Romania
mminescu@upg-ploiesti.ro

Dragos Valentin Iacob

Department of Mechanical Engineering, Petroleum-Gas University, Ploiesti, Romania
dragoshicb@gmail.com (corresponding author)

Received: 14 June 2025 | Revised: 26 July 2025 and 2 August 2025 | Accepted: 11 August 2025

Licensed under a CC-BY 4.0 license | Copyright (c) by the authors | DOI: <https://doi.org/10.48084/etasr.12739>

ABSTRACT

Given the growth of the 3D printed parts' utilization in various applications and the need for the efficient use of the 3D printer and materials, this paper presents the results of research on the influence of the construction plan on the compressive strengths of specimens manufactured additively by the thermoplastic extrusion of the Acrylonitrile Styrene Acrylate (ASA) filament. The mechanical performances of parts manufactured using additive technologies vary significantly depending on the process parameters used. For this reason, it is necessary to optimize the manufacturing parameters of thermoplastic extrusion. Using the Anycubic 4 Max Pro 2.0 3D printer and the variable thermoplastic extrusion parameters ($L_h = 0.10$ mm, 0.15 mm, 0.20 mm, and $I_d = 50\%$, 75%, 100%) 45 compression specimens of ASA were manufactured. The specimens made of ASA in the X-Z plane were tested in compression on the Barrus White universal testing machine using a speed of 10 mm/min. The results indicate that the construction orientation significantly influences the compressive strength, with specimens manufactured in the X-Z plane showing values 3.26%–29.09%, which are lower than those of the specimens manufactured under identical conditions in the X-Y plane.

Keywords-FDM; compression; experimental determinations; ASA; construction plan

I. INTRODUCTION

Additive manufacturing technologies are used in an increasing number of applications due to the considerable advantages they offer compared to conventional manufacturing technologies [1, 2]. However, to maximize the benefits of additive manufacturing technologies, it is necessary to optimize the process parameters [3-13]. The most important parameters of the additive manufacturing technology by the extrusion of plastic masses are the height of the layer deposited in one pass (L_h), the filling density (I_d), the printing speed (V_p), the filling pattern (I_p), the orientation of the part (P_o), the extrusion temperature (T_e), and the platform temperature (B_i) [12-19]. Research has been conducted on the influence of the part orientation on the mechanical behavior; however, opportunities

remain for studies that have not yet been addressed. ASA, is a thermoplastic material with good Ultraviolet (UV) resistance and mechanical properties. These characteristics make it suitable for applications in the automotive industry (dashboards, supports, etc.) and the construction industry (manufacture of profiles for carpentry), among others. In [20], a study on the effects of the orientation of tensile, resilience, and hardness specimens on the mechanical characteristics is presented. The highest values of tensile strength were recorded for the specimens additively manufactured in the Y-Z plane. In the case of the specimens for the impact bending test, the highest values of impact strength were recorded for the specimens printed in the Y-Z plane, and the maximum values of Rockwell hardness were recorded for the specimens manufactured in the X-Y plane. Authors in [21] examined the

impact of printing orientation (X-Y; Y-Z and X-Z planes) on the surface roughness of the parts manufactured using Fused Deposition Modeling (FDM). The results highlight the fact that the printing orientation has a major influence on the surface roughness. The parts printed in the X-Y plane showed the lowest roughness, while the parts manufactured in the Y-Z plane recorded the highest roughness. Authors in [22] studied the effect of the printing parameters (nozzle diameter, layer height per pass, and printing orientation) on the refractive index, attenuation coefficient, and birefringence of plastic materials. The results showed that the printing orientation significantly influences the optical properties. Findings reported in previous research confirm that the printing orientation influences the mechanical characteristics of the 3D-printed parts.

The knowledge gap regarding the sustainable use of materials to exploit the maximum potential of the additive technology through plastic extrusion has inspired the current study. The latter investigates the influence of part orientation on the compressive strength. The novelty of this work lies in establishing the optimal part orientation and selecting the optimal manufacturing parameters to obtain the best mechanical characteristics. Also, this study makes significant contributions to the specialized literature by addressing a research topic that is not sufficiently studied before.

The fabrication and testing of the specimens used in this study were carried out in the laboratories of the Faculty of Mechanical and Electrical Engineering of the University of Petroleum and Gas of Ploiești, Romania.

II. INFLUENCE OF FDM PARAMETERS ON THE COMPRESSION BEHAVIOR OF ASA SPECIMENS

A. Additive Manufacturing of Specimens in the X-Z Plane

Using the CAD software SolidWorks-2023, the 2D and later 3D model of the specimen were created. Utilizing the same software, the file corresponding to the 3D model of the specimen was converted to STL format [23]. Table I presents the 3D printing parameters used to manufacture compression specimens by the thermoplastic extrusion of ASA [16].

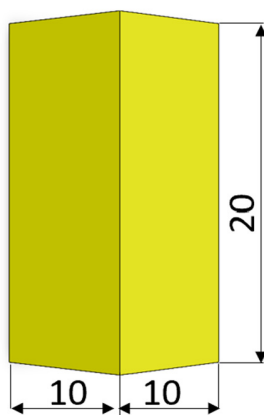


Fig. 1. 3D model of the specimen in SolidWorks-2023.

TABLE I. FDM 3D PRINTING PARAMETERS FOR ASA SPECIMENS

Constant parameters	Variable parameters
Part orientation: X-Z	Layer height (L _h): 0.10, 0.15, 0.20 mm
Extruder temperature (E _t): 250 °C	Infill density (I _d): 50%, 75%, 100%
Platform temperature (B _t): 70 °C	Number of specimens: 45
Printing speed (P _t): 30 mm/s	
Filling pattern (I _p): Grid	

Using the file corresponding to the compression specimen in STL format, the parameters presented in Table I, and the Cura Slicer program, the work instructions were generated in G-Code format for the manufacture of ASA compression specimens on the Anycubic 4Max Pro 2.0 3D printer. Figure 2 depicts the compression specimens with L_h = 0.20 mm and I_d = 50% in the Cura Slicer program [24].

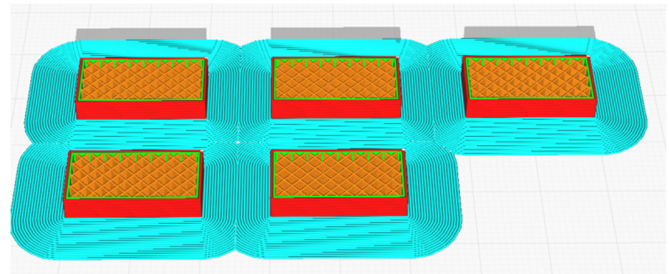


Fig. 2. Compression specimens in Cura Slicer.

```
;TARGET_MACHINE.NAME:Anycubic 4Max
;Generated with Cura_SteamEngine 5.7.2
M140 S90
M105
M190 S90
M104 S240
M105
M109 S240
M82 ;absolute extrusion mode
G21 ;metric values
G90 ;absolute positioning
M82 ;set extruder to absolute mode
M107 ;start with the fan off
G28 X0 Y0 ;move X/Y to min endstops
G28 Z0 ;move Z to min endstops
G1 Z15.0 F60 ;move the platform down 15mm
G92 E0 ;zero the extruded length
G1 F200 E3 ;extrude 3mm of feed stock
G92 E0 ;zero the extruded length again
G1 F60
M117 Printing...
--
```

Fig. 3. G-Code file structure for manufacturing compression specimens.

Figure 3 shows the structure of the G-Code file that contains the printing instructions for the compression specimens from ASA with the parameters L_h = 0.20 mm and I_d = 50%. Using the Anycubic 4 Max Pro 2.0 3D printer, 45 compression specimens, as shown in Figure 4, were printed

from Everfil brand ASA filament with diameter 1.75 mm, density 1.06 g/cm³, tensile modulus 1.74 GPa.

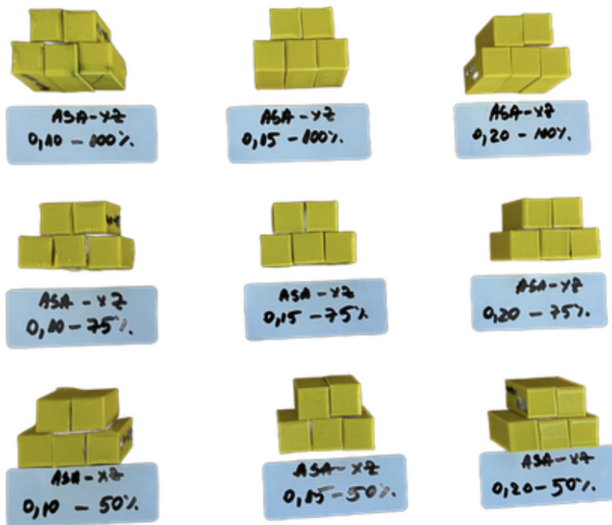


Fig. 4. Compression specimens additively manufactured with thermoplastic extrusion of ASA.

B. Compression Testing of Specimens

The 45 compression specimens additively manufactured from ASA on Anycubic 4 Max Pro 2.0 3D printers were tested in compression on the Barrus White 20 kN universal testing machine using a speed of 10 mm/min [25].

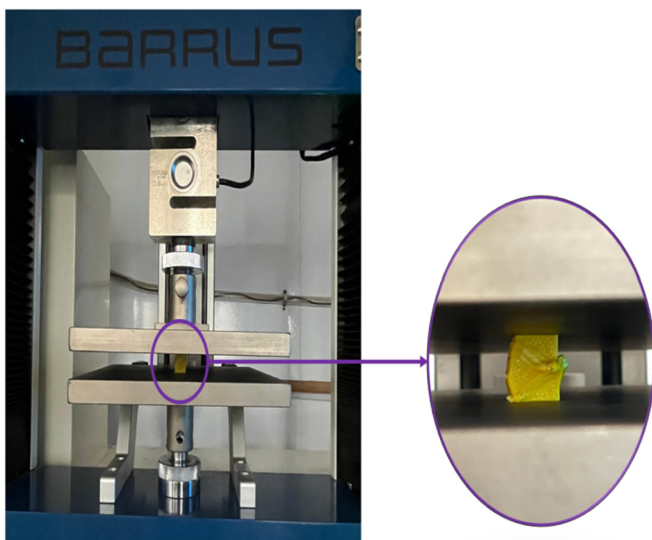


Fig. 5. Compression test using Barrus White 20 kN.

III. RESULTS AND DISCUSSION

The results obtained from the compression test of the 45 additively manufactured ASA specimens are graphically represented in Figures 6-8.

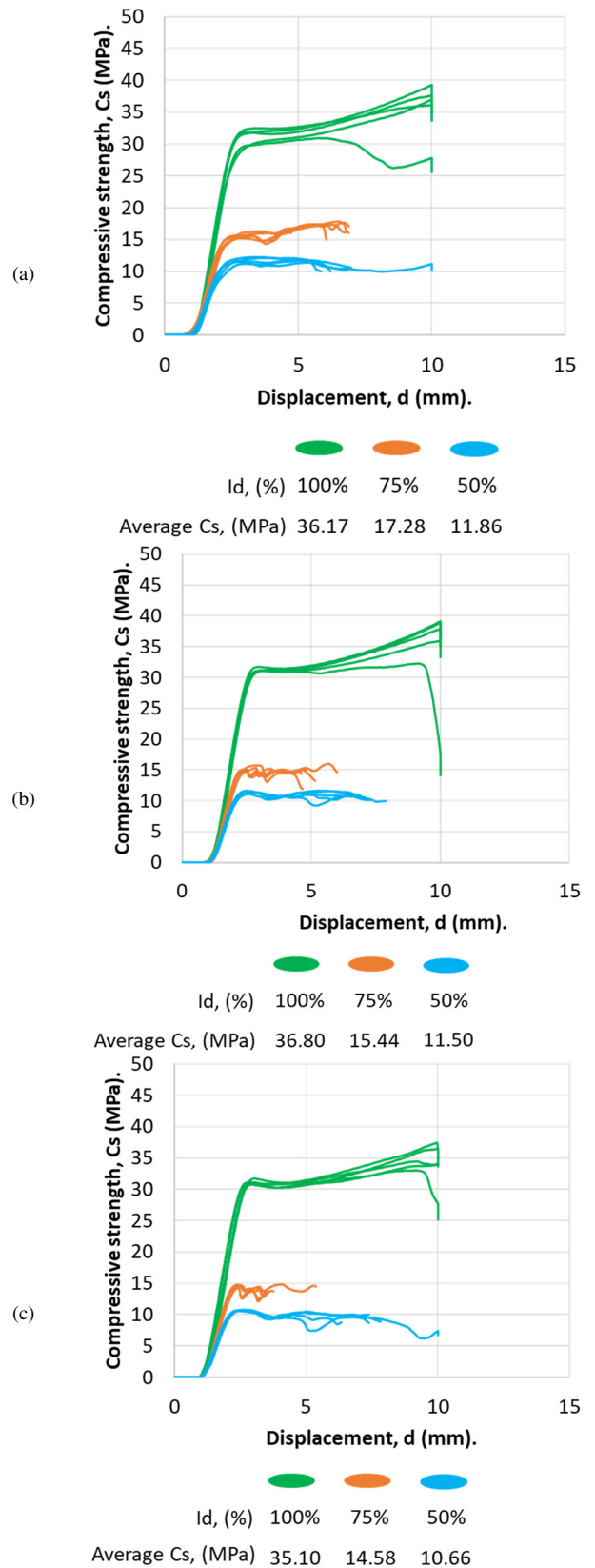


Fig. 6. Compressive strength test results for ASA specimens with $L_d = 50\%$, 75% , 100% , and: (a) $L_h = 0.10$ mm, (b) $L_h = 0.15$ mm, (c) $L_h = 0.20$ mm.

Figure 6(a) shows the influence of the filling density (I_d) on the compressive strength of the specimens manufactured from ASA. The maximum average compressive strength value of 36.17 MPa was recorded for the specimens manufactured with the filling density $I_d = 100\%$. Decreasing the filling density from 100% to 75%, reduces the compressive strengths by 47.44% and 54.60%, and decreasing the filling density from 75% to 50% reduces the compressive strengths by 29.97% and 31.29%. Figure 6(b) displays the major influence of the filling density (I_d) on the compressive strengths of the specimens manufactured from ASA. The maximum average compressive strength value of 36.80 MPa was recorded for the specimens manufactured with the filling density $I_d = 100\%$. By decreasing the filling density from 100% to 75%, the compressive strengths decrease by 53.59% – 59.02%, and by decreasing the filling density from 75% to 50% the compressive strengths decrease by 24.30% – 27.37%. Finally, Figure 6(c) depicts the influence of the filling density (I_d) on the compressive strengths of the specimens manufactured by additive manufacturing using FDM from ASA. The maximum average compressive strength value of 35.10 MPa was recorded for the specimens with the filling density $I_d = 100\%$. The decrease in the filling density from 100% to 75% caused the decrease in the compressive strengths by 33.03% – 37.42%, and the decrease in the filling density from 75% to 50% caused the decrease in the compressive strengths by 25.66% – 27.37%.

A. Optimization of Thermoplastic Extrusion Parameters

The results illustrated in Figures 7-9 were obtained using the average compressive strengths, variable parameters of thermoplastic extrusion presented in Table I, and the Minitab software, exhibiting the influence of the L_h and I_d parameters on the average compressive strengths for the additively manufactured ASA specimens [26]. Figure 7 shows the influence of the variable parameters of FDM (L_h and I_d) on the average compressive strengths of the additively manufactured ASA specimens in the X-Z plane. Among L_h and I_d , the filling density (I_d) exerts a significant influence on the compressive strengths of the additively manufactured ASA specimens in the X-Z plane.

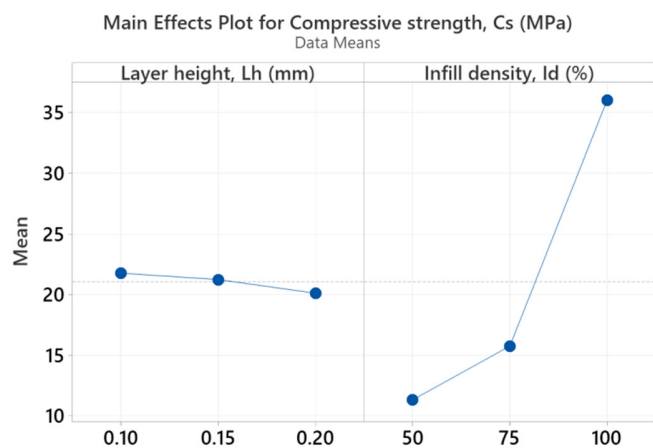


Fig. 7. Influence of variable FDM parameters L_h and I_d on the compressive strengths of ASA specimens.

According to the Pareto chart depicted in Figure 8, it can be noted that the filling density $B = I_d$ substantially influences the compressive strength of the specimens manufactured from ASA in the X-Z plane. The influence value of factor A (L_h) is 0.440265 units, while the influence value of factor B (I_d) is 6.56606 units, which means that factor B has a greater influence by 1392.03% compared to factor A.

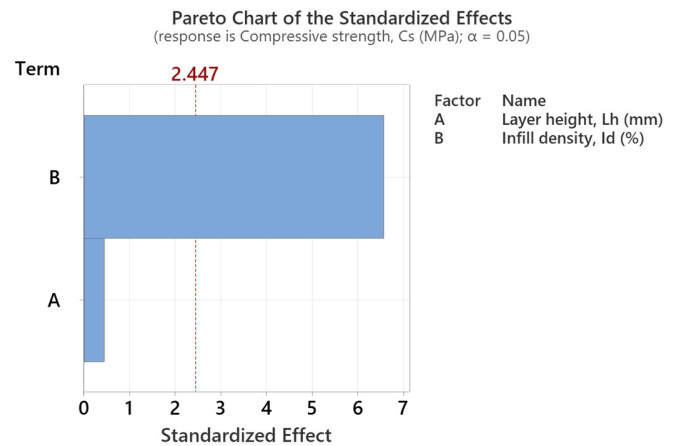


Fig. 8. Pareto chart showing the influence of parameters $A = L_h$ and $B = I_d$ on the compressive strength of ASA specimens.

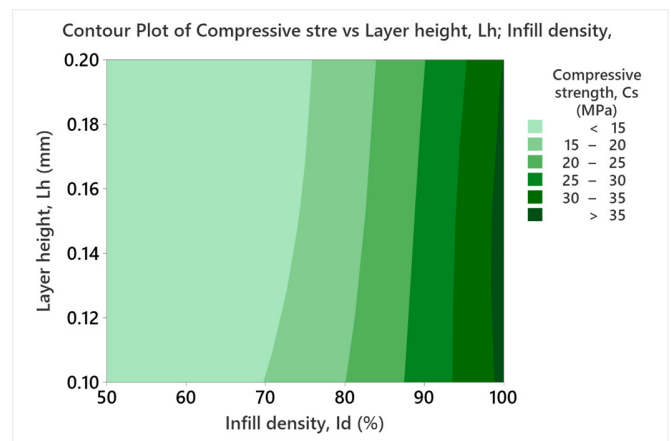


Fig. 9. Contour plot of compressive strengths for ASA specimens manufactured using FDM.

Figure 9 demonstrates that by increasing the filling density (I_d) results in higher compressive strength. Figure 10 shows the optimization graph of variable FDM parameters for the fabrication of compression specimens in the X-Z plane, with the maximization of the compressive strength being the objective function.

Following the optimization of the FDM parameters (L_h and I_d) for maximizing the compressive strengths of the ASA specimens fabricated in the X-Z plane, the optimal parameter settings were determined as a deposited layer height of $L_h = 0.10$ mm and a filling density of $I_d = 100\%$. With the optimized parameters, the predicted compressive strength increases to 34.2144 MPa, with a desirability index of 0.90104.

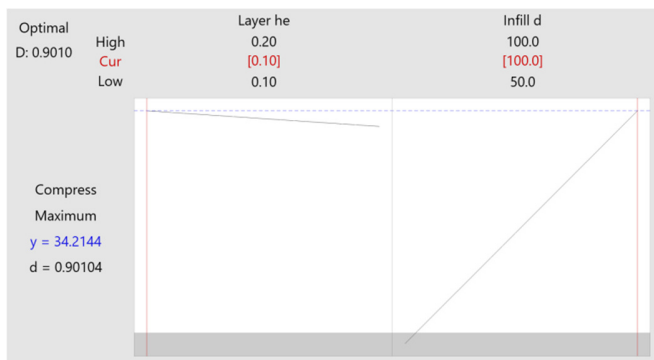


Fig. 10. Optimization graphs of FDM parameters (L_h and I_d) for maximizing the compressive strengths of ASA specimens.

IV. CONCLUSIONS

This paper presents a study on the influence of the part orientation on the compression behavior of additively manufactured Acrylonitrile Styrene Acrylate (ASA) specimens. A total of 45 ASA specimens were additively manufactured in the X-Z plane on the Anycubic 4 Max Pro 2.0 3D printer using the variable parameter layer height deposited in one pass $L_h = 0.10$ mm, 0.15 mm, 0.20 mm, and the filling density $I_d = 50\%$, 75%, and 100%. The additively manufactured ASA specimens in the X-Z plane were tested in compression on the Barrus White 20 kN universal testing machine using a speed of 10 mm/min.

The variable printing parameters (L_h and I_d) significantly affected the compressive strength of the additively manufactured ASA specimens, with I_d being the most influential parameter. The maximum average compressive strength value of 36.80 MPa was recorded for the additively manufactured specimens using the parameters $L_h = 0.10$ mm and $I_d = 100\%$, and the minimum average compressive strength value of 10.66 MPa was recorded for the specimens manufactured with $L_h = 0.20$ mm $I_d = 50\%$.

Using the statistical analysis software Minitab, the optimization of the variable parameters of Fused Deposition Modeling (FDM) was performed to maximize the compressive strength. The optimization resulted in a maximum compressive strength, with $L_h = 0.10$ mm and $I_d = 100\%$.

Comparing the results obtained in this study with the findings in [16], regarding compression specimens additively manufactured in the X-Y plane and using the same material, printer, and parameters leads to the following conclusions:

- Minimum compressive strength for specimens manufactured in the X-Y plane: 15.04 MP
- Maximum compressive strength for specimens manufactured in the X-Y plane: 38.04 MPa
- Average compressive strength of the 45 specimens manufactured in the X-Y plane: 26.78 MPa
- The minimum compressive strength for the specimens manufactured in the X-Z plane is 29.13% lower than the minimum compressive strength value for the specimens manufactured in the X-Y plane

- The maximum compressive strength value for the specimens manufactured in the X-Z plane is 3.26% lower than the maximum compressive strength value for the specimens manufactured in the X-Y plane
- The average compressive strength for the specimens manufactured in the X-Z plane is 21.43% lower than the average compressive strength of the specimens manufactured in the X-Y plane

The study highlights the importance of optimizing the additive manufacturing parameters to maximize the mechanical properties of the manufactured parts.

The 3D printing process parameters identified in this study offer practical application for the additive manufacturing of parts for the automotive industry and the construction industry of exterior decorations, with ASA being a suitable material for manufacturing parts that are exposed to Ultraviolet (UV) rays. Considering the need to apply the concepts of sustainability and circular economy in the manufacturing processes, the results of this study provide optimal values of the process parameters of thermoplastic extrusion. Using the optimal parameters reduces the number of defective parts ensuring that the manufactured parts have the desirable mechanical characteristics for the field of use. The study also provides a basis for new research on recycled materials and the integration production and consumption based on the circular economy in the field of additive manufacturing technology by the extrusion of plastics.

The study proposes extending the research to other materials, such as recycled ASA, Polyethylene Terephthalate Glycol (PETG), recycled PETG, as well as to other types of mechanical tests including tensile, three-point bending, and shock bending.

REFERENCES

- [1] F. Zhang, N. A. S. Abdullah, and M. Mohd Rosli, "Analysis of Critical Success Factors of Agile Software Projects based on the Fuzzy Delphi Method," *Engineering, Technology & Applied Science Research*, vol. 15, no. 1, pp. 19424–19433, Feb. 2025, <https://doi.org/10.48084/etasr.9151>.
- [2] D. G. Zisopol and A. Dumitrescu, *Ecotehnologie: Studii de Caz*, Ploiești, România, Editura Universității Petrol-Gaze din Ploiești, 2020.
- [3] A. Papatheodorou, I. Gavalas, D. Ntenekou, and A. Karatza, "The Influence of Thermoplastic Composite Recycling on the Additive Manufacturing Process and In-Use Phase as Candidate Materials for Wearable Devices Applications," *Polymers*, vol. 15, no. 18, Sept. 2023, Art. no. 3775, <https://doi.org/10.3390/polym15183775>.
- [4] H. Wei *et al.*, "Optimizing FDM 3D Printing Parameters for Improved Tensile Strength Using the Takagi–sugeno Fuzzy Neural Network," *Materials Today Communications*, vol. 38, Mar. 2024, Art. no. 108268, <https://doi.org/10.1016/j.mtcomm.2024.108268>.
- [5] S. Dusanapudi, R. L. Krupakaran, A. Srinivas, K. S. Nikhil, and T. Vamshi, "Optimization and Experimental Analysis of Mechanical Properties and Porosity on FDM Based 3d Printed Abs Sample," *Materials Today: Proceedings*, Nov. 2023, Art. no. S2214785323050022, <https://doi.org/10.1016/j.matpr.2023.10.096>.
- [6] A. P. Agrawal, V. Kumar, J. Kumar, P. Paramasivam, S. Dhanasekaran, 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, June 2023, Art. no. e16531, <https://doi.org/10.1016/j.heliyon.2023.e16531>.

- [7] A. Sharma, D. Chhabra, R. Sahdev, A. Kaushik, and U. Punia, "Investigation of Wear Rate of FDM Printed TPU, ASA and Multi-material Parts Using Heuristic GANN Tool," *Materials Today: Proceedings*, vol. 63, pp. 559–565, 2022, <https://doi.org/10.1016/j.matpr.2022.04.015>.
- [8] S. Raam Kumar, S. Sridhar, R. Venkatraman, and M. Venkatesan, "Polymer Additive Manufacturing of ASA Structure: Influence of Printing Parameters on Mechanical Properties," *Materials Today: Proceedings*, vol. 39, pp. 1316–1319, 2021, <https://doi.org/10.1016/j.matpr.2020.04.500>.
- [9] R. Rakshit, P. Kalvettukaran, S. K. Acharyya, S. C. Panja, and D. Misra, "Development of High Specific Strength Acrylonitrile Styrene Acrylate (ASA) Structure Using Fused Filament Fabrication," *Progress in Additive Manufacturing*, vol. 8, no. 6, pp. 1543–1553, Dec. 2023, <https://doi.org/10.1007/s40964-023-00420-z>.
- [10] B. Zharylkassyn, A. Perveen, and D. Talamona, "Effect of Process Parameters and Materials on the Dimensional Accuracy of FDM Parts," *Materials Today: Proceedings*, vol. 44, pp. 1307–1311, 2021, <https://doi.org/10.1016/j.matpr.2020.11.332>.
- [11] A. El Magri, S. Ouassil, and S. Vaudreuil, "Effects of Printing Parameters on the Tensile Behavior of 3D -Printed Acrylonitrile Styrene Acrylate (ASA) Material in Z Direction," *Polymer Engineering & Science*, vol. 62, no. 3, pp. 848–860, Mar. 2022, <https://doi.org/10.1002/pen.25891>.
- [12] A. Z. Hameed, S. Aravind Raj, J. Kandasamy, M. A. Shahzad, and M. A. Baghdadi, "3D Printing Parameter Optimization Using Taguchi Approach to Examine Acrylonitrile Styrene Acrylate (ASA) Mechanical Properties," *Polymers*, vol. 14, no. 16, Aug. 2022, Art. no. 3256, <https://doi.org/10.3390/polym14163256>.
- [13] N. E. Karkalos, K. Rydzoń, E. L. Papazoglou, and P. Karmiris-Obratański, "Analyzing the Effect of Infill Density on the Mechanical Compression of ASA in Additive Manufacturing: A FEM Perspective," *The International Journal of Advanced Manufacturing Technology*, vol. 134, no. 5–6, pp. 2815–2832, Sept. 2024, <https://doi.org/10.1007/s00170-024-14297-x>.
- [14] A. Sh. Jaber, A. M. Saleh, and M. Q. Ibraheem, "A Study on the Influence of Enclosure Temperature Control on the Printing of ABS Filament in a Three-Dimension Printer," *Engineering, Technology & Applied Science Research*, vol. 15, no. 2, pp. 20681–20686, Apr. 2025, <https://doi.org/10.48084/etasr.9762>.
- [15] S. Valvez, A. P. Silva, and P. N. B. Reis, "Compressive Behaviour of 3D-Printed PETG Composites," *Aerospace*, vol. 9, no. 3, Feb. 2022, Art. no. 124, <https://doi.org/10.3390/aerospace9030124>.
- [16] D. G. Zisopol, M. Minescu, and D. V. Iacob, "A Study on the Influence of FDM Parameters on the Compressive Behavior of ASA Parts," *Engineering, Technology & Applied Science Research*, vol. 14, no. 5, pp. 16237–16241, Oct. 2024, <https://doi.org/10.48084/etasr.8067>.
- [17] M. Minescu, D. G. Zisopol, and D. V. Iacob, "Study on the Breaking Strength of Tensile Specimens Manufactured Additively by Thermoplastic Extrusion of PLA, rPLA, PETG and rPETG," *Journal of Engineering Sciences and Innovation*, vol. 10, no. 1, pp. 13–20, Mar. 2025.
- [18] A. Kholil, E. Asyaefudin, N. Pinto, and S. Syaripuddin, "Compression Strength Characteristics of ABS and PLA Materials Affected by Layer Thickness on FDM," *Journal of Physics: Conference Series*, vol. 2377, no. 1, Nov. 2022, Art. no. 012008, <https://doi.org/10.1088/1742-6596/2377/1/012008>.
- [19] H. B. Ali, J. K. Oleiwi, and F. M. Othman, "Compressive and Tensile Properties of ABS Material as a Function of 3D Printing Process Parameters," *Revue des composites et des matériaux avancés*, vol. 32, no. 3, pp. 117–123, June 2022, <https://doi.org/10.18280/rcma.320302>.
- [20] M. A. N. B. Mohd Khairul Nizam, K. I. B. Ismail, and T. C. Yap, "The Effect of Printing Orientation on the Mechanical Properties of FDM 3D Printed Parts," in *Enabling Industry 4.0 through Advances in Manufacturing and Materials*, A. S. Abdul Sani, M. N. Osman Zahid, M. R. Mohamad Yasin, S. Z. Ismail, M. Z. Mohd Zawawi, A. R. Abdul Manaf, S. N. Mohd Saffe, R. Abd Aziz, and F. Mohd Turan, Eds., Singapore: Springer Nature Singapore, 2022, pp. 75–85.
- [21] I. Buj-Corral, A. Domínguez-Fernández, and R. Durán-Llucià, "Influence of Print Orientation on Surface Roughness in Fused Deposition Modeling (FDM) Processes," *Materials*, vol. 12, no. 23, Nov. 2019, Art. no. 3834, <https://doi.org/10.3390/ma12233834>.
- [22] A. T. Clark, J. F. Federici, and I. Gatley, "Effect of 3D Printing Parameters on the Refractive Index, Attenuation Coefficient, and Birefringence of Plastics in Terahertz Range," *Advances in Materials Science and Engineering*, vol. 2021, no. 1, Jan. 2021, Art. no. 8276378, <https://doi.org/10.1155/2021/8276378>.
- [23] *SolidWorks*. (2023), Dassault Systèmes. Accessed: Jan. 2024. [Online]. Available: <https://www.solidworks.com/>.
- [24] *UltiMaker Cura*. (2023), Ultimaker B.V. Accessed: Jan. 2024 [Online]. Available: <https://ultimaker.com/software/ultimaker-cura/>.
- [25] *Plastics: Determination of compressive properties*, ISO 604:2002, International Organization for Standardization, Geneva, Switzerland 2002.
- [26] *Minitab*. (2023), Minitab LLC, Accessed: Jan. 2024 [Online]. Available: <https://www.minitab.com/en-us/>.