STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Issue 2, 2026
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Enhancement of Flexural Strength in FDM-Printed Components through Taguchi-Based Process Parameter Optimization

PVR Girish Kumar [1,*], R. Sudarshan [2], B. Srinivas Reddy [3], K. Satish Babu [4]

Abstract

Additive manufacturing (AM), especially Fused Deposition Modeling (FDM), has emerged as a widely adopted and versatile method for producing three-dimensional components. The process involves the deposition of a thermoplastic filament in a semi-molten state, which solidifies in successive layers to form the final structure. While this method enables the production of complex geometries at relatively low cost, the printed parts often exhibit inferior surface quality and reduced mechanical performance compared to components manufactured by traditional techniques. Such drawbacks are primarily attributed to the layer-wise fabrication process, which may result in poor interlayer adhesion, and anisotropy in mechanical properties.To improve part performance, various studies have investigated the influence of process parameters on mechanical properties using statistical design approaches. Among these, the Taguchi method has been effectively employed to identify significant factors impacting flexural strength. Experimental findings suggest that shell thickness has the most dominant effect on flexural performance, followed by layer thickness, while infill percentage and other process parameters play comparatively minor roles. These results highlight the importance of optimizing shell thickness to enhance structural strength in FDM-printed parts, thereby offering valuable insights for achieving improved reliability and functional application of additively manufactured components.

Keywords: PLACF, process parameters, flexural, FDM, Taguchi method

***Author for Correspondence**
PVR Girish Kumar
E-mail id: pvrgirishkumar.me@gcet.edu.in

[1]Senior Assistant Professor, Department of Mechanical Engineering, Geethanjali College of Engineering and Technology, Cheeryal(V), Keesara(M), Medchal (D), Telangana, India
[2]Associate Professor, Department of Mechanical Engineering, Geethanjali College of Engineering and Technology, Cheeryal(V), Keesara(M), Medchal (D), Telangana, India
[3]Assistant Professor, Department of Mechanical Engineering, PACE Institute of Technology and Sciences, Ongole, Andhra Pradesh, India
[4]Professor, Department of Mechanical Engineering, MINA Institute of Engineering & Technology for Women, Ramachandragudem, Miryalguda, Nalgonda, Telangana, India

Received Date: September 26, 2025
Accepted Date: October 30, 2025
Published Date: March 30, 2026

Citation: PVR Girish Kumar, R. Sudarshan, B. Srinivas Reddy, K. Satish Babu. Enhancement of Flexural Strength in FDM-Printed Components Through Taguchi-Based Process Parameter Optimization. Journal of Polymer & Composites. 2026; 14 (2): 272–280p.

INTRODUCTION AND LITERATURE REVIEW

A comparative survey between the process parameters and mechanical strength for PLA-CF composite is conducted, and the variations in their properties along with corresponding parameters are discussed. Components are printed by method fused deposition modeling find out the flexural strength of the specimen by conducting experiment on it [1] have used different methods to upgrade the properties of PLA, altering the printing process parameters, and utilizing additives to discuss the upgradation of mechanical properties [2]. Mechanical Properties of PLA Filament which is blended with Recycled PLA Materials by using layer thickness and PLA build material which is mixed with recycled PLA material. And find out the tensile strength and flexural strength of the specimen by conducting experiment on it Failure Analysis and tensile strength of components printed with material ABS w.r.to layer thickness and

Orientation [4]. Optimization of Charpy-impact strength of 3D-printed carbon fiber/polyamide composites by taguchi method by changing the infill density, raster angle, extruder temperature, and printing speed. [5] Continuous fiber reinforced thermoplastic composites tested using three-point bending [6] and comparison also done using Scanning Electron Microscope (SEM) [7]. Most of the researcher are printed components by changing Build direction, infill percentage, and layer height and found out strength of the material [8] and also printed components by using, extrusion width, printing temperature, and printing speed [9]. And also selected unidirectional and mixed-isotropic configurations [0°/90°/+45°/-45°] conducted tensile and flexural test[10], Investigation of the Mechanical Properties of a Carbon Fiber-Reinforced Nylon Filament for 3D Printing the components by using parameters building direction, the infill percentage, found out thermal stresses and Hardness altering raster angle, layer thickness, number of coatings [12] Interfacial bonding strength of short carbon fiber/acrylonitrile-butadiene-styrene composites fabricated by fused deposition modeling by changing printing speed and layer thickness and determine X-ray μ-CT Tensile test [13]. Analysis mechanical properties of a carbon fiber-reinforced polyamide by changing Layer height Printing pattern Infill density Nozzle temperature Build plate temperature, Printing speed [14] and found out its tensile and Flexural strength [15] was investigated in the 3D printing of continuous carbon fiber reinforced thermoplastic (CFRTP) tensile test specimens, which were fabricated in the longitudinal direction to evaluate their mechanical properties [16]. Studies also examined variations in viscosity and breaking strength [17, 21, 22]. Key process parameters such as printing temperature (240 °C) and extrusion rate (120%) were fixed [18], while factors including build orientation, raster orientation, nozzle diameter, extruder temperature, infill density, shell number, and extrusion speed were varied [19]. Further research focused on optimizing printing temperature and feed rate to produce high-quality composite parts [20, 27].

In this work, the mechanical properties, particularly flexural strength, of FDM-printed PLA-CF parts were studied by varying infill percentage, shell thickness, and layer thickness using the Taguchi statistical technique. A comparative study of the mechanical behavior of PLA and carbon fiber-reinforced PLA properties as shown in Table 1 for thin-walled applications was also carried out. The article reports how specimens with different thicknesses, material deposition strategies, and printing orientations were designed, fabricated, and measured to assess geometric and dimensional accuracy, followed by flexural testing and scanning electron microscopy (SEM) analysis [23, 24, 31–41]. In these studies, printing temperature [25] and printing speed [26,42,43,44,45] were kept constant, while the influence of slicing parameters on flexural strength of FDM-printed CF/PLA composites was investigated [28–30].

The flexural test specimens, with dimensions of 125 mm × 12.7 mm × 6 mm, are shown in Figure 1. The slicing parameters considered—layer thickness, infill percentage, and shell thickness—play a significant role in determining part strength. Flexural strength tests (ASTM D790) were performed by varying these parameters according to the experimental plan outlined in Table 2.

Table 1. Properties of PLA-CF filament.

Properties	**Specifications**
Density	1.27 Kg/m^3
Nozzle Temperature	210°C
Print Speed	80mm/s
Melting Range	180°C to 230°C
Bed Temperature	80^0C
Infill pattern	Grid type
Orientation	0^0

Table 2. Selected FDM process parameters.

Factor	Levels	Values
Layer Thickness (mm)	4	0.1, 0.2, 0.3, 0.4
Infill % (%)	4	20, 40, 60, 80
Shell Thickness (Count)	4	2, 4, 6, 8

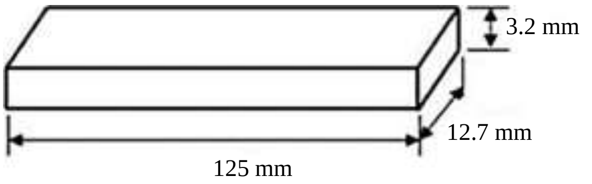

Figure 1. ASTM D790 Flexural specimen dimensions.

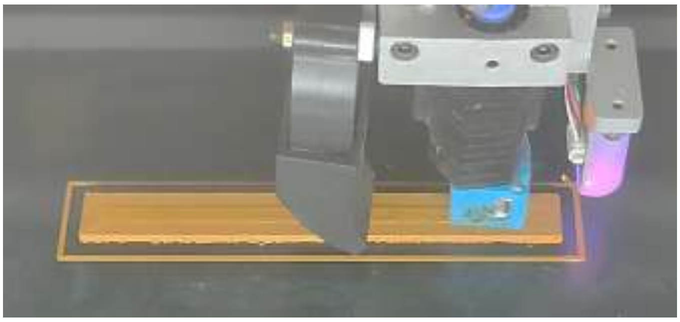

Figure 2. Specimen printing on FDM.

Figure 3. Printed specimens.

After printing the test specimens on the FDM machine (Figure 2), the samples (Figure 3) were subjected to three-point bending tests (flexural tests) using an Instron 1195 testing machine (Figure 4). The tested specimens are presented in Figure 5.

Figure 4. 3-point bending test of specimen.

Figure 5. Flexural specimens after testing.

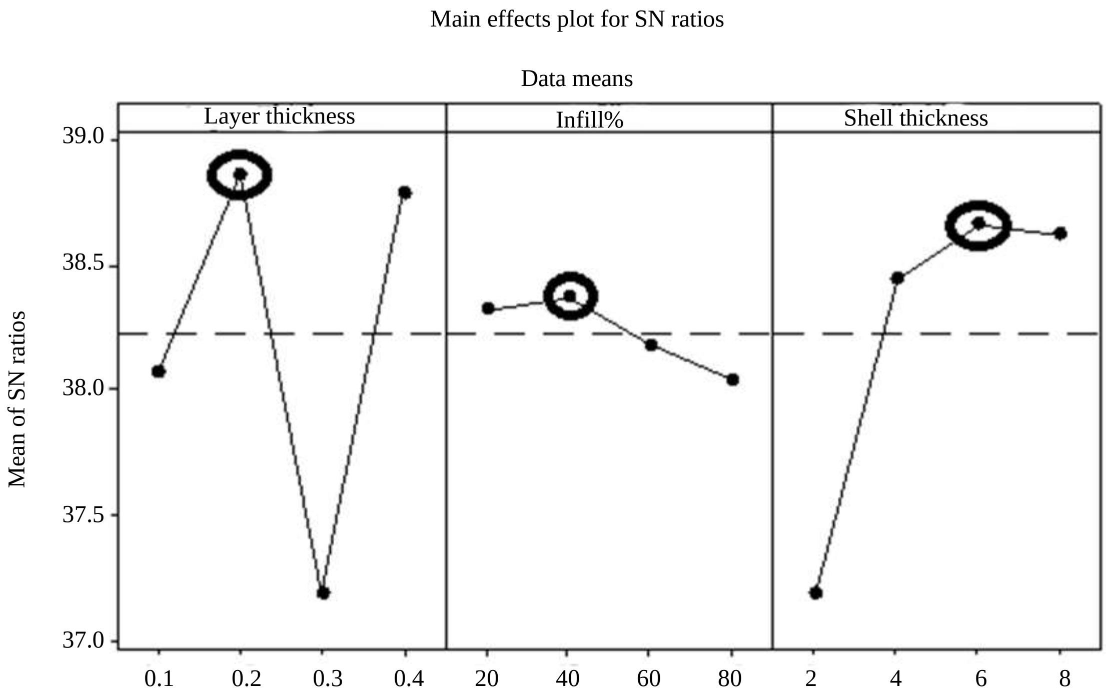

Figure 6. Main effects plot for S/N ratio.

RESULT

The test findings for each experiment carried out by the Taguchi's L16 OA are reviewed as the first stage in the analysis in the current study. Applying Larger is the Best features to each trial yields the S/N ratios, as indicated in Table 3. The highest value of S/N denotes an ideal control factor.

Table 3. Flexural strength results

S.N.	Layer thickness	Infill %	Shell thickness	Flexural strength (MPa)	S/N ratio
1	0.1	20	2	69.27	36.81
2	0.1	40	4	79.77	38.04
3	0.1	60	6	87.26	38.82
4	0.1	80	8	85.45	38.63
5	0.2	20	4	92.58	39.33
6	0.2	40	2	84.32	38.52
7	0.2	60	8	85.25	38.61
8	0.2	80	6	89.12	39.00
9	0.3	20	6	74.16	37.40
10	0.3	40	8	74.91	37.49
11	0.3	60	2	65.87	36.37
12	0.3	80	4	74.88	37.49
13	0.4	20	8	97.19	39.75
14	0.4	40	6	93.75	39.44
15	0.4	60	4	88.35	38.92
16	0.4	80	2	71.15	37.04

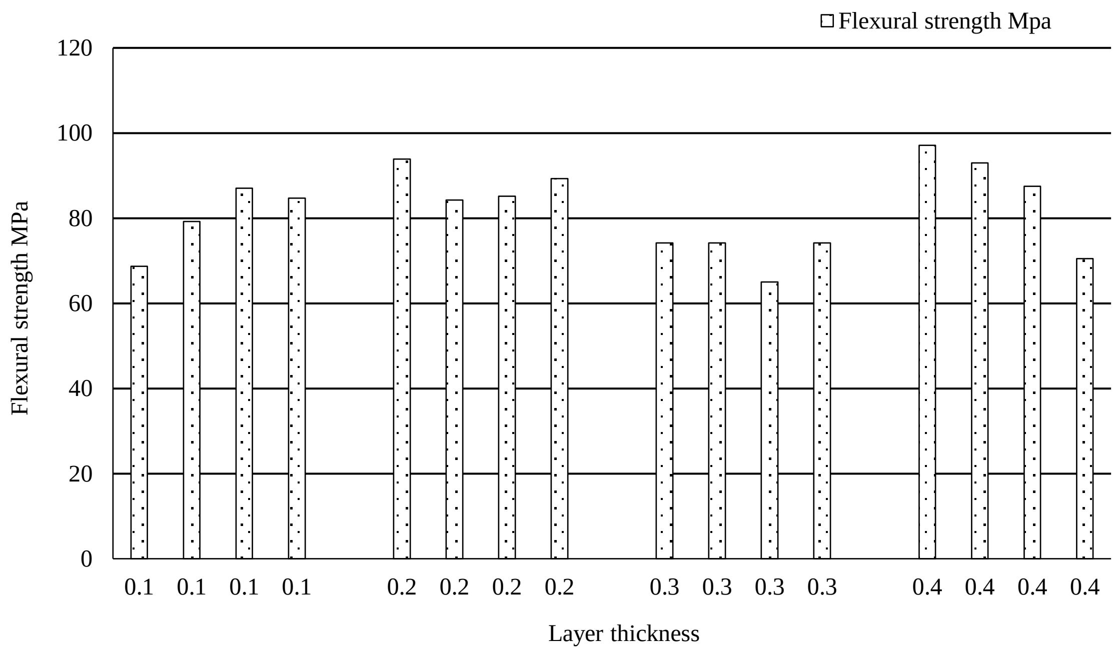

Figure 7. Flexural strength vs layer thickness.

Figure 6 displays the plot of the average S/N ratio values for each factor at various levels and the optimal values for achieving the desired thickness value are shown by the factors at levels A2, B2, and C3. The Maximum Flexural strength achieved at 0.4 mm Layer thickness. Flexural strength is inversely proportional to Layer Thickness shown in Figure 7.

The Maximum Flexural strength achieved at 20 Infill%, Flexural strength is Directly proportional to Infill % shown in Figure 8.

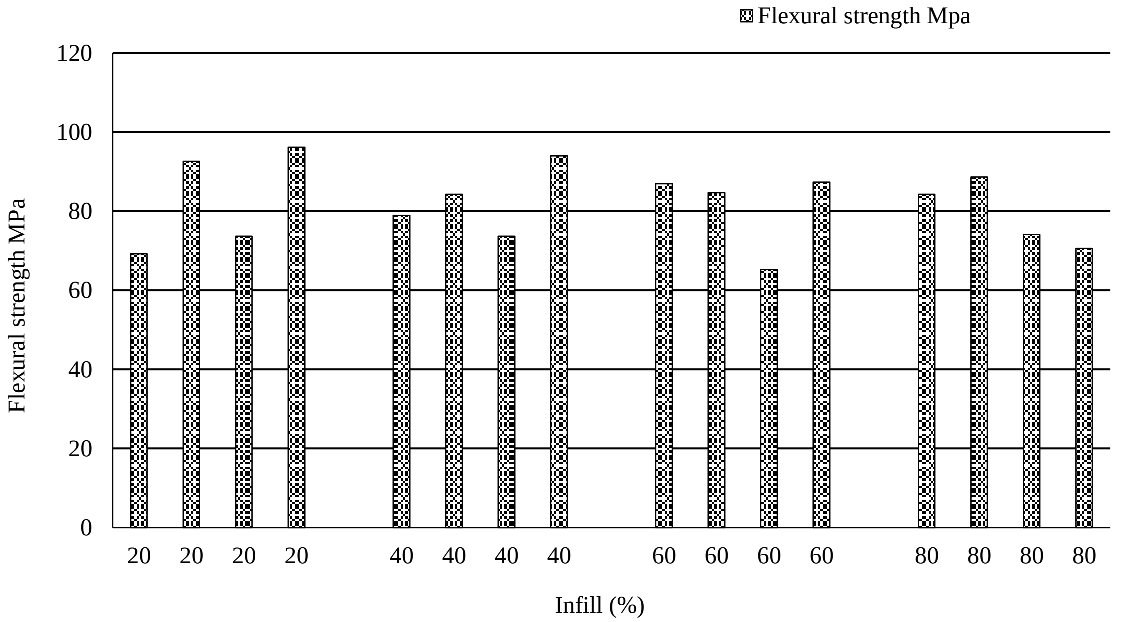

Figure 8. Flexural strength vs infill %.

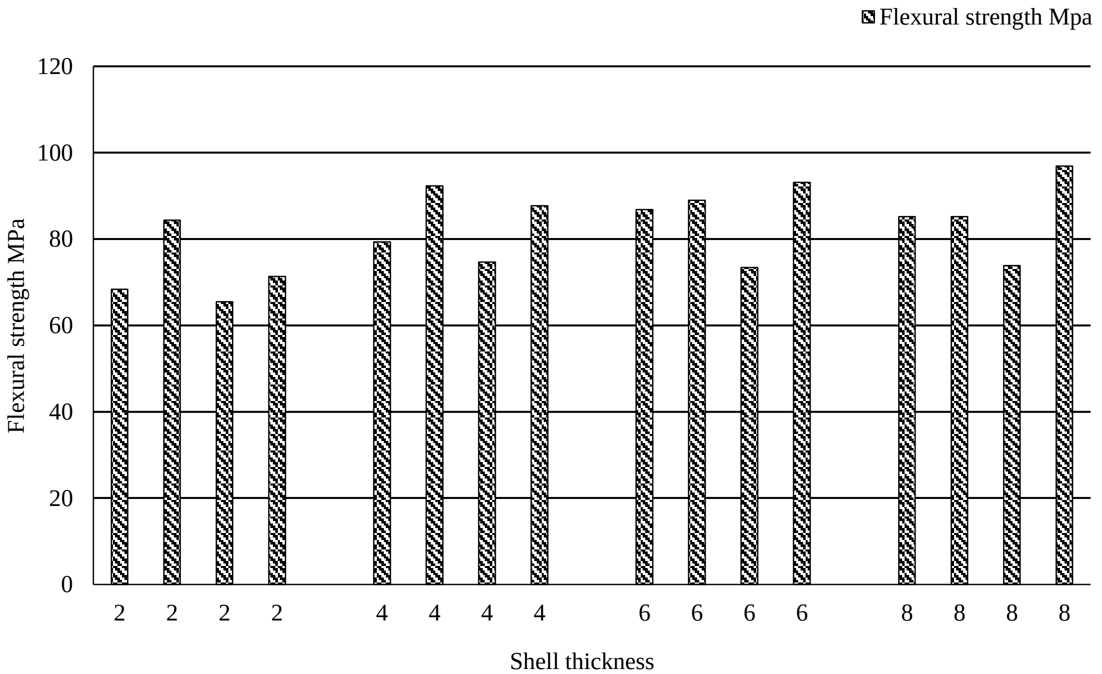

Figure 9. Flexural strength vs shell thickness.

Table 4. Analysis of variance.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Layer Thickness	3	635.35	211.7	6.76	0.024 (Significant)
Infill %	3	26.39	8.7	0.28	0.838 Non-(Significant)
Shell Thickness	3	484.87	161.6	5.16	0.042 (Significant)
Error	6	187.91	31.318		
Total	15	1334.5			

The Maximum Flexural strength achieved at 8 mm Shell thickness. Flexural strength is Directly proportional to Shell Thickness shown in Figure 9.and also, from the table shell thickness parameter got significant value got P value <0.05 shown in Table 4, not only that layer thickness also got significant factor. The regression equation is shown below equation 1.

$$R = 58.47 + 42.35tL + 8.72tS - 0.11I. \quad (1)$$

The results of the three-point bending test (Fig. 4) for PLA-CF specimens are summarized in Table 3. It was observed that the flexural strength values exceeded the tensile strength values, since the modulus of rupture represents the maximum stress at the outermost fiber of the beam. The highest flexural strength of 97.19 MPa was obtained for a layer thickness of 0.4 mm, infill percentage of 20%, and shell thickness of 8 mm, while the lowest value of 71.15 MPa was recorded for a layer thickness of 0.4 mm, infill percentage of 80%, and shell thickness of 2 mm. The reduced flexural strength in the latter case is attributed to weak interlayer bonding inherent to rapid prototyping samples.

CONCLUSION

Effect of three process parameters layer thickness, infill percentage and shell thickness are studied on flexural strength of test specimen. Experiments were conducted using taguchi. The optimum parameter foe maximum strength is layer thickness 0.4mm, infill percentage 20 and shell thickness 8mm. Even though increase of layer thickness and less infill deposition of material, by increasing of shell thickness can significantly improve a components flexural strength. Suitable for making strong frames and support structures.

Funding

This research was funded by the Geethanjali College of Engineering and Technology, Cheeryal (V), Keesara(M), Medchal-Malkajgiri (D), Telangana, India under the Seed Money Grant.

REFERENCES

1. Van Der Klift, F., Koga, Y., Todoroki, A., Ueda, M., Hirano, Y., & Matsuzaki, R. (2015). 3D printing of continuous carbon fibre reinforced thermo-plastic (CFRTP) tensile test specimens. Open Journal of Composite Materials, 6(1), 18-27.
2. Sharma, P., Dhanopia, A. K., & Joshi, D. (2021). An experimental study on carbon fiber thickness and layer thickness of depositing material in fused deposition modeling. Materials Today: Proceedings, 44, 4479-4484.
3. de Toro, E. V., Sobrino, J. C., Martínez, A. M., & Eguía, V. M. (2019). Analysis of the influence of the variables of the Fused Deposition Modeling (FDM) process on the mechanical properties of a carbon fiber-reinforced polyamide. Procedia Manufacturing, 41, 731-738.
4. Zhang, W., Cotton, C., Sun, J., Heider, D., Gu, B., Sun, B., & Chou, T. W. (2018). Interfacial bonding strength of short carbon fiber/acrylonitrile-butadiene-styrene composites fabricated by fused deposition modeling. Composites Part B: Engineering, 137, 51-59.
5. Appusamy, A. M., Karuppan, S., Subramaniyan, M., & Chinnappan, B. A. (2024). The influence of filler and FDM printing parameters on the strength of PLA. Polimery, 69(2), 92.
6. Calignano, F., Lorusso, M., Roppolo, I., & Minetola, P. (2020). Investigation of the mechanical properties of a carbon fibre-reinforced nylon filament for 3D printing. Machines, 8(3), 52.
7. Parmiggiani, A., Prato, M., & Pizzorni, M. (2021). Effect of the fiber orientation on the tensile and flexural behavior of continuous carbon fiber composites made via fused filament fabrication. The International Journal of Advanced Manufacturing Technology, 114, 2085-2101.
8. Dou, H., Cheng, Y., Ye, W., Zhang, D., Li, J., Miao, Z., & Rudykh, S. (2020). Effect of process parameters on tensile mechanical properties of 3D printing continuous carbon fiber-reinforced PLA composites. Materials, 13(17), 3850.
9. Kamaal, M., Anas, M., Rastogi, H., Bhardwaj, N., & Rahaman, A. (2021). Effect of FDM process parameters on mechanical properties of 3D-printed carbon fibre–PLA composite. Progress in Additive Manufacturing, 6, 63-69.

10. Li, N., Li, Y., & Liu, S. (2016). Rapid prototyping of continuous carbon fiber reinforced polylactic acid composites by 3D printing. Journal of Materials Processing Technology, 238, 218-225.
11. Chacón, J. M., Caminero, M. A., Núñez, P. J., García-Plaza, E., García-Moreno, I., & Reverte, J. M. (2019). Additive manufacturing of continuous fibre reinforced thermoplastic composites using fused deposition modelling: Effect of process parameters on mechanical properties. Composites science and technology, 181, 107688.
12. Beylergil, B., Al-Nadhari, A., & Yildiz, M. (2023). Optimization of Charpy-impact strength of 3D-printed carbon fiber/polyamide composites by Taguchi method. Polymer Composites, 44(5), 2846-2859.
13. 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. Journal of Failure Analysis and Prevention, 16, 467-481.
14. Samykano, M., Selvamani, S. K., Kadirgama, K., Ngui, W. K., Kanagaraj, G., & Sudhakar, K. J. T. I. J. O. A. M. T. (2019). Mechanical property of FDM printed ABS: influence of printing parameters. The International Journal of Advanced Manufacturing Technology, 102, 2779-2796.
15. Babagowda, Kadadevara Math, R. S., Goutham, R., & Srinivas Prasad, K. R. (2018, February). Study of Effects on Mechanical Properties of PLA Filament which is blended with Recycled PLA Materials. In IOP conference series: materials science and engineering (Vol. 310, p. 012103). IOP Publishing.
16. Hasan, M. R., Davies, I. J., Pramanik, A., John, M., & Biswas, W. K. (2024). Potential of Recycled PLA in 3D Printing: A Review. Sustainable Manufacturing and Service Economics, 100020.
17. Fernandes, C. P. (2019). Use of recycled poly lactic acid (PLA) polymer in 3D printing: a review. Research Journal of Engineering and Technology, 123(104.34), 98-32.
18. Mishra, V., Negi, S., & Kar, S. (2023). FDM-based additive manufacturing of recycled thermoplastics and associated composites. Journal of Material Cycles and Waste Management, 25(2), 758-784.
19. Yap, E. P., Koay, S. C., Chan, M. Y., Choo, H. L., Ong, T. K., & Tshai, K. Y. (2021, December). Recycling polymer blend made from post-used styrofoam and polyethylene for fuse deposition modelling. In Journal of Physics: Conference Series (Vol. 2120, No. 1, p. 012021). IOP Publishing.
20. Hikmat, M., Rostam, S., & Ahmed, Y. M. (2021). Investigation of tensile property-based Taguchi method of PLA parts fabricated by FDM 3D printing technology. Results in Engineering, 11, 100264.
21. Heidari-Rarani, M., Rafiee-Afarani, M., & Zahedi, A. M. (2019). Mechanical characterization of FDM 3D printing of continuous carbon fiber reinforced PLA composites. Composites Part B: Engineering, 175, 107147.
22. Camargo, J. C., Machado, Á. R., Almeida, E. C., & Silva, E. F. M. S. (2019). Mechanical properties of PLA-graphene filament for FDM 3D printing. The International Journal of Advanced Manufacturing Technology, 103, 2423-2443.DM 3D Printing.
23. Kamaal, M., Anas, M., Rastogi, H., Bhardwaj, N., & Rahaman, A. (2021). Effect of FDM process parameters on mechanical properties of 3D-printed carbon fibre–PLA composite. Progress in Additive Manufacturing, 6, 63-69.
24. Bochnia, J., Blasiak, M., & Kozior, T. (2021). A comparative study of the mechanical properties of FDM 3D prints made of PLA and carbon fiber-reinforced PLA for thin-walled applications. Materials, 14(22), 7062.
25. Mani, M., Karthikeyan, A. G., Kalaiselvan, K., Muthusamy, P., & Muruganandhan, P. (2022). Optimization of FDM 3-D printer process parameters for surface roughness and mechanical properties using PLA material. Materials Today: Proceedings, 66, 1926-1931.
26. Lokesh, N., Praveena, B. A., Reddy, J. S., Vasu, V. K., & Vijaykumar, S. (2022). Evaluation on effect of printing process parameter through Taguchi approach on mechanical properties of 3D printed PLA specimens using FDM at constant printing temperature. Materials today: proceedings, 52, 1288-1293.

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

27. Reddy, M. V., Hemasunder, B., Chavan, P. M., Dish, N., & Savio, A. P. (2023). Study on the significance of process parameters in improvising the tensile strength of FDM printed carbon fibre reinforced PLA. Materials Today: Proceedings.
28. Srinivasan, R., Aravindkumar, N., Krishna, S. A., Aadhishwaran, S., & George, J. (2020). Influence of fused deposition modelling process parameters on wear strength of carbon fibre PLA. Materials Today: Proceedings, 27, 1794-1800.
29. Vinoth Babu, N., Venkateshwaran, N., Rajini, N., Ismail, S. O., Mohammad, F., Al-Lohedan, H. A., & Suchart, S. (2022). Influence of slicing parameters on surface quality and mechanical properties of 3D-printed CF/PLA composites fabricated by FDM technique. Materials Technology, 37(9), 1008-1025.
30. Kumar, M. A., Khan, M. S., & Mishra, S. B. (2020). Effect of fused deposition machine parameters on tensile strength of printed carbon fiber reinforced PLA thermoplastics. Materials Today: Proceedings, 27, 1505-1510.
31. SAE uses the Chicago Manual of Style in formatting references. In the text of the paper the citations are numerically identified using square brackets [1]. Up to four authors should be listed; more than four, et al. should be used after the fourth author is listed. Refer to the SAE Technical Paper Style Guide for formatting of different types of references. Apply the List-Ordered-Numeric style tag to format references. Below are some examples.
32. Guo, Q. and Liu, B., "Simulation and Physical Measurement of Seamless Passenger Airbag Door Deployment," SAE Technical Paper 2012-01-0082, 2012, doi:10.4271/2012-01-0082.
33. Kunkel, S., Zimmer, T., and Wachtmeister, G., "Friction Analysis of Oil Control Rings during Running-In," SAE Technical Paper 2011-01-2428, 2012, doi:10.4271/2011-01-2428.
34. Morgan, R., Scullion, P., Nix, L., Kan, C. et al., "Injury Risk Investigation of the Small, Rear-seat Occupant in Side Impact," SAE Technical Paper 2012-01-0092, 2012, doi:10.4271/2012-01-0092.
35. Kimura, Y. and Murakami, M., "Analysis of Piston Friction - Effects of Cylinder Bore Temperature Distribution and Oil Temperature," *SAE Int. J. Fuels Lubr.* 5(1):1-6, 2012, doi:10.4271/2011-01-1746.
36. SAE International Surface Vehicle Recommended Practice, “Laboratory Measurement of the Composite Vibration Damping Properties of Material on a Supporting Steel Bar,” SAE Standard J1637, Rev. Aug. 2007.
37. Giri, Jayant, Neeraj Sunheriya, T. Sathish, Yash Kadu, Rajkumar Chadge, Pallavi Giri, A. Parthiban, and Chetan Mahatme. "Optimization of process parameters to improve mechanical properties of fused deposition method using taguchi method." Interactions 245, no. 1 (2024): 87.
38. Kumar, P. G. (2023). Impact of compression and bending behavior on fused deposition modeling of 3D printed components. Materials Today: Proceedings, 92, 554-560.
39. PVR, G. K. (2024). Optimizing mechanical properties of virgin and recycled PLA components using Anova and neural networks. Mathematical Models in Engineering, 10(1), 1-10.
40. Reddy, V. S. N., Oshin, P., Babu, D. S., Janbhasha, S., Ch, S. C., Kumar, P. G., & Raju, Y. (2024). Optimization of Manufacturing Parameters of PLA Components Using Taguchi and Neural Network (NN) Technique. Nanotechnology Perceptions, 405-412.
41. KUMAR PVR, G., & DEVI K, D. (2024). The Study Focus on Optimizing Processing Parameters for 3D Printed Composites Using Taguchi. Management and Production Engineering Review.
42. Kiran, A., Kumar, P. G., Sastry, N., Sudarshan, R., & Babu, K. S. (2025, September). Investigation on parameters used for fused deposition modeling and inspection of the printed parts. In AIP Conference Proceedings (Vol. 3342, No. 1, p. 020018). AIP Publishing LLC.
43. Pvr, G. K., & Devi, K. D. (2025). Influence of ManufacturIng ParaMeters on the ProPertIes of 3D PrInteD PolylactIc acID carbon fIber coMPonents. Archives of Metallurgy and Materials, 97-104.
44. Kumar, P. G., Madhurima, K., Devi, K. D., Tejaswi, R., & Spandana, G. (2025, November). Optimizing selective laser melting parameters for AlFeSi10Mg alloy using GRA and DEAR techniques. In *AIP Conference Proceedings* (Vol. 3361, No. 1, p. 030085). AIP Publishing LLC.
45. Reddy, K. J., Kumar, P. G., Devi, K. D., Babu, K. S., & Reddy, K. H. C. (2025, November). Fabrication of virgin and recycled polymer components using FDM & its mechanical properties. In *AIP Conference Proceedings* (Vol. 3361, No. 1, p. 030087). AIP Publishing LLC.