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Investigation and analysis of infill pattern and layer thickness on tensile strength of PLA and PETG material in 3D printing

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Abstract

Increased customization and design freedom, decreased waste, quicker prototyping, and the creation of challenging profile forms are all made possible by additive manufacturing (AM)8. In 3D printing, the printing parameters have a direct impact on the mechanical strength of the final product. This study examined the impact of various infill configurations (Grid, Rectilinear, Honeycomb), infill densities (15 %), and material (PLA, PETG) and layer thickness (0.1 mm, 0.2 mm) in that sequence. According to experimental research, at every infill pattern and layer thickness, the honeycomb infill pattern exhibits a higher tensile strength than the grid and rectilinear infill pattern. The tensile strength of honeycomb infill geometry is stronger when the layer thickness is 0.1mm,

Keywords: 3D Printing; Infill Pattern; Infill Density; Layer Thickness; Tensile Strength

1. Introduction

In addition to creating new avenues and opportunities for us, technologies have improved our lives in many ways [1]. However, it sometimes takes a while—sometimes even generations—before the truly disruptive nature of technology is apparent. Additive manufacturing (AM), also known as 3D printing, is widely believed to have enormous potential for integration with these technologies [2]. Recently, a wide range of media entities, including major newspapers, television stations, and websites, have covered the issue of 3D printing. But what is this "3D printing" that some claim would destroy traditional manufacturing as we know it, revolutionize design, and have an impact on our daily lives in geopolitical, economic, social, demographic, environmental, and security ways? Being an additive manufacturing process is one of the most basic characteristics that distinguishes 3D printing from other manufacturing techniques [3,4,5]. And this is unquestionably the most crucial element since three-dimensional printing is a whole new production method based on state-of-the-art technology that builds components in an additive fashion by stacking them at submillimetre sizes [6,7]. Many applications cannot tolerate the limitations imposed by traditional design and production techniques. One of the limitations of traditional manufacturing methods is the need to assemble complex components and the reliance on expensive tools and fixtures. Additionally, during production processes such as milling, up to 90 percent of the original block of material can be wasted. In contrast, three-dimensional printing, commonly known as 3D printing, directly creates objects by layering material in various ways, depending on the technology used [8,9,10]. To better understand 3D printing, one can compare it to the process of assembling something mechanically with Lego pieces. This analogy can help clarify the concept for those who may still be struggling to grasp it.

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Any three-dimensional printing process starts with creating a 3D digital model. Various 3D software packages can be used for this purpose; in the production sector, this is referred to as 3D CAD (Computer-Aided Design) [11,12]. However, there are simpler and more accessible applications available for Makers and buyers. Another option is to use a 3D scanner to capture a physical prototype and convert it into a digital model. Once the model is ready, it is divided into layers, generating a file that the 3D printer can interpret. The printer then constructs the object by stacking the material according to the design and printing process [13,14]. There are several 3D printing techniques, each utilizing a distinct set of processes to create a final product from various raw materials. In modern industrial prototyping and production environments, materials such as sand, metals, ceramics, and versatile polymers are commonly employed. Additionally, research is currently being conducted on 3D printing with different types of food and biomaterials. However, at the entry level of the market, the available materials are often much more limited. The most widely used materials today are plastics, particularly ABS and PLA, but there is an increasing variety of alternatives, including nylon [15,16]. The main objective of this work is to examine how the direction of material deposition, the infill structure, and the infill density impact the tensile properties of specimens printed using Fused Deposition Modeling (FDM) [17,18,19]. This study incorporates experimental results from the PLA material, focusing on aspects such as maximum tensile strength, failure mechanisms, and deformation tendencies, drawn from various sets of experiments.

2. Material and Process parameters.

PLA (Polylactic Acid) and PETG (Polyethylene Terephthalate Glycol) are both popular thermoplastics used in 3D printing,The PLA and PETG wire filament used to create the printing specimens for this study and is commercially available. The table below outlines the properties of the PLA and PETG material provided by the manufacturer, along with the filament itself. PLA, or polylactic acid, is a biodegradable thermoplastic polymer made from renewable resources such as sugarcane and maize starch.

PLA is particularly well-suited for Fused Deposition Modeling (FDM) operations due to its outstanding dimensional stabilityAdditionally, PLA is more cost-effective and durable than ABS. The infill pattern is used to create the internal structure of an object where necessary. There are many geometrical patterns available, including rectilinear, linear, concentric, and hexagonal. When selecting an infill pattern, several factors should be considered, such as personal preference and how much filling the item and its material can handle. More complex infill patterns will require longer printing times and more material. This study focused on the two most popular infill patterns: tri-hexagonal and triangular shapes.

Table 1 PLA filament properties

Properties	**Value**
Melting point	190-220 °C
Melt flow index	7.8 g/10 min
Tensile yield strength	62.63 MPa
Elongation at break	4.43 mm
Flexural strength	65.02 MPa
Impact strength	4.28 J/m2

Due to its versatility and ease of printing, PETG is a very useful thermoplastic printing medium. Many 3D printing businesses and private individuals utilize it for their printed models or parts because of its adaptability. Many people use PETG because of its smooth surface quality, simplicity of printing, and hygroscopic nature.

Table 2 PETG filament properties

Properties	**Value**
Melting point	210-230 °C
Melt flow index	20-30 g/10 min
Tensile yield strength	40-60 MPa

Elongation at break	Between 18 -80%
Flexural strength	50-77 MPa
Impact strength	2.473- 3.1J/m^2

3. Experimental work and sample Preparation

To assess the tensile strength of PLA and PETG materials with different infill geometries, rectangle shaped samples were created using Fused Deposition Modeling (FDM) under various conditions. After designing the rectangle structure in SolidWorks, the model was exported as an STL file into the 3D printing software. The dimensions of the specimen are illustrated in the following graphic. In each scenario regarding infill pattern and thickness layer, two different material were evaluated. The table below lists the various combinations used in the trials. Several process parameters were taken into account during the manufacturing of the rectangle structure using FDM, even while operating the 3D printer. An overview of the processing parameters considered during the FDM printing process is provided in the following table.

Table 3 Constant parameters

Parameters	Value
Filament Diameter	0.75 mm
Modelling process	FDM
Layer height	0.1 mm
Infill density	15%
Raster angle	0 degree
Nozzle diameter	0.25 mm
Nozzle temperature	225 degrees
Printing speed	30 mm/s
Printing bed temperature	65 degrees
Room temperature	25 degrees
Relative humidity	50 (%RH)

Table 4 Process parameters and their levels

Parameter		Level 1	Level 2	Level 3
1	Infill pattern	Grid	Rectilinear	Honeycomb
2	Layer thickness	0.1 mm	0.2 mm	-
3	Material	PLA	PETG	-

Figure 1 displays three different infill patterns: (a) grid, (b) rectilinear, and (c) honeycomb. The object layer is printed in 90-degree crossing lines by the grid pattern, which form a 45-degree angle with regard to the specimen's axial axis. The object layer is printed using the honycomb pattern in three distinct path directions, each of which rotates by 120 degrees. Thirty degrees is the smallest travel angle relative to the specimen's axial axis.

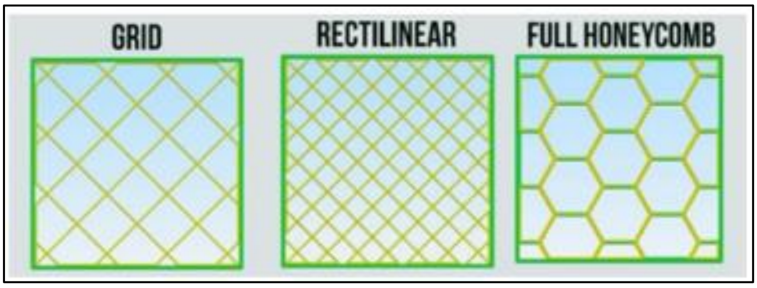

Figure 1 Selected Infill patterns

The Anycubic i3 Mega extruder was used to print the specimens which is as shown in figure 2. The printing melting temperature of the 1.75 mm PLA filament is between 190°C and 230°C. 210°C was chosen as the printing temperature for the specimen. As seen in figure 3 below, the specimens' dimensions complied with ASTM D638-Type I. Anycubic slicer an open-source slicer program, was utilized to manage the printing parameters.

Figure 2 3D printing machine with filament

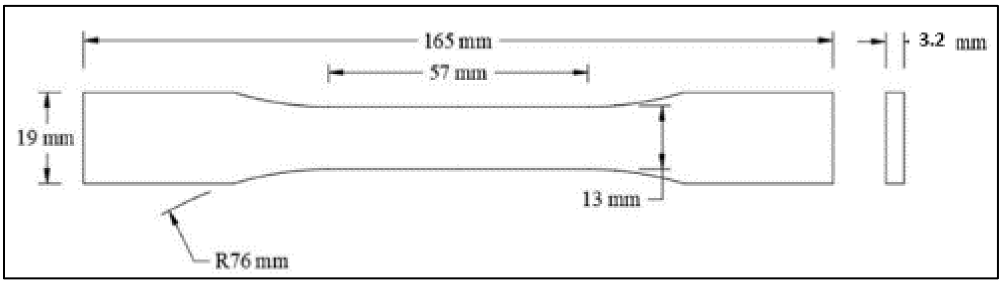

Figure 3 The 2D geometric specification

Previous research has established the impact of infill density on specific materials. However, to our knowledge, no one has examined how different infill geometries affect the mechanical properties of FDM-printed components. This study investigates the effects of various infill pattern shapes on different types of materials. For this process, we focused on PLA and PETG material in FDM printing. The project aimed to examine how different infill pattern affect the properties of 3D-printed materials. Infill densities of 15% were considered. Additionally, three infill pattern for material deposition were evaluated for each infill 15% density. To assess the impact of these varying orientations, the ASTM D628-1 standard, which outlines a method for evaluating the tensile strength of plastics, was followed during the production of each sample.

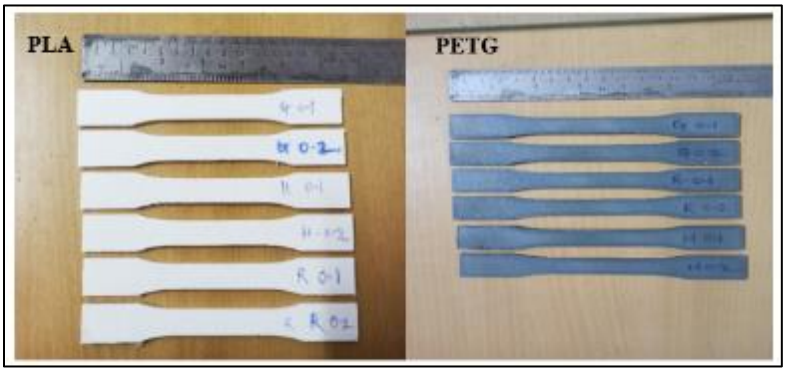

Figure 4 Tensile specimen at 15% infill density for PLA and PETG material.

3.1. Tensile testing

A tensile test was conducted on the FDM-printed specimens after they were prepared. Unidirectional tensile testing was performed using the Electronic Control Panel Series Universal 2020 (UTE) make FIE. The strain rate for the tensile tests was consistently set at 0.1 s^-1 for all specimens. The tests were divided into three distinct sets, each arranged according to the shapes and forms of the infill material. The two sets used for the tensile testing of the FDM materials are illustrated in the following image.

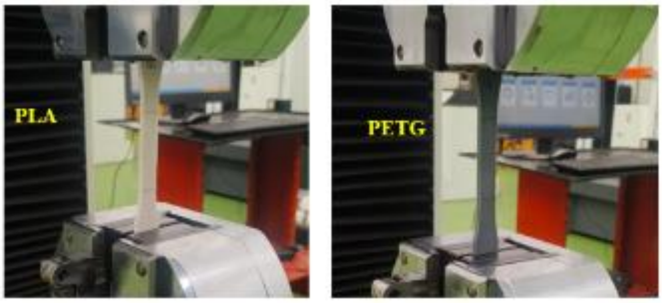

Figure 5 Tensile setup used for testing.

4. Result and Discussion

This study focused on infill pattern and layer thickness on two different material PLA and PETG. The strength of the component is affected by both the infill pattern and the layer thickness of material deposition.

Table 5 and 6 provides a summary of the test results for the twelve combinations, and Figure 4 plots the data. Tensile strength are the values displayed; they were taken from the average measurement values of each combination of the two specimens that were evaluated in accordance with ASTM standard.

Table 5 Tensile strength at layer thickness 0.1mm.

Material	**Layer thickness 0.1 mm**		
	Grid pattern	**Rectilinear**	**Honeycomb**
	Tensile strength (MPa)	**Tensile strength (MPa)**	**Tensile strength (MPa)**
PLA	26.68	26.827	27.452
PETG	28.101	28.918	31.827

Table 6 Tensile strength at layer thickness 0.2mm**.**

Material	**Layer thickness 0.2 mm**		
	Grid pattern	**Rectilinear**	**Honeycomb**
	Tensile strength (MPa)	**Tensile strength (MPa)**	**Tensile strength (MPa)**
PLA	21.912	21.340	22.239
PETG	23.976	24.327	27.713

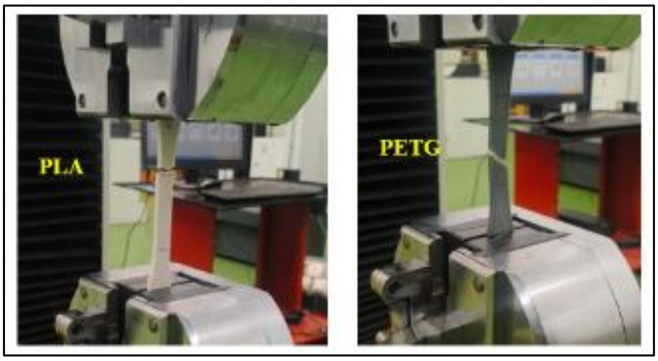

Figure 6 Sample brake at tensile strength

The accompanying image illustrates the sample brake at various load condition of PLA and PETG material. We investigated how varying infill pattern and layer thickness influenced the performance of the material structure during tensile testing. The following graphics illustrate the tensile strength curves for PLA and PETG material.

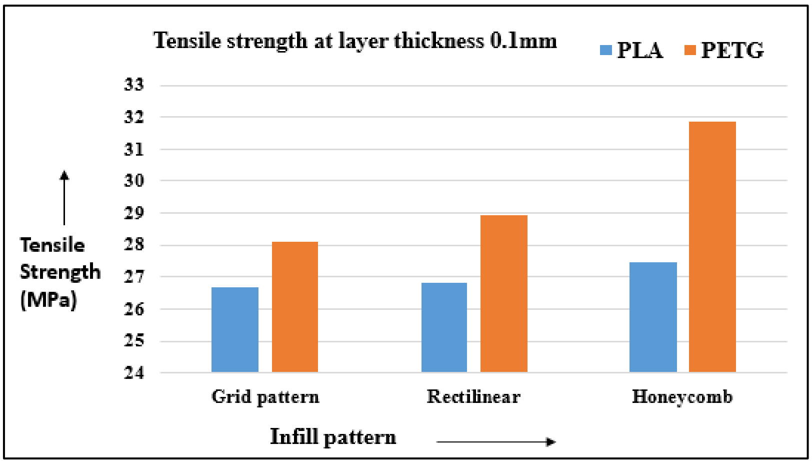

Figure 7 Tensile graph for 15% infill density with layer thickness 0.1mm

A Honeycomb infill pattern for material PETG demonstrates the highest tensile load, followed by rectilinear infill pattern for PETG material, as indicated by the graph PETG material gives better tensile strength as compared to PLA material. In contrast, the grid pattern exhibits the lowest tensile load among all orientations with PLA material. Specifically, the Honeycomb infill pattern and 15% infill density has a maximum tensile strength is 31.827 MPa, while Grid pattern with PLA material gives lowest tensile strength 26.68 MPa at 0.1mm layer thickness.

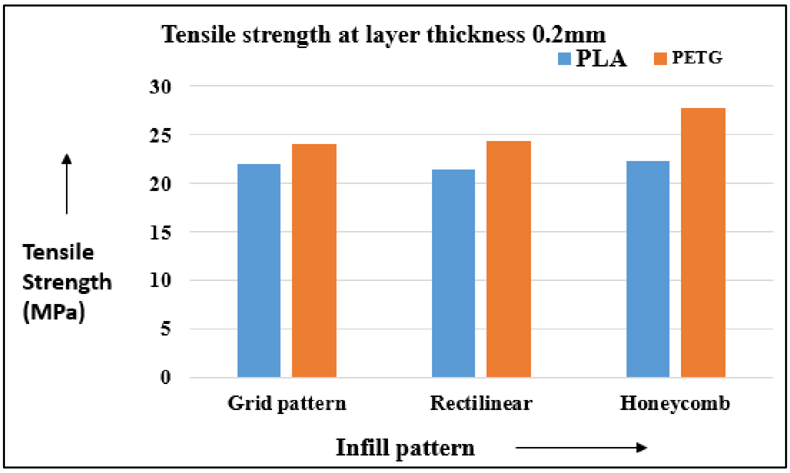

Figure 8 Tensile graph for 15% infill density with layer thickness 0.2mm

A Honeycomb infill pattern for material PETG demonstrates the highest tensile load, followed by rectilinear and grid infill pattern shows near about same value for PLA material, as indicated by the graph PETG material gives better tensile strength as compared to PLA material. In contrast, the Grid pattern exhibits the lowest tensile load among all orientations with PLA material. Specifically, the Honeycomb infill pattern and 15% infill density has a maximum tensile strength is 27.713 MPa, while Rectilinear pattern with PLA material gives lowest tensile strength 21.340 MPa at 0.2mm layer thickness. Additionally, the strength of the PLA and PETG tensile specimens improves when the layer thickness id decreased from 0.2 mm to 0.1 mm.

5. Conclusion

Layer thickness, infill geometry, and material deposition direction significantly affect the tensile characteristics of FDM-printed components. Experimental investigations have shown that a honeycomb infill structure offers greater tensile strength compared to grid and rectilinear infill structure. Furthermore, when using honeycomb infill pattern, layer thickness 0.1 mm with PETG material is stronger than PLA material. Decreasing the layer thickness for both material enhances the strength of the FDM-printed component.

Compliance with ethical standards

Disclosure of conflict of interest

There is no conflict of interest.

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