Effect of Different Infill Material Deposition Orientation on the Deformation Behavior of FDM 3D-Printed Components

[1]Satish Saini, [2]Yogesh Parkhi
[1]School of Research and Technology,People's University, Bhopal.
[2]School of Research and Technology,People's University, Bhopal.

* Corresponding Author: Satish Saini

Abstract: *This study investigates the influence of material orientation on the tensile strength of parts fabricated using the Fused Deposition Modeling (FDM) process with PETG, ABS, and PLA materials. Eighteen sets of experiments were conducted to evaluate the tensile strength under different orientations. The results indicate that the direction of material deposition significantly impacts tensile strength, with 0-degree orientation consistently exhibiting superior performance compared to 45 and 90-degree orientations across all materials. ABS demonstrates higher tensile strength than PLA and PETG, with PLA exhibiting a higher tensile strength than PETG. For example, ABS with 50% infill density at 0-degree orientation achieves a tensile load strength of 2.08 kN compared to 2.05 kN and 1.95 kN at 45 and 90-degree orientations, respectively. Similarly, PLA and PETG exhibit similar trends. Overall, the findings suggest that 0-degree orientation is optimal for FDM printing with these materials. Additionally, ABS emerges as the material of choice for applications requiring high tensile strength in 3D printing.*

Keywords: *FDM printing, infill density, orientation, material, deformation behavior*.

I. INTRODUCTION

Fused Deposition Modeling (FDM) is an additive manufacturing technique that builds objects layer by layer from thermoplastic materials. In FDM printing, a filament of material is fed through a heated nozzle, which melts the filament. The molten material is then extruded onto a build platform or previously deposited layers, where it quickly cools and solidifies, forming the desired shape. FDM printers are widely used due to their affordability, ease of use, and ability to produce functional prototypes and end-use parts. They can utilize a variety of thermoplastic materials, including ABS, PLA, PETG, and more, offering flexibility in material selection to suit specific application requirements. One of the key advantages of FDM printing is its ability to produce complex geometries with intricate details. Additionally, FDM printing allows for customization and rapid prototyping, enabling designers and engineers to iterate designs quickly and cost-effectively.

However, FDM printing does have some limitations. The layer-by-layer deposition process can result in visible layer lines on the finished part, which may require post-processing techniques such as sanding or painting for a smoother surface finish. Additionally, FDM-printed parts may have anisotropic mechanical properties, meaning their strength and performance can vary depending on the direction of printing. Overall, FDM printing offers a versatile and accessible means of manufacturing parts and prototypes, making it a valuable tool in various industries, including automotive, aerospace, healthcare, and consumer goods. In FDM, thermoplastic materials such as Polyethylene Terephthalate Glycol (PETG), Acrylonitrile Butadiene Styrene (ABS), and Polylactic Acid (PLA) are commonly employed for fabricating parts with various mechanical properties. The orientation of material deposition during the printing process plays a crucial role in determining the mechanical strength of the final product. This study focuses on investigating the impact of material orientation on the tensile strength of parts produced through FDM using PETG, ABS, and PLA materials. Tensile strength is a fundamental mechanical property that influences the performance and durability of printed parts, making it essential to understand how different printing orientations affect this aspect.

Through a series of eighteen experiments, varying material orientations were examined to comprehensively evaluate the tensile strength of parts. The findings of this research shed light on the optimal printing orientation for achieving the highest tensile strength with each material, providing valuable insights for optimizing FDM printing processes. Furthermore, the comparative analysis between PETG, ABS, and PLA materials offers valuable insights into their respective tensile strengths and performance characteristics in FDM applications. Understanding these differences is crucial for selecting the most suitable material based on specific application requirements. Overall, this study aims to contribute to the advancement of FDM technology by providing valuable knowledge on how material orientation influences tensile strength, thereby aiding in the optimization of printing parameters and material selection for various industrial and engineering applications.

Water is vital for human survival, supporting crucial activities such as agriculture, irrigation, and domestic use. However, fresh water availability is a growing concern worldwide. Approximately 97% of Earth's water is saline, and only a fraction of 1% is accessible freshwater. Increasing population, industrial pollution, and varying rainfall patterns, especially in arid and desert regions, exacerbate the depletion of existing freshwater sources. Desalination stands as a critical solution for obtaining potable water from saline sources.

II. SAMPLE PREPARATION AND MATERIALS

Structural tensile specimens made of dog bones are printed in three dimensions using FDM technology. In order to evaluate the deformation behaviour and mechanical characteristics of different materials at different built orientations. The dog bone's structure was created in Solidwork and then imported as a .STL file into the 3D printer. The figure 1 underneath has the same size as the dog bone. The experimental work was carried out at Mcube 3D Pvt. Ltd., M.P.Nagar Bhopal, India. Total 18 set of experiment was conducted with different combination of material (i.e. PLA, ABS and PETG), infill density (i.e. 50, and 75) and material deposition orientation (i.e. 0, 45 and 90). In each set of experiment three-three samples were prepared and the average data was reported.

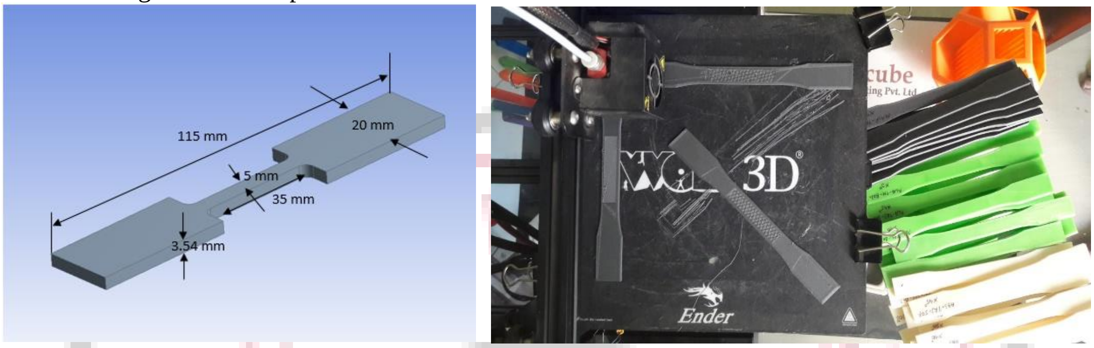

Fig.1 Dog bone structure and sample preparation with different specification

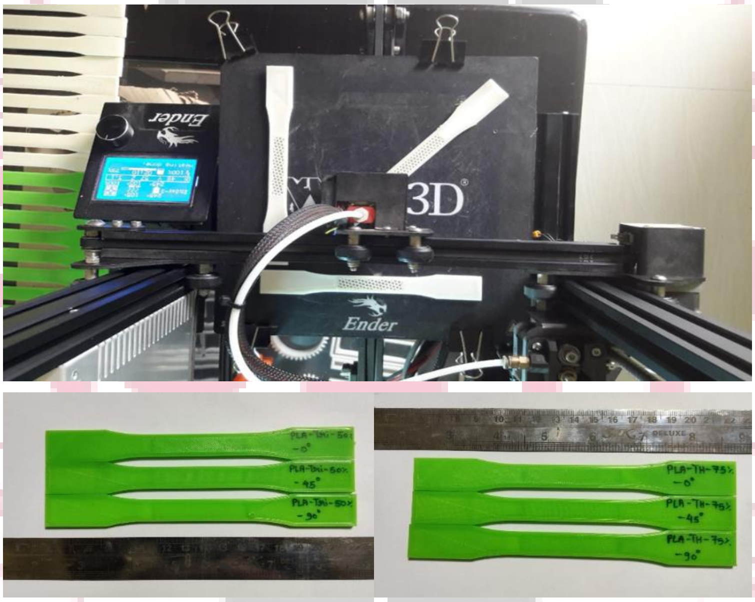

Fig.2 Tensile specimens of PLA material with different orientation and infill density

Table 1. Printing parameters considered during the experiment

Parameters	**Value**
Filament Materials	PLA, ABS, PETG
Modeling process	FDM
Layer height	0.1 mm
Infill density	80 %
Infill geometric shapes	Lines, concentric, triangular
Raster angle	0 degree
Nozzle diameter	0.25 mm
Nozzle temperature	225 degree

Printing speed	30 mm/s
Printing bed temperature	60 degree
Room temperature	25 degree
Relative humidity	50 (%RH)

3. TESTING OF TENSILE SPECIMENS

Once the samples were printed at various specifications, uniaxial tensile testing was done. The UTM machine was utilised to conduct the tensile test at a strain rate of 0.01/s on each sample. In order to facilitate the evaluation of the precise strength and impact of various printing parameters on the samples' performance, the tensile testing specimens were produced in compliance with the ASTM code.

IV. RESULT AND DISCUSSION

A. Tensile strength of the specimens

The primary focus of this study is on the tensile strength and deformation behaviour of several materials, with 50 and 75% infill density and distinct deposition orientation angles for each material. There are two sections to the results. The yield strength and distortion behaviour of a single material at different infill densities are examined in the first section. The third section examines the behaviour of deformation and tensile strength in different materials. The PLA material's tensile stress-strain graph at 50% infill density reveals a sharp rise in stress relative to strain. It is evident from the graph that higher values are displayed in the 0-degree orientation. On the other hand, 45 and 90 degrees exhibit the same deformation behaviour and 40 MPA yield strength. A 50% infill density PLA material exhibits higher plastic deformation in a 90-degree orientation, with 0 and 45 degrees following. For a 0-degree orientation, PLA's maximum yield strength at 50% infill density is 41.37 MPa. With PLA material, there is relatively little plastic deformation following yielding. The graph indicates that the PETG material's tensile yield strength at a 0-degree orientation and 50% infill density is 24.95 MPa. However, the 45- and 90-degree orientations had tensile strengths of 18.95 and 11.78 MPa, respectively. PETG material has considerably lower tensile strength at all orientations when compared to specimens printed with PLA and ABS. Furthermore, compared to PLA and ABS material, the stress-strain deformation curve is not as stiff. The stress-strain graph of PETG material exhibits notable changes in deformation along with the shift in material deposition direction.

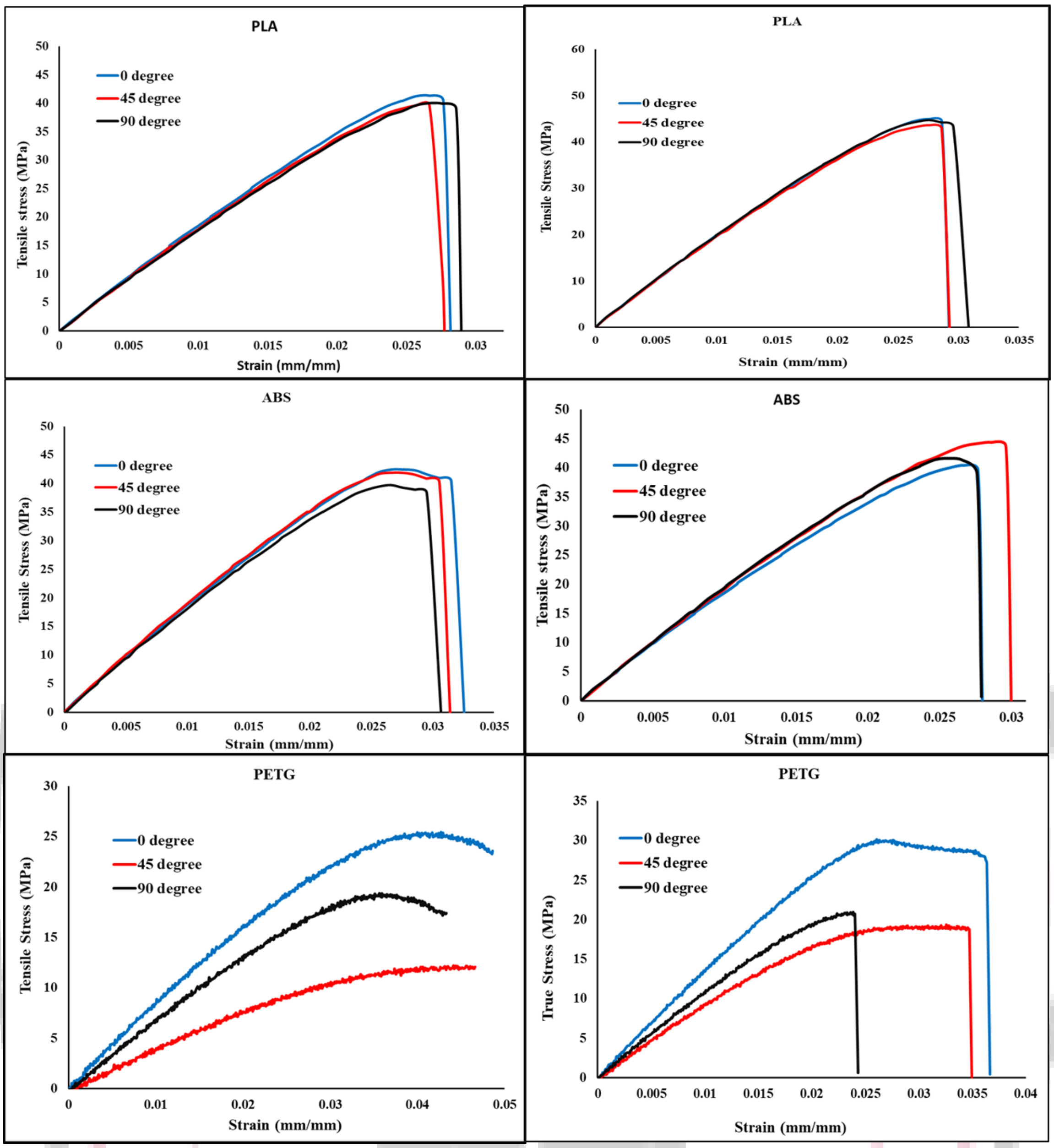

Fig. 3 shows the tensile stress-strain graph of different material at different parameters that is PLA, ABS, and PETG with 50 and 75% infill density

B. Comparison

Comparison was carried out after assessing the performance of various 3D printed samples for various materials at various deposition orientations. The yield stress, maximum load, and strain were the primary factors used in the comparison. From comparison of value of yield stress for different specimens, it is found that at 0 and 45 degree orientation ABS shows higher yield strength which is followed by PLA and PETG material. Whereas at 90 degree orientation, PLA shows higher strength as compared to ABS and PETG. PETG shows much lesser strength as compared to PLA and ABS at each material deposition orientation.

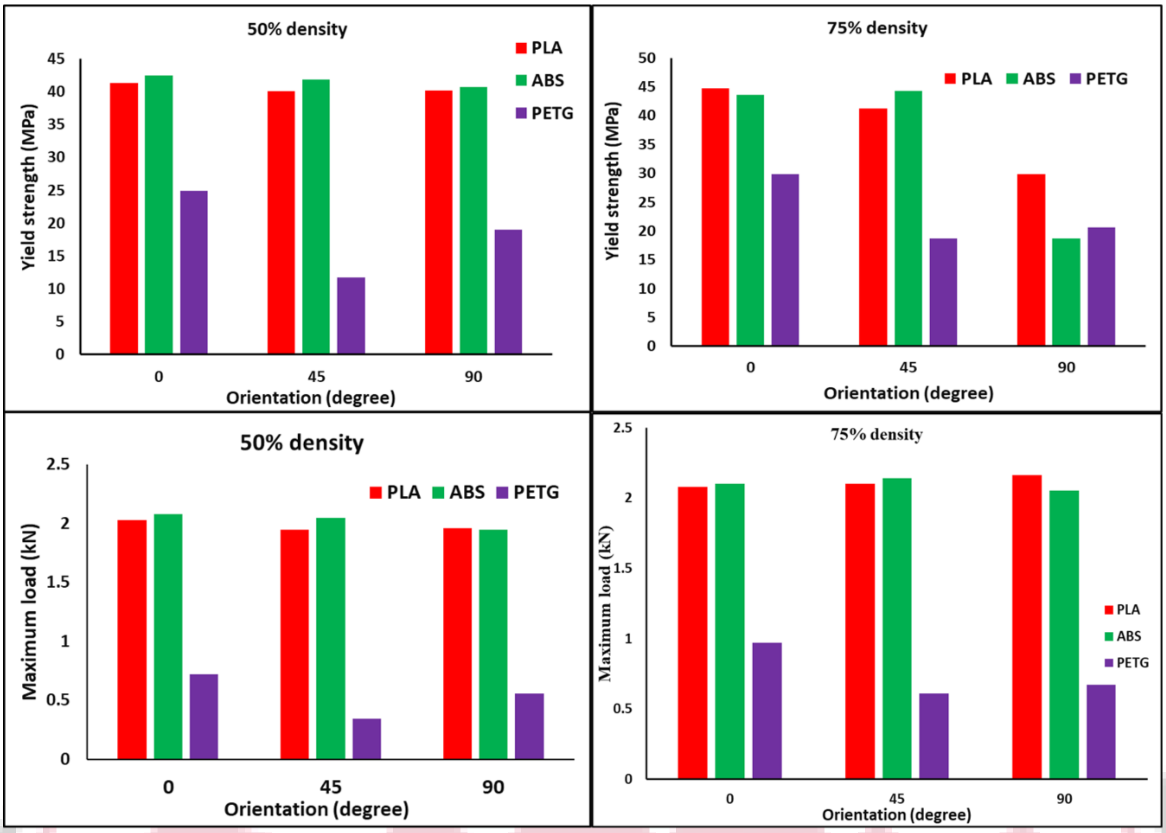

Fig.4 Comparison of yield strength and maximum tensile load for different set of parameters

In terms of maximum load bearing capacity also, ABS shows higher values as 0 and 45 degree orientation as compared to PLA and PETG. Whereas as through graph it is seen that at each degree of orientation PETG shows lesser value of tensile load carrying capacity.

V. CONCLUSION

Through experimental analysis, it is found that the PLA and PETG materials have lower tensile strength values than ABS, although PLA has a much greater value than PETG. The tensile load strength of ABS with 50% infill density at a 0-degree orientation is 2.08 kN, while at 45 and 90 degrees, it is 2.05 and 1.95 kN, respectively. The tensile strength of PLA with 50% infill density at a 0-degree orientation is 2.03 kN, while at 45 and 90 degrees, the load is 1.95 and 1.96 kN. The tensile strength of PETG with 50% infill density at a 0-degree orientation is 0.72 kN, while at 45 and 90 degrees, the load is 0.34 and 0.56 kN. All things considered, the optimal orientation for FDM printing PLA, ABS, and PETG material is 0 degrees for material deposition.

REFERENCES

[1] Vaezi, M., H. Seitz, and S. Yang, A review on 3D micro-additive manufacturing technologies. The International Journal of Advanced Manufacturing Technology, 2013. 67(5): pp. 1721-1754.

[2] Krivec, M., et al., Exploiting the combination of 3D polymer printing and inkjet Ag-nanoparticle printing for advanced packaging. Microelectronic Engineering, 2017. 176: pp. 1-5.

[3] Zhai, Y., D.A. Lados, and J.L. LaGoy, Additive Manufacturing: Making Imagination the Major Limitation. JOM, 2014. 66(5): pp. 808-816.

[4] Bak, D., Rapid prototyping or rapid production? 3D printing processes move industry towards the latter. Assembly Automation, 2003. 23(4): pp. 340-345.

[5] Carneiro, O.S., A.F. Silva, and R. Gomes, Fused deposition modeling with polypropylene. Materials & Design, 2015. 83: pp. 768-776.

[6] Alsoufi, M.S. and A.E. Elsayed, How Surface Roughness Performance of Printed Parts Manufactured by Desktop FDM 3D Printer with PLA+ is influenced by Measuring Direction. American Journal of Mechanical Engineering, 2017. 5(5): pp. 211-222.

[7] Alsoufi, M.S. and A.E. Elsyeed, Warping Deformation of Desktop 3D Printed Parts Manufactured by Open Source Fused Deposition Modeling (FDM) System. International Journal of Mechanical and Mechatronics Engineering, 2017. 17(4): pp. 7-16.

[8] Alsoufi, M.S. and A.E. Elsayed, Surface Roughness Quality and Dimensional Accuracy – A Comprehensive Analysis of 100% Infill Printed Parts Fabricated by a Personal/Desktop Cost Effective FDM 3D Printer Materials Sciences and Applications, 2018. 9(1): pp. 11-40.

[9] Alsoufi, M.S. and A.E. Elsayed, Quantitative analysis of 0% infill density surface profile of printed part fabricated by personal FDM 3D printer International Journal of Engineering & Technology, 2018. 7(1): pp. 44-52.

[10] Joanne Ee Mei, T., et al., Multi-stage responsive 4D printed smart structure through varying geometric thickness of shape memory polymer. Smart Materials and Structures, 2017. 26(12):pp.125001.

[11] Hull, C.W., Apparatus for production of three-dimensional objects by stereolithography. 1986, Google Patents.

[12] Boschetto, A. and F. Veniali, Intricate shape prototypes obtained by FDM. International Journal of Material Forming, 2010. 3(1): pp. 1099-1102.

[13] Mostafa, M.A.G., M.S. Alsoufi, and B.A. Tayeb, CAD/CAM Integration Based on Machining Features for Prismatic Parts. International Journal of Emerging Trends & Technology in Computer Science 2015. 4(3): pp. 106-110.

[14] Li, G., et al., Ultrasonic strengthening improves tensile mechanical performance of fused deposition modeling 3D printing. The International Journal of Advanced Manufacturing Technology, 2018. 96(5): pp. 2747-2755.

[15] International Journal of Advanced Science and Technology Vol. 29, No. 6, (2020), pp. 3362 – 3371 ISSN: 2005-4238 IJAST Copyright ⓒ 2020 SERSC

[16] Chen, L., et al., The research status and development trend of additive manufacturing technology. The International Journal of Advanced Manufacturing Technology, 2017. 89(9): pp. 3651-3660.