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Experimental investigation and analysis of FDM operation parameters on tensile strength.

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Abstract - In the feild of fast prototyping, 3D printing is seeing a stream in popularity thanks to its ability to quickly produce a wide range of complex shapes and structures. This production technique employs a computer-aided design (CAD) blueprint to generate a tangible prototype. It works by layering material to build the prototype. A major benefit of this approach is its sucessfullness in creating convoluted parts with little to no material being wasted. There are numerous methods for rapid prototyping on the market, with fused deposition modeling (FDM) standing out as a favorite. The predictable of 3D printed items made from PLA (Polylactic Acid) are shaped by different process settings and the material's inherent properties. In this study, the effect of condemnatory process settings, like layer thickness, volume fill, and printing rate, on the material's mechanical strength was investigated. The results specify that a higher volume fill resulted in greater tensile strength, where as lowering the printing rate and decreasing layer thickness improved the material's mechanical strength. The experimental results were compared to those forecast by ANSYS.

Key Words: FDM, Additive Manufacturing, 3D Printing, PLA, CAD.

INTRODUCTION

Fused Deposition Modeling (FDM) shines as a favored and environmentally friendly method of additive manufacturing (AM). It's widely used in both the consumer and industrial realms for the creation of intricate 3D objects, as depicted in Figure 1, which shows the various parts of an FDM printer that work together to quickly produce components with little waste of material and tools. The process starts with the design and development of the model using computer-aided design (CAD) software. Afterward, the file must be converted into a format that the FDM 3D printer can understand. This conversion typically involves the use of the standard triangle language (STL) and specialized software is needed to transform the CAD file into STL. Next, stepper motors move the material, in the shape of a solid filament, through the nozzle. The material is heated by the extruder to a specific temperature, causing it to melt, and it is then placed onto the platform. The material cools quickly and sticks to the platform. Subsequently, the printer follows a numerical G-code sequence in a layer-by-layer manner, repeating this step until the object is finished.

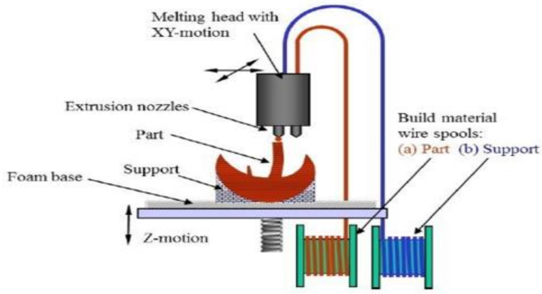


Figure 1: components of Fused Deposition Modeling printers

A variety of substances, including low-temperature metal alloys and composites, can be utilized in FDM, but the primary materials for this technique are thermoplastics and polymer-based composites. The success of creating a product with desirable mechanical characteristics is linked to factors such as the orientation of the build, the pattern and density of the infill, the temperature of the nozzle, the size of the nozzle, the rate at which the printing is done, and the thickness of each layer. Inadequate conditions and low temperatures can lead to problems during the printing process, such as warpage and shrinkage. It's important to mention that determining the elongation at break, Young's modulus, and tensile strength is essential for improving the mechanical properties of isotropic and anisotropic engineering plastics. One of the challenges of the FDM method is the need for support structures to prevent material droppings and to reduce gaps for better adhesion. However, these support structures can affect the surface texture and the quality of the areas where supports are placed, making them appear rough and of lower quality. Another issue with FDM-printed parts is the staircase effect, which occurs due to the way layers bind together.

LITERATURE REVIEW

Ahn et al [1]. Examined the experiment design and determined that the design of the experiment, including the air gap and raster pattern orientation, influences the tensile strength of the part produced through FDM processes, while the width of the raster pattern, the temperature of the model, and the color do not significantly impact it. They also conducted a comparison between the tensile strength of FDM parts created at various raster pattern angles and air gap versus those produced using injection molding techniques. The material used for both fabrication methods is ABSP400. FDM parts with a no air gap have a tensile strength range from 10% to 73%, peaking at 0° and dipping to minimum at 90° in the direction the load is applied. However, parts with an air gap show a notable increase in tensile strength at certain raster pattern angles but still remain less than the strength of injection molded parts. Out of all the specimens, only one, with a mixed order of layers' raster angles ranging from 45° to -45°, broke in the transverse direction. This specimen's failure occurred at a 45° direction. An analysis of the specimens made with the axis of the part perpendicular to the table versus those made parallel to the table found that the parts made perpendicular showed less compressive strength. From these findings, it was determined that the tensile strength of FDM parts is directional, meaning its strength varies in different directions.

Mohammad Hossain et al[2]. The objective was to enhance the tensile mechanical strength of parts created through FDM by tweaking the FDM processing settings. The settings are set by the user through Insight, the software used for preparing files for most FDM devices. Despite Insight seeming to suggest that the roads should be uniformly laid and connected, a visual inspection of the material showed that the roads were not always properly connected, creating gaps that weakened the mechanical strength. Hence, this study details the tensile mechanical strength characteristics of samples created using three different sets of parameters: the default or standard parameters, the Insight's version-specific parameters, and an approach that relies on visual feedback. Comparing the samples created with the default approach to those made using visual feedback in some cases showed an impressive improvement in the ultimate tensile strength, reaching up to 19% higher than the standard parameters. Future research could explore the impact of the orientation of the build and the thickness of the layers on the mechanical strength of FDM parts. However, increasing layer thickness could potentially reduce the build time. While the visual feedback method does help to minimize gaps, it does not fully eliminate them, suggesting that further tests could be done to understand how eliminating air gaps affects the density of the samples.

S.H.Masood et[3] al. Fused deposition modeling (FDM) stands out as a leading technology in additive manufacturing for a variety of engineering needs. It was first made available for commercial use in the early 1990s by Stratasys Inc., a company based in the USA. The quality of parts produced through the FDM method is largely influenced by the precise selection of its process variables. Therefore, it's crucial to pinpoint the FDM process parameters that have a significant impact on the quality of the parts created. Over the past few years, researchers have investigated numerous strategies to enhance the mechanical characteristics and quality of the parts by employing different experimental design methodologies and principles. This paper intends to summarize the research conducted to date in identifying and refining the process parameters of the FDM method.

Rapid Prototyping Techniques

Most commercially available rapid prototyping machines use one of six techniques. At present, trade restrictions severely limit the import/export of rapid prototyping machines,

1 Selective Laser Sintering:
2 Stereolithography (SL)
3 Fused Deposition Modelling (FDM):

Fused Deposition Modelling (FDM):

Fused Deposition Modeling (FDM) was first introduced by Stratasys, located in Minnesota, USA. It involves extruding a fine material through a nozzle that's in a semi-liquid state, which is then spread across a base. This nozzle is positioned in both the X-Y plane to create a thin, layered cross-section of the component. With each layer that's extruded, it adheres to the layer below it, causing it to solidify. The base is then lowered in relation to the nozzle, and the process is repeated, adding another layer on top of the previous one. Another nozzle is utilized to extrude a different material to construct support frameworks for the component as necessary. Once the component is finished, the support frameworks are removed from it.

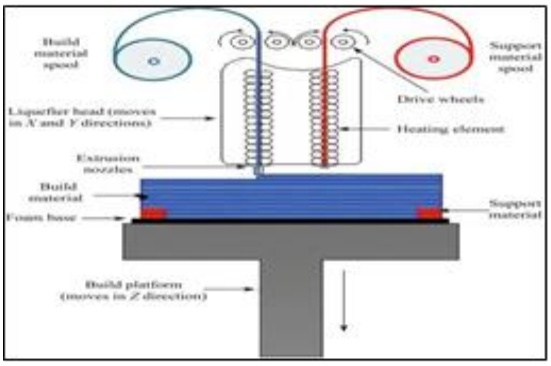


Figure 2. Principle of Fused Deposition Modeling process

This technology involves 3D printing, which employs a device equipped with a computer-operated nozzle to create an ongoing thread of plastic. On a bigger scale within industrial machinery, this process takes place within an environment that's tightly regulated, maintaining a precise temperature and conditions. Yet, in cheaper 3D printers, acieving such accuracy isn't practical.

Applications of fused deposition modeling (FDM).

•Production of prototypes for testing purposes in terms of size and function

•Creation of parts made from materials that have been deemed suitable by regulatory bodies for aerospace applications

•The ability to apply surface coating to ABS parts

•Production of small quantities of items for high-volume but low-cost manufacturing projects

•Creation of parts that are more economical to produce

METHODOLOGY

Design of Specimen

For specimen preparation, the CAD files of a dog-bone tensile specimen by Type I of ASTM D638 standard40 were modelled in CATIA software and exported as STL format. The imported file then was converted to the STL file to be able to be readable by the FDM machine. The process parameters such as layer thickness, volume infill, and print speed were considered for different combinations. All other process parameters such as shell thickness, print temperature, diameter of filament and nozzle size were kept constant for all samples which their values were listed in Table1. These parameters were selected from the recommendations of 3D printer manufacturer and our experiences about the quality of different 3D printed specimens with good mechanical strength. The specimens were printed and selected for further analysis.

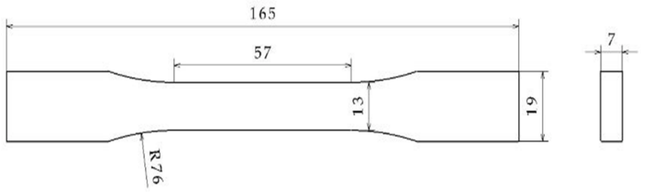


Figure 3 a: Dimension of the specimen as per standards.

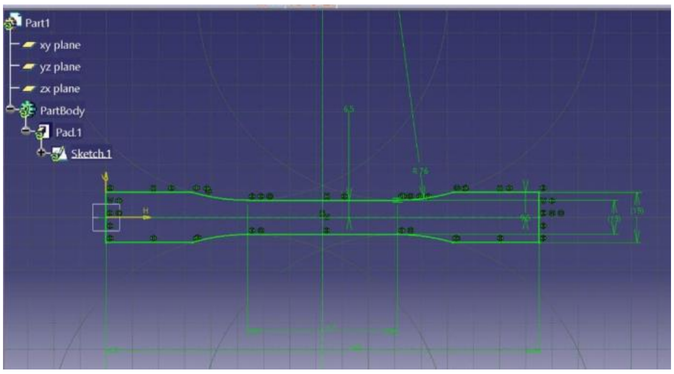


Figure 3 b: CAD representation of Specimen.

Sample preparation process

The permanence of parts made from PLA is influenced by several factors. In this research, three factors that could be adjusted were identified: the thickness of the layers, the amount of material used between each layer (also known as infill density), and the rate at which the printing is done. These factors were varied during the experiments. The parts were made using a Global 3D Pramaan 3D printer. The setup for each set of factors included layer thickness options of 0.1 mm and 0.2 mm, infill densities of 10% , 20% and 30%, and print speeds of 20mm/sec and The specific setups for the factors are detailed in Table 1.

Table 1: Design of Experiments of specimen

S. No	Sample	Infill density (%)	Print speed (mm/sec)	Layer Thickness (mm)
1	Sample 1	10	20	0.1
2	Sample 2	20	20	0.2
3	Sample 3	30	20	0.3

Experimental Procedure

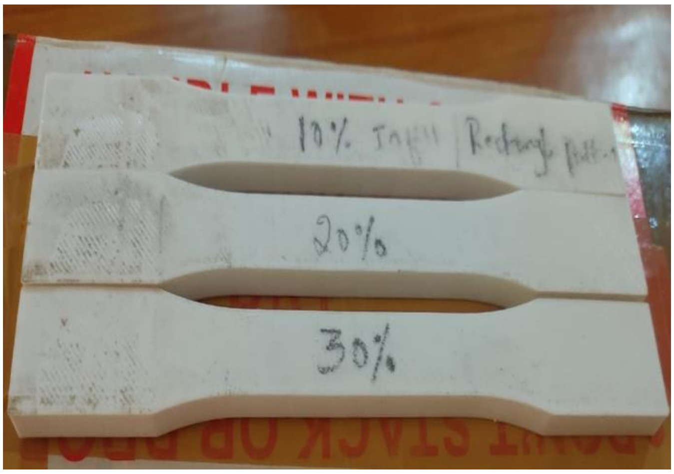
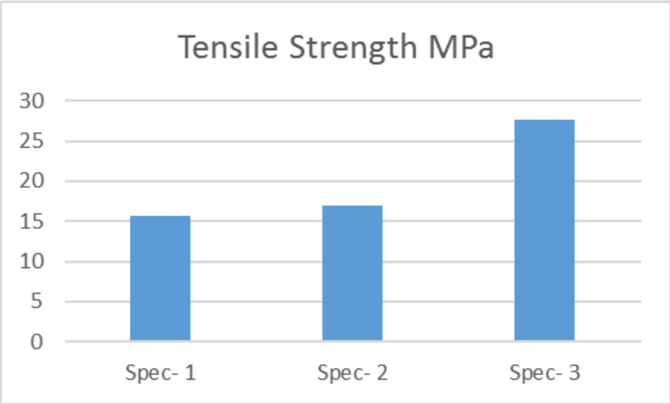


Figure 5: Tensile Testing Specimen

After the samples were made, they were put to the test. To carry out these experiments, a standard testing device (STD) was used to check the materials' ability to withstand stretching and compression. Stiffness is one of the most important physical properties often tested. For the stretch test, the parts needed followed the guidelines set by the American Standard for Testing and Materials (ASTM) D638, a standard designed to measure the stretching properties of thermoplastics. The sample materials were shaped like dumbbells for this test.

Table 2: Tensile testing results.

Sl.No	Sample Name	Elongation (mm)	Tensile Strength MPa	Young's Modulus MPa	Peak Load N
1	Spec- 1	1.633	15.653	1034.61	623.6
2	Spec- 2	2.43	16.965	950.27	692.5
3	Spec- 3	2.6	27.601	1065.25	849.1



Graph 1: Tensile strength of specimens

Analyzing by Finite Element Analysis

To more accurately understand how structural modifications, affect test results, we incorporated simulations with our experimental work. In this case, we employed the finite element method (FEM) for analysis. The material was considered uniform and isotropic, relying on stable engineering parameters such as Young's modulus and Poisson's ratio, which were calculated from data from tensile tests. The strategy involved breaking the problem into smaller, more solvable components through linear functions and tetrahedron elements, ensuring a solution's rapid convergence through analysis. All required preliminary tasks, like generating 3D models, establishing boundary conditions, and segmenting the model into triangles, were finished with ANSYS, an effective tool for these tasks. A conventional uniaxial testing simulation was then carried out under different stress conditions. In this process, one end of the specimen was secured, and the other end was subjected to a stress applied per unit area.

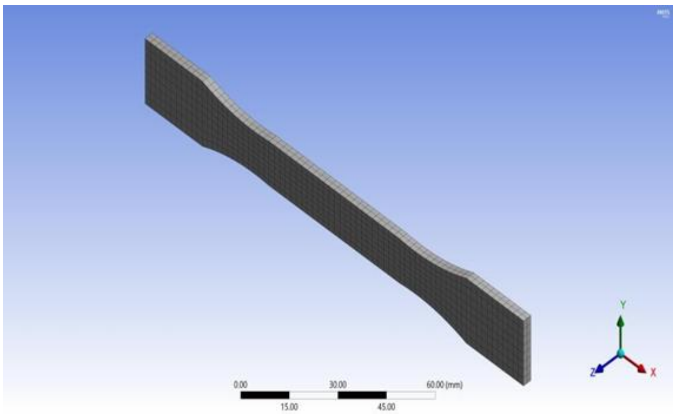


Figure 6: Mesh model of the specimen

Table 3: Simulated results Ansys.

Sample	Deformation mm	Equ Stress MPa	Max Principal Stress MPa	Min Principal Stress MPa	Equ Elastic Strain
1	2.1242	16.622	20.281	4.3368	0.01591
2	2.5371	18.459	22.452	4.816	0.01988
3	2.7263	22.633	27.529	5.9051	0.02124

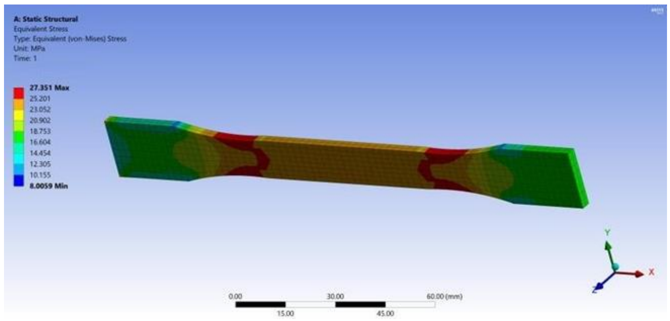


Figure 7: maximum deformation by Ansys.

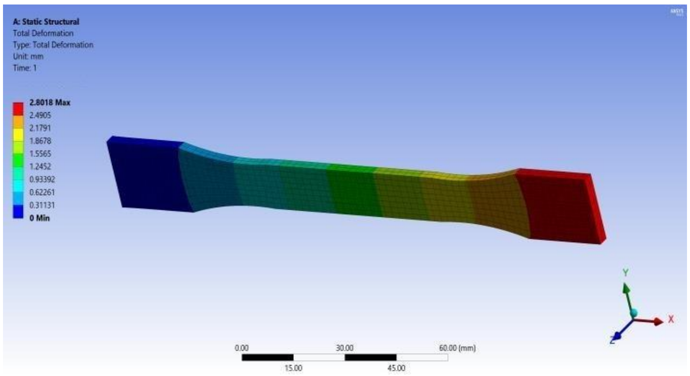


Figure 8: Maximum Stress by Ansys.

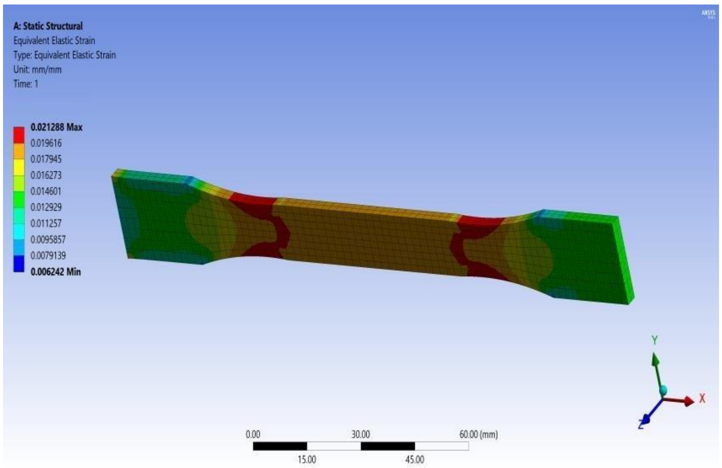


Figure 9: Maximum strain by Ansys.

CONCLUSION

This research first looked into how the parameters of the FDM process, such as layer thickness, volume fill, and printing speed, affect the PLA material. Additionally, tensile strength tests were carried out. The locating showed that the ideal setup demands a layer thickness of 0.3 mm, a volume fill of 30%, and a printing speed of 20mm/s. Among these parameters, the highest tensile strength was achieved at 27 MPa. Subsequently, the result in outcomes were compared with the predictions generated by ANSYS simulations. The simulated data closely aligned with the actual experimental results.

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BIOGRAPHIES

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