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Original Research Article

Variation in Tensile Strength of 3D Printed PLA Parts by Varying Infill Density and Infill Pattern

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Abstract

3D printing has emerged as a transformative technology that has revolutionized various industries and unlocked endless possibilities in the world of Research and Development. 3D printing allows the fabrication of three- dimensional parts from computerized designs by utilizing additive manufacturing technologies. Its importance stems from its capacity to expedite prototyping, speed up production, and stimulate innovation in industries including as healthcare, manufacturing and aerospace. The main objective of this study is to analyze the mechanical behavior of 3 dimensional (3D) printed Poly-Lactic Acid (PLA) parts when their infill density and infill geometry are varied. We have taken 3 infill geometries (Grid, Triangle, Gyroid) at 4 different infill densities (40%, 60%, 80%, 100%), these parts are measured for tensile strength and optimal conditions are identified.

Keywords: Poly Lactic Acid (PLA), Fused Deposition Modelling (FDM), Infill Density, Infill Pattern, Tensile Strength, 3D Printing.

1. INTRODUCTION

In recent decades, the use of 3D printers has increased significantly, and this trend is anticipated to continue. By making it relatively simple to create complex and customized objects, 3D printers have revolutionized the manufacturing sector. They have found applications in various fields, ranging from prototyping and design to healthcare and aerospace. One of the most widely used 3D printing processes is fused deposition modelling (FDM). Many companies produce and market FDM printers, resulting in a wide availability of options for consumers. This has led to increased competition and subsequently reduced the cost of entry-level FDM printers.

In the first task the filament, which is typically a thermoplastic material on a spool, is unwound and fed into the 3D printer. This can be done manually or through an automated system. Motors power rollers that control the movement of the filament, ensuring a steady and controlled feed. Once the filament is fed into the printer, it passes through a heating element, often an electric resistance. The heat generated by the resistance melts the solid filament, converting it into a molten state. The molten filament is then extruded from a nozzle or an extrusion head. The extrusion head and printing bed are moved in the Cartesian plane by a mechanical system as the material is extruded, which consists of the X, Y, and Z axes.

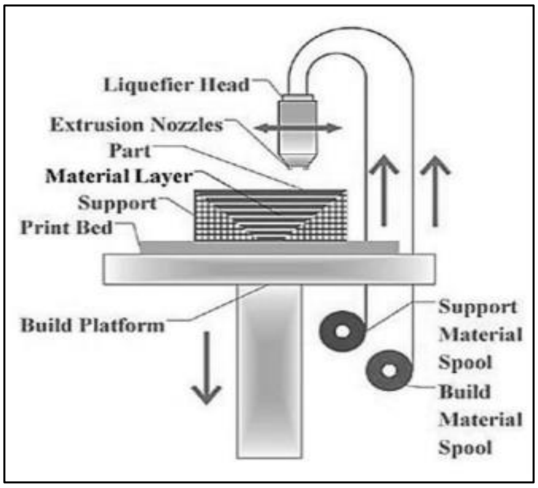

Fig. 1: Schematic of FDM 3D Printing

Numerous factors influence a 3D printed component's mechanical property, but the most important ones are listed below:

I) Infill density refers to the percentage of the object's inner volume that is filled with material during the 3D printing process. It determines the amount of material that is used to create the internal structure of the object, while the remaining percentage is occupied by air. When setting the infill density, you have the flexibility to choose a value between 0% and 100%, representing the extremes of a hollow item and a fully filled object, respectively.

II) The infill pattern is another crucial aspect of 3D printing that influences the structural stability and mechanical properties of the printed component. The infill pattern refers to the specific arrangement of the internal structure that fills the object's inner volume. Different infill patterns can be chosen.

III) The raster angle is the angle that controls how the material filaments inside an object are oriented.

IV) layer thickness, refers to the height or thickness of each individual layer that makes up a 3D-printed object. When printing a 3D object, the overall height of the object is divided into multiple layers, and the layer thickness determines the height of each of those layers.

V) The temperature of the material at the time of extrusion is referred to as the extrusion temperature.

The use of various thermoplastic filaments, such as ABS, PLA, and PETG, in Fused Deposition Modeling technique is indeed common. Due to its smooth printing capabilities, guarantee of mechanical properties, and biodegradability, PLA in particular has attracted considerable attention for 3D printing. However, one issue with PLA- based filaments is that the processing conditions have a significant impact on their properties, which affects its crystallinity. To achieve desired mechanical properties in 3D-printed PLA parts, it is crucial to identify suitable process parameters. This study aims to examine how 3D-printed PLA part's tensile strength measurements are affected by infill pattern and infill density.

2. PREPARATION OF SAMPLES

2.1 Specimen Creation According to the Test Standards

The main objective of the study is to analyse the connection between the mechanical nature of the created object and the properties of 3D printing related to it. Out of the various testing related to mechanical testing, only tensile test is conductible. SOLIDWORKS software is used to design the samples for tensile test. According to the ASTM D638 Type 1, the measurements of the specimen, Thickness (T) is 4mm, Overall width (W_O) is 19mm, Length of the gauge (G) is 50mm, Narrow portion length (L) is 57mm, Overall length (L_o) is 165mm, Grip's distance (D) is 115mm, Fillet radius (R) is 76mm, Narrow portion width (w_o) is 13mm.

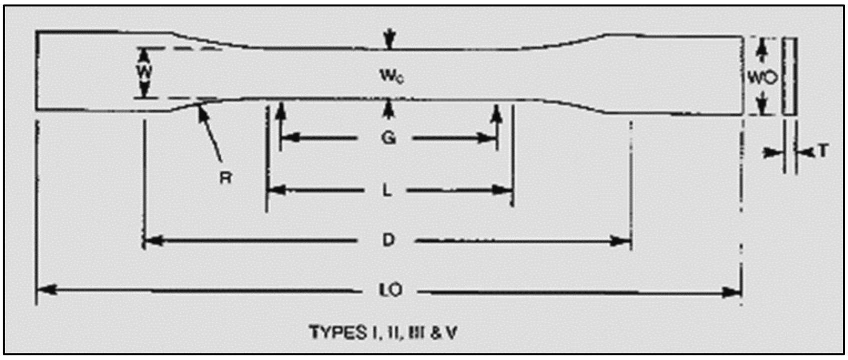

Fig. 2: Tensile test sample as per the ASTM D638 Type 1 [8]

2.2 Making of the Specimen

3D printed Poly-lactic acid test specimens are created with the help of Ultimaker printer. After keeping in mind, the infill density ranged from forty percent to hundred percent, along with the gyroid, triangular, grid infill pattern around twelve test specimens were created. These specimens were grouped to do tensile test measurements.

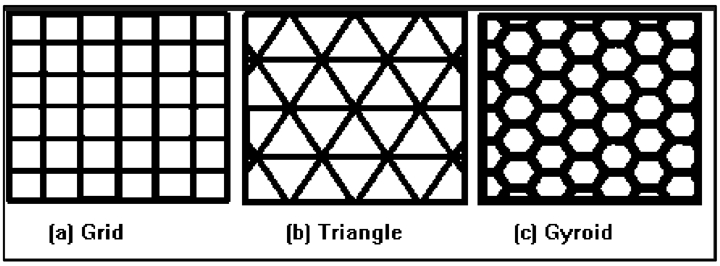

Fig. 3: Different Infill patterns used for making the specimens

2.3 Characterization

Build time is basically the time required for the completion of printing every specimen. UTM is used to characterize the 3D printed poly-lactic acid test specimens' tensile strength, according to the ASTM standard D638. The equation used to calculate tensile strength is;

Tensile Strength= Maximum load applied/Sample cross section area

3. RESULTS AND DISCUSSIONS

The 3D printed PLA specimen where subjected to uniaxial tension test and recorded in Table 1 and plotted against infill pattern and fill density.

Table 1: Tensile strength measurements of 3D printed PLA test samples

In-fill Density (%)	In-fill pattern	Tensile strength (MPa)
40	Grid	26.4
60	Grid	28.5
80	Grid	30.3
40	Gyroid	23.4
60	Gyroid	24.5
80	Gyroid	25.2
40	Triangle	21.3
60	Triangle	22.7
80	Triangle	23.9

Our results also showed us the relation of the variation in tensile property of the PLA test-samples and quality with respect to 3D printed in-fill patterns regardless of their in-fill densities. This can be inferred clearly that, the test- samples made with and in-fill density of 40% and grid in-fill pattern has comparatively better tensile property compared to those which had triangular & gyroidal in-fill patterns when the in-fill density is same. It should be noted that the grid pattern test-sample with 40% in-fill density exhibited a tensile property of 26.4MPa whereas those with triangular and gyroidal in-fill pattern indicated tensile property of 21.3 MPa and 23.4MPa at same in-fill density (40%).

Taking in account the previous findings, it obvious that the in-fill density has a measurable correlation with the tensile property of 3D printed PLA test-samples. The increase in in-fill density significantly caused an enhancement, (regardless of the in-fill pattern) the tensile properties of the 3D printed PLA Test-samples. Like in test-samples printed with in-filled grid pattern and 80% comparative density have indicated a superior tensile property than that of the parts produced with identical in-fill pattern but, 40% in-fill density. Likewise, test-samples with gyroidal in-fill pattern and triangular in-fill pattern have exhibited an improvement in tensile property with increment in in-fill density viz., grid in- fill pattern test-samples which were printed with 80% in-fill density resulted in tensile property of 30.3MPa and in test- sample with same grid in-fill pattern is 26.4MPa for 40% in-fill density.

This behaviour could be attributed to the test-sample's impedance towards tensile loads resulting from linear structure of the material flow of the grid in-fill pattern which resulted in improved product. The photograph of broken test test-samples is indicated point towards the fact that the test-samples with varied in-fill patterns and in-fill densities have dissimilar fracture surfaces. The linear grid pattern with greatest filling density test-sample offers greater impedance against applier loads due to when compared to shown greater contact than test-samples printed with another in-fill pattern. It can be noticed that in the test-samples with gyroidal pattern, the filled-in material is not collinear with the applied force direction.

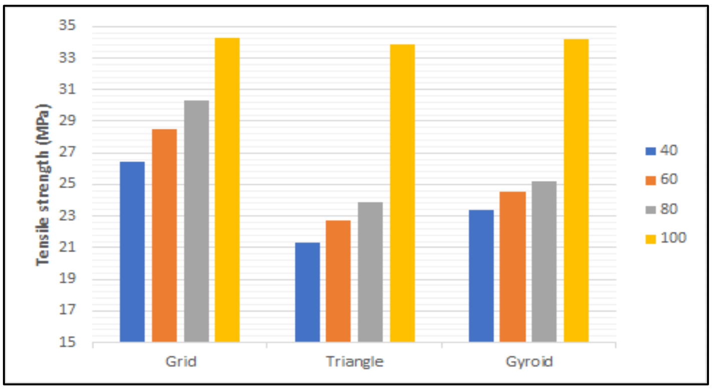

Fig. 4: Tensile strength measurements of 3D printed specimens against varying infill density

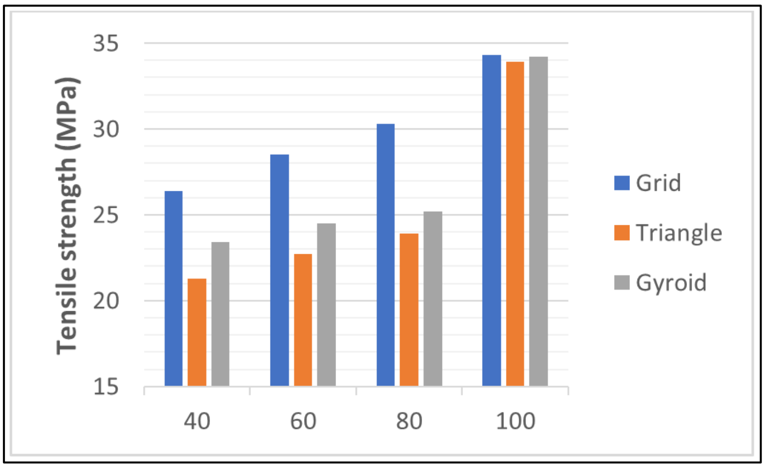

Fig. 5: Varying infill pattern and their corresponding tensile strength measurements

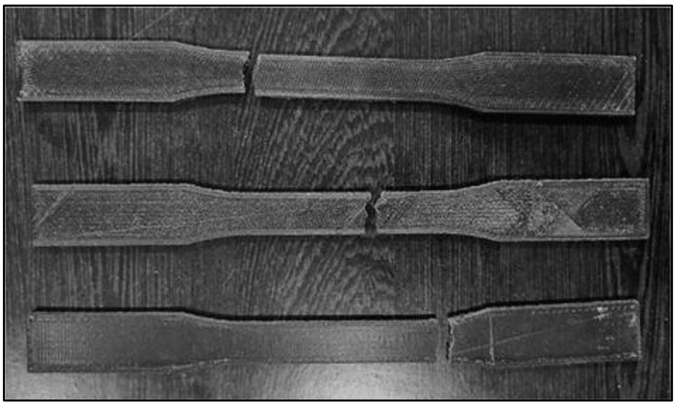

Fig. 6: Image of broken 3D printed tensile test samples [9]

CONCLUSION

The main takeaway points from the study of variation in tensile strength with changing infill pattern and density are as follows-

- Tensile strength increased with increasing infill density.
- Grid pattern offered maximum tensile strength as compared to other two.
- In the case of the grid pattern, the direction of the infill material when aligned to the direction of the applied tensile stress, provides better resistance when compared to the other two patterns discussed.

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REFERENCES

- Ambati, S. S., & Ambatipudi, R. (2022). Effect of infill density and infill pattern on the mechanical properties of 3D printed PLA parts. *Materials Today: Proceedings*, *64*, 804-807. ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2022.05.312.
- ASTM D638-14, Standard Test Method for Tensile Properties of Plastics, ASTM International, West Conshohocken, PA (2017). DOI: 10.1520/D0638-14
- Bellini, A., & Güçeri, S. (2003). Mechanical characterization of parts fabricated using fused deposition modeling. *Rapid Prototyping Journal*, *9*(4), 252-264. https://doi.org/ 10.1108/13552540310489631.
- Desta, A. (2019). Investigation on Production of Light Weight High Tensile Strength Concrete Using Sugarcane Bagasse Fiber. *Saudi Journal of Engineering and Technology (SJEAT)*, *10*. DOI:10.21276/sjeat.2019.4.3.5
- Dey, A., & Yodo, N. (2019). A systematic survey of FDM process parameter optimization and their influence on part characteristics. *Journal of Manufacturing and Materials Processing*, *3*(3), 64. https://doi.org/10.3390/jmmp3030064.
- Frazelle, J. (2021). Out-of-this-world additive manufacturing. *Communications of the ACM*, *64*(3), 58-62. https://doi.org/10.1145/3424254.
- MASAUD, Z., KHAN, M. Z., HUSSAIN, A., ISHFAQ, H. A., SONG, R. H., LEE, S. B., ... & LIM, T. H. (2021). Recent activities of solid oxide fuel cell research in the 3D printing

processes. *한국수소및신에너지학회논문집*, *32*(1), 11-40. https://doi.org/10.7316/KHNES.2021.32.1.11.

- Ngo, T. D., Kashani, A., Imbalzano, G., Nguyen, K. T., & Hui, D. (2018). Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. *Composites Part B: Engineering*, *143*, 172-196. https://doi.org/10.1016/j.compositesb.2018.02.012.
- Rahim, T. N. A. T., Abdullah, A. M., & Md Akil, H. (2019). Recent developments in fused deposition modeling-based 3D printing of polymers and their composites. *Polymer Reviews*, *59*(4), 589-624. https://doi.org/10.1080/15583724.2019.1597883.
- Wang, J., Xie, H., Weng, Z., Senthil, T., & Wu, L. (2016). A novel approach to improve mechanical properties of parts fabricated by fused deposition modeling. *Materials & Design*, *105*, 152-159. https://doi.org/10.1016/ j.matdes.2016.05.078.