A Review Paper on Analysis of Layer Thickness of 3D Printed Plastic Parts

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Abstract — Fused Deposition Modelling (FDM) in Additive Manufacturing (AM), has emerged as a versatile and efficient production method, enabling the fabrication of complex geometries with minimal material waste and reduced post-processing. This study investigates the influence of two key FDM process parameters printing speed and layer thickness on the mechanical behaviour of 3D printed components made from ABS and PLA. Standard tensile test specimens were modelled as per ASTM D638 Type 1 and printed using varying parameter combinations. The objective is to analyse the effects of these settings and to compare findings with trends reported in earlier research. Previous studies have demonstrated that parameter selection plays a important role in determining the mechanical properties of 3D printed parts. For instance, ABS samples printed in the axial direction with a 0.3 mm layer thickness exhibited improved tensile strength compared to those printed in the lateral direction, where void formation was more prevalent. Other research focused on optimizing printing temperature and infill density to enhance the tensile performance of ABS parts, especially in automotive applications, using ASTM D638 standards for evaluation. Additionally, studies incorporating design of experiments approaches found that mechanical behaviour can be significantly affected by combinations of infill pattern, layer thickness, and infill density, where gyroid patterns and fine layers showed enhanced strength characteristics. Unlike broader investigations that explore multiple parameters simultaneously, this study focuses solely on printing speed and layer thickness to offer a more detailed and controlled analysis. By incorporating both ABS and PLA materials and comparing results with previously published work, the study seeks to contribute to the understanding of parameter-specific behaviour in FDM printing and support future efforts in process optimization for functional and load-bearing applications.

Keywords: 3D Printing, ABS+, PLA+, UGNX, UTM, FDM

I. INTRODUCTION

Traditional manufacturing includes subtractive processes, where material is removed from a larger block; forming processes, which reshape materials through applied force; and casting, in which materials are melted and poured into molds. Additive manufacturing (AM), also known as 3D printing, introduces a fourth paradigm—building parts layer by layer from digital models [3].

Additive manufacturing has rapidly evolved since its introduction in the 1980s, especially in the past two decades. It is now widely used across industrial, educational, and consumer domains [18], [3]. AM processes, particularly Fused Deposition Modeling (FDM), offer unprecedented design freedom, often described by the phrase "complexity is free." This enables the creation of intricate geometries that would be difficult or impossible using traditional methods [10]. However, this complexity comes at a cost, especially when optimizing parameters such as printing speed, infill density, temperature and layer thickness. These factors significantly impact both mechanical performance and cost efficiency [5], [14].

FDM is currently the most accessible and widely used 3D printing method due to its simplicity, affordability, and compatibility with a range of thermoplastics including PLA, ABS, PC, and PEEK [3], [13]. In FDM, a filament is heated and extruded through a nozzle, depositing material layer by layer to form a 3D object. This process is controlled by G-code instructions, which guide the printer in forming each layer and positioning support structures. The technology relies on slicing software that converts CAD models into STL files and further processes them into printable layers [4].

Among the materials used in FDM, Acrylonitrile Butadiene Styrene (ABS) has a prominent role. It is favored for its high impact resistance, good mechanical properties, and ability to withstand elevated temperatures, making it ideal for engineering applications [22], [6]. ABS also offers excellent surface finish and chemical resistance, though it is sensitive to polar solvents. Its broad processing window makes it suitable for various manufacturing techniques such as extrusion, injection molding, and blow molding [20].

Despite these advantages, FDM-printed ABS components often show inferior mechanical properties compared to parts produced via injection molding. This is primarily due to weak interlayer adhesion. Several studies have investigated how FDM parameters influence mechanical properties. For example, variations in printing temperature, layer thickness, and build orientation have been shown to significantly affect tensile strength and surface quality [1], [9], [19]. Researchers have used Design of Experiments (DoE) and Taguchi methods to systematically evaluate the effects of these process variables on mechanical performance [14], [19].

In practical applications, such as the Silesian Greenpower project, FDM was employed to print lightweight automotive components like mirror housings and fairings. These use cases illustrate the real-world potential of 3D printing in reducing weight and customizing parts for performance [18].

The aim of this research is to investigate the mechanical properties of ABS components fabricated using the FDM process. Specifically, it focuses on how key printing parameters—such as layer thickness, print speed, and extrusion temperature—influence tensile and compressive strength. This study not only contributes to optimizing the mechanical performance of 3D-printed parts but also supports the broader goal of making additive manufacturing a competitive alternative to conventional methods in engineering applications.

II. OBJECTIVES:

The project focuses on optimizing the mechanical performance of 3D printed plastic parts by adjusting key printing parameters: layer thickness, printing speed, and printing temperature.

Identifying the best combination of these parameters is essential for improving strength, durability, and surface quality of the printed parts.

Two commonly used materials, ABS+ and PLA+, are selected to study how material choice influences the performance under varying printing conditions.

III. METHODOLOGY

A. Design Phase:

The ASTM D638 Type 1 tensile test specimens were designed using Siemens NX (UGNX) CAD software. The dimensions were maintained as per the ASTM D638 Type 1 standard to ensure compatibility with conventional testing equipment. Once the design was completed, it was exported in STL format, which is widely accepted by 3D printing software. The STL file was then carefully checked for errors such as gaps, overlaps, or inaccuracies to ensure it was ready for the slicing process.

B. Slicing Phase

The verified STL file was imported into slicing software such as Cura or Prusa Slicer. Within the software, printing parameters including layer height, infill density, print speed, and nozzle temperature were configured according to the specific requirements of the chosen material—ABS, ABS Plus, or PLA. Following this configuration, the slicing software generated a G-code file containing all necessary machine instructions. A preview of the G-code was reviewed to ensure the layer-by-layer structure was accurate and free from potential errors that could affect print quality.

C. 3D Printing Phase

An FDM (Fused Deposition Modelling) 3D printer was used for fabricating the specimens. Prior to printing, the printer was calibrated to ensure accuracy in output, including proper bed levelling and nozzle alignment. The appropriate filament ABS, ABS Plus, or PLA was loaded into the printer, and a preliminary extrusion test was conducted to verify smooth and consistent material flow. Specimens were then printed either individually or in batches, depending on the printer's capacity. After printing, the parts were allowed to cool and were carefully removed from the build plate to avoid warping or other forms of deformation.

D. Testing Phase

The printed specimens were subjected to tensile testing using a Universal Testing Machine (UTM), following the guidelines provided by ASTM D638 standards. During testing, critical mechanical properties such as ultimate tensile strength, yield strength, and elongation at break were recorded. These values provided insight into the material performance of each printed specimen.

E. Data Analysis

The data obtained from the tensile tests were analyzed to evaluate the mechanical and physical properties of the 3D-printed specimens. A comparative assessment was performed for ABS, ABS Plus, and PLA materials to determine their respective performance characteristics. Furthermore, the influence of FDM printing parameters on these properties was studied to understand how changes in process settings affect the final part quality.

F. Conclusion and Optimization

Based on the experimental results and observations, several recommendations were developed to improve the overall performance of 3D-printed parts. These included suggestions related to design adjustments, material selection strategies, and optimization of printing parameters. The insights obtained through this methodology contribute to a better understanding of how to enhance mechanical performance and support the wider adoption of FDM technology in engineering applications.

IV. TOOLS/ PLATFOTM

The design, fabrication, and testing of 3D-printed plastic parts rely on an integrated approach involving advanced software tools, additive manufacturing hardware, and mechanical testing equipment. Each phase of this process—ranging from design to evaluation—requires specific platforms to ensure accuracy, standardization, and the reliability of experimental results.

A. Siemens NX (UGNX) for Design and Modelling

Siemens NX (UGNX) is a powerful Computer-Aided Design (CAD) software widely employed in mechanical and product design. In this study, UGNX was used to create the ASTM D638 Type 1 tensile test specimens, ensuring precise dimensional accuracy in accordance with ASTM standards. The software offers robust tools for geometric modelling, enabling the development of detailed and printable 3D designs. Upon finalizing the model, it was exported as an STL file—an industry-standard format for 3D printing that represents the object's surface geometry as a mesh of triangles. UGNX also ensures the generation of clean, error-free STL files, thereby minimizing the chances of defects during the slicing and printing stages.

B. Slicing Software for 3D Printing (KISslicer)

Once the STL model is created, it must be processed by slicing software such as Cura, PrusaSlicer, or KISslicer. These tools convert the 3D model into G-code, which contains the sequential commands needed by the 3D printer to build the part layer by layer. During this phase, critical parameters like layer thickness, print speed, nozzle temperature, and infill density are configured based on the selected printing material. The slicing software also provides visual previews of the build process, allowing for the identification of potential errors and optimizing material use and part strength. The quality and consistency of this stage directly influence the mechanical performance of the printed specimens.

C. 3D Printer for Fabrication

Fused Deposition Modelling (FDM) was the selected method for fabricating the ASTM D638 Type 1 specimens using thermoplastic materials such as ABS, ABS Plus, and PLA. In FDM, the filament is heated to its melting point and extruded through a nozzle, depositing the material layer by layer as per the G-code instructions. The reliability of the printing process depends on several factors, including accurate nozzle calibration, consistent filament feed, and proper bed levelling. Careful attention to these parameters ensures dimensional precision, uniform layer adhesion, and overall part quality. The FDM technique is widely accepted for its cost-effectiveness, accessibility, and ability to produce functional prototypes and test specimens.

D. Testing Equipment for Mechanical and Physical Analysis

After fabrication, the printed parts underwent mechanical and physical testing to determine their structural integrity and suitability for engineering applications. The Universal Testing Machine (UTM) was employed to perform both tensile and compression tests. For tensile testing, the specimen was gripped at both ends and pulled until failure, with the UTM recording properties such as yield strength, tensile strength, and elongation at break. In compression testing, the same machine was used to apply axial loads, enabling the measurement of compressive strength and deformation characteristics. These evaluations help assess the material's mechanical behaviour under different loading conditions and contribute valuable data for comparative analysis of the different thermoplastics used.

V. IMPLEMENTATION

A. Design of ASTM D638 Type 1 Specimen

The design of the ASTM D638 Type 1 specimen was carried out using Siemens NX (UGNX) CAD software, chosen for its precision in creating complex geometries. The goal was to design a specimen that would effectively capture the tensile properties of 3D-printed PLA+ and ABS+ materials while adhering to ASTM standards.

B. Selection of the ASTM D638 Standard

The ASTM D638 Type 1 specimen was selected due to its widespread use in tensile testing of plastics. Its dog-bone shape ensures consistent stress distribution during testing, making it ideal for evaluating the mechanical properties and characteristics of 3D-printed materials.

C. CAD Modelling and Geometry

The specimen was modelled in Siemens NX with exact compliance to ASTM D638 dimensions. Key design features included symmetrical geometry, fillets at the ends to reduce stress concentration, and flat gripping surfaces to ensure stable placement in the Universal Testing Machine (UTM).

D. Orientation and Layering Considerations

The specimen was designed for vertical printing, with layers deposited perpendicular to the direction of tensile loading. Layer heights of 0.25 mm, 0.35 mm, and 0.45 mm were selected to assess the effect of layer thickness on mechanical strength, with finer layers expected to improve bonding between layers.

E. Exporting the Model for 3D Printing

Once the design was finalized, it was exported as an STL file for slicing in software like Cura or PrusaSlicer. Printing parameters such as layer height, infill, and temperature were configured, and G-code was generated to guide the 3D printer.

F. Final Design Adjustments

Minor adjustments were made to the model after initial print tests to improve printability and ensure proper fit within the UTM grips. These refinements ensured that the printed specimens adhered to ASTM specifications and would perform reliably during testing.

VI. RESULT

Table No. 1 represents the reference data taken from Hind B. Ali et al. (2022), showing the effects of different infill patterns, infill densities, and layer thicknesses on the mechanical properties of 3D-printed ABS. It includes values for ultimate tensile stress and Young's modulus, highlighting that the GYROID pattern with 60% infill and 0.05 mm layer thickness achieved the highest strength and stiffness.

Layer Thickness (mm)	Infill density (%)	Infill pattern	Tensile strength (MPa)	Young's Modulus (GPa)
0.05	20	ZIGZAG	23.8	2.153
0.05	40	CROSS	25.3	2.130
0.05	60	GYROID	27.0	2.473
0.15	20	CROSS	24.4	2.175
0.15	40	GYROID	26.2	2.184
0.15	60	ZIGZAG	29.1	2.236
0.25	20	GYROID	25.6	2.276
0.25	40	ZIGZAG	28.3	2.274
0.25	60	CROSS	31.0	2.148

Table 1: Results from Hind B. Ali et al. (2022)

Layer Thickness (mm)	Printing direction	Tensile Strength (MPa)	Young's Modulus (GPa)
0.1	Axial	30.5	2.01
0.2	Axial	28.24	1.86
0.3	Axial	30.60	2.2
0.1	Lateral	14.22	0.93
0.2	Lateral	18.24	1.21
0.3	Lateral	19.42	1.28

Table 2: Results from S.T. Dwiyati et al

As shown in Table 2, the tensile strength of specimens varied significantly with changes in layer thickness and print orientation. At a layer thickness of 0.1 mm, the axial and lateral orientations recorded tensile strengths of 30.50 MPa and 14.22 MPa, respectively, indicating a substantial improvement when the print path aligns with the load direction. This observation is consistent with the findings of S.T. Dwiyati et al., who reported that tensile strength tends to increase when layers are oriented parallel to the applied load. When the layer thickness was increased to 0.2 mm, tensile strengths dropped slightly to 28.24 MPa (axial) and 18.24 MPa (lateral), but the axial orientation continued to show better mechanical performance. At 0.3 mm layer thickness, the tensile strength values were 30.60 MPa for axial and 19.42 MPa for lateral orientation. These results, as detailed in Table 2, clearly demonstrate that axial orientation consistently delivers superior tensile strength, and that orientation has a more pronounced effect on strength than layer thickness alone, supporting the trends reported by Dwiyati et al.

VII. Conclusion

The study demonstrates that both print orientation and layer thickness significantly influence the tensile strength of ASTM D638 Type II specimens. Axial orientation consistently provides higher tensile strength compared to lateral orientation across all tested layer thicknesses, confirming the critical role of layer alignment with the loading direction. While tensile strength tends to decrease slightly with increasing layer thickness, the effect of print orientation is more pronounced. These findings are consistent with those reported by S.T. Dwiyati et al., who emphasized the importance of layer orientation on tensile strength. Additionally, comparison with the reference data from Hind B. Ali et al. (2022) shows that optimized infill patterns, such as the gyroid structure combined with fine layer thickness and higher infill density, can further improve mechanical properties beyond what is achieved by orientation and layer thickness alone. Therefore, future research should focus on combining layer thickness, print orientation, and infill pattern optimization to maximize the strength and durability of 3D-printed parts.

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