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Impact of infill pattern and line width on tensile strength of PLA FDM 3d printing

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ABSTRACT

Mechanical properties of Fused Deposition Modelling (FDM) 3D-printed products are a top priority in prosthesis manufacturing. Damage to 3D-printed products is often caused by the low mechanical strength when subjected to loading. Many parameters can influence the strength of the printed product during the process, including the infill pattern and line width. The infill pattern and line width serve as benchmarks for product quality, making it important to understand the impact of printing parameters to achieve optimal product strength. This study aims to analyze the mechanical properties of 3D-printed products through tensile testing with variations in infill pattern and line width. The method used to determine the mechanical properties is tensile testing. The tensile test samples were made using a Creality Ender 3 Pro 3D printer. The printing parameters were varied with three patterns: cubic, line, and triangle, as well as two infill line widths: 0.4 mm and 0.5 mm. The tensile test results showed significant differences in the variations of infill pattern and line width. The highest tensile strength was obtained with the line pattern and 0.5 mm line width, with an average tensile strength of 28.85 MPa, while the lowest value was observed with the cubic pattern and 0.4 mm line width, with an average of 27.63 MPa. These findings can serve as a valuable reference in the printing of prosthetic products using FDM 3D printing.

Keywords: Infill pattern; infill line width; polylactic acid; 3D printing

1. INTRODUCTION

The development of manufacturing technology has created competition in producing products with increasing speed and dimensional accuracy. Conventional production processes using machine tools are becoming less popular and are falling behind. The lengthy process and the generation of a lot of material waste are the main reasons why this technology is being abandoned. Advanced industries have developed technology capable of quickly producing prototypes with minimal waste. This technology is known as additive manufacturing (AM). AM can create products by gradually adding layers of material, and the most commonly used method in this process is 3D printing [1].

There are several 3D printing technologies, such as Digital Light Processing (DLP), which offers high printing accuracy with resin materials widely used for printing dentures [2]. However, the type of 3D printer that is most popular due to its ease of use and low cost is Fused Deposition Modelling (FDM). This device is used in manufacturing technology with thermoplastic materials. The capability of FDM 3D printing is that it can produce complex geometric parts according to its virtual 3D design [3]. The filament materials commonly used in 3D printing are polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) [4]. PLA filament has a lower working temperature compared to ABS. Additionally, PLA is considered environmentally friendly, making it more widely preferred.

Prostheses are assistive devices used to replace moving body parts such as legs and arms. These parts may be damaged or lost due to injury, amputation, or congenital conditions. Prosthetics are assistive tools for patients with special needs, such as prosthetic legs. A prosthetic leg is an artificial limb typically made from resin and usually produced through simple casting methods or conventional techniques. The use of 3D printing methods for making prosthetic legs is still not widespread, so 3D printing machines can serve as a new alternative in the production of prosthetic limbs [5].

The production process using 3D printing technology converts CAD data into a 3D object using rapid prototyping techniques. This method heats the thermoplastic filament to its melting point, then extrudes it through a nozzle layer by layer until a 3D object is formed. The strength of 3D-printed objects is highly influenced by the printing parameters [6]. Several printing parameters have been analyzed by previous researchers [7], [8]. The use of 3D printing for prosthetic manufacturing must consider the mechanical strength of the printed object to ensure it does not pose a risk to patients [9]. The printing parameters used in prosthetic manufacturing must be precise. Previous research has scarcely addressed the combination of printing patterns and infill line width. Therefore, in-depth research is needed to determine the optimal printing parameters for prosthetic manufacturing.

This study aims to analyze the influence of infill pattern and infill line width on the tensile strength of FDM 3D printed objects. The patterns used are cubic, line, and triangle, while the infill line widths are 0.4mm and 0.5mm. Samples are printed using a 3D printer and then subjected to tensile testing according to ASTM D638 Type-I standards. The results of this study can be used to print prosthetic legs with optimal strength.

2. METHOD

This study used an experimental method. The process of sample preparation through to tensile testing is illustrated in Figure 1. The research began with the 3D design of the sample using SolidWorks. The samples were shaped according to the ASTM D638 Type I standard [10], as shown in Figure 2. The design was saved as an STL file and then sliced using Cura-Ultimaker software. Printing parameters, such as infill pattern and infill width, were set in this software. The Cura-Ultimaker software generated G-code files, which were then transferred to the 3D printer for the printing process. The printed samples were subsequently subjected to tensile testing.

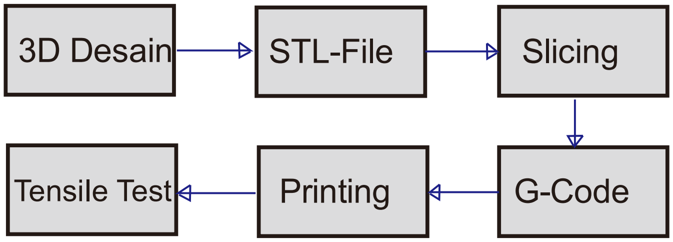

Figure 1. Sample preparation process

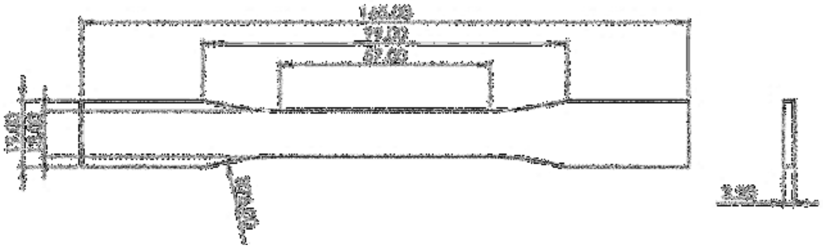

Figure 2. Shape and dimensions of the specimen (ASTM D638 Type- I)

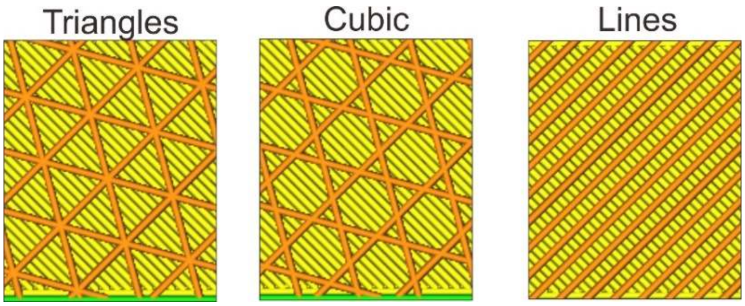

Figure 3. Variations in printing patterns

Variations in printing patterns are shown in Figure 3. The chosen printing patterns were line, cubic, and triangle, with each pattern having three samples at infill widths of 0.4 and 0.5 mm. These patterns were commonly used in the printing process. The 3D printer used was the Ender 3 Pro. This study employed thermoplastic filament made of PLA, with a filament diameter of 1.75 mm and a printing temperature of 200ºC. Tensile testing was conducted using a Hung-Ta brand machine controlled by a computer, with a pulling speed of 5 mm/min.

3. RESULTS AND DISCUSSION

The effect of infill line width with different variations is shown in Figure 4. The difference in infill line width affects the printing time and the amount of filament required. For an infill line width of 0.4 mm, the time needed to print a line pattern was 35 minutes, whereas an infill line width of 0.5 mm required 29 minutes. This time difference is an important consideration in the production process using a 3D printer. Figure 5 shows the average tensile strength results of different printing patterns and infill line widths. The analysis indicates that there is an effect of pattern variation on mechanical properties [11], [12], [13]. The results show that the line pattern has an advantage in tensile strength. The graph in Figure 5 indicates that the highest tensile strength result was obtained with an infill line width of 0.5 mm and a line pattern, with a value of 28.85 MPa, while the lowest tensile strength result was found with an infill line width of 0.4 mm and a cubic pattern, with a value of 27.63 MPa. For the triangle pattern, at both 0.4 mm and 0.5 mm infill line widths, the average tensile strength showed the smallest difference compared to other patterns. In this case, a smaller infill line width increases tensile strength, while the printing pattern affects the direction of filament arrangement, thereby influencing tensile strength.

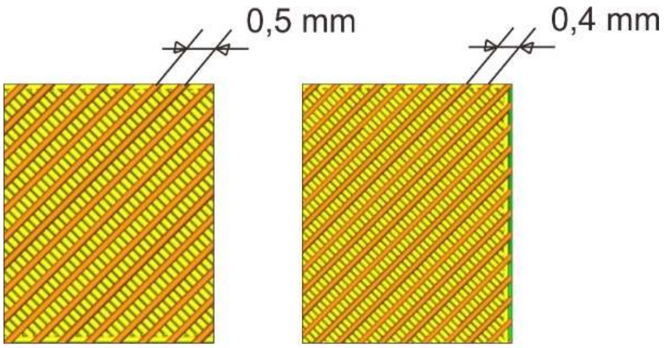

Figure 4. Variations in infill line width

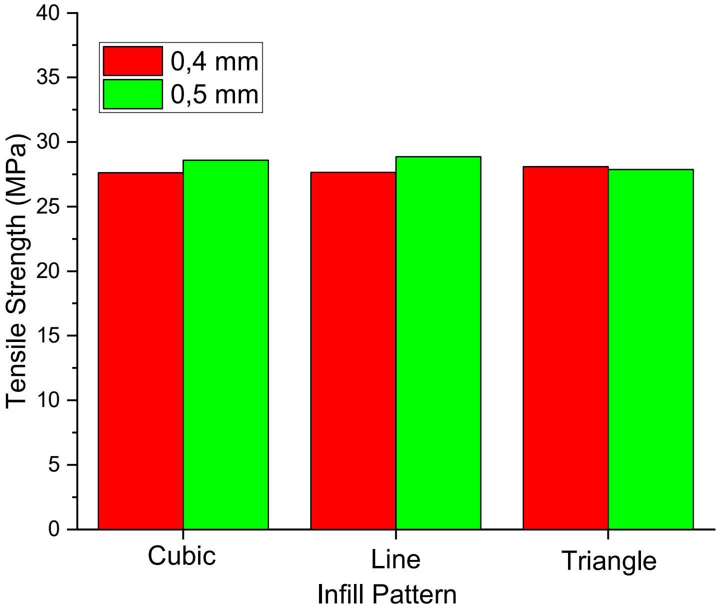

Figure 5. Differences in tensile strength values of samples

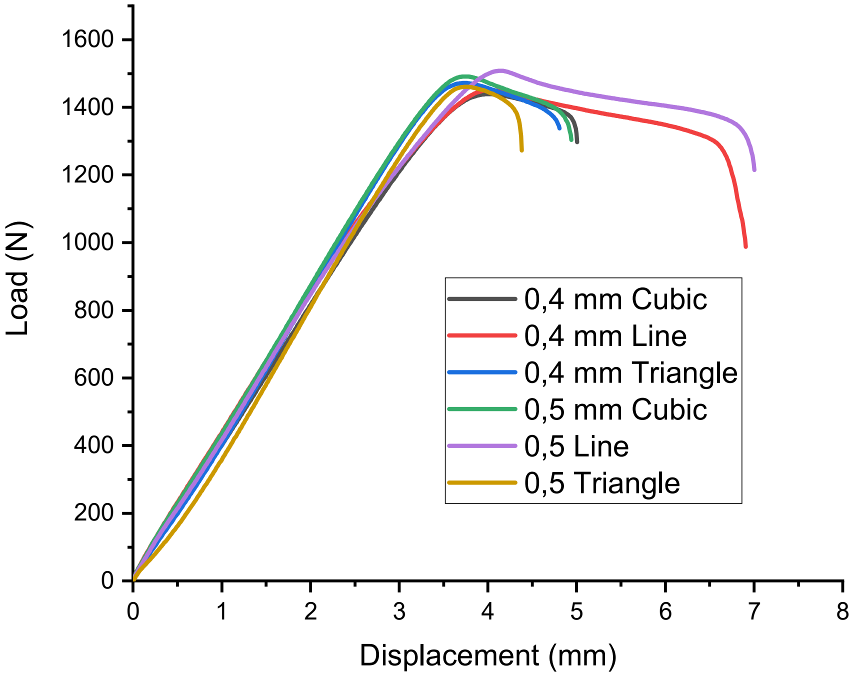

Figure 6. Results of load vs. displacement testing

Figure 6 shows the results of load vs. displacement testing, where the sample with a line pattern and an infill line width of 0.5 mm exhibited the highest load-bearing capacity compared to other samples. Additionally, this sample had the greatest extension before failure due to tensile loading. The sample with a line pattern and an infill line width of 0.4 mm also showed nearly the same high extension. This indicates that the line pattern samples have high strain values. In prosthetic applications subject to both static and dynamic loading, the line pattern is more advantageous compared to other patterns. Conversely, the triangle pattern showed the lowest extension, making it less suitable for prosthetic legs. Figure 7 indicates that the strain in the line pattern reached approximately 14%, whereas the strain in the triangle and cubic patterns was around 10%.

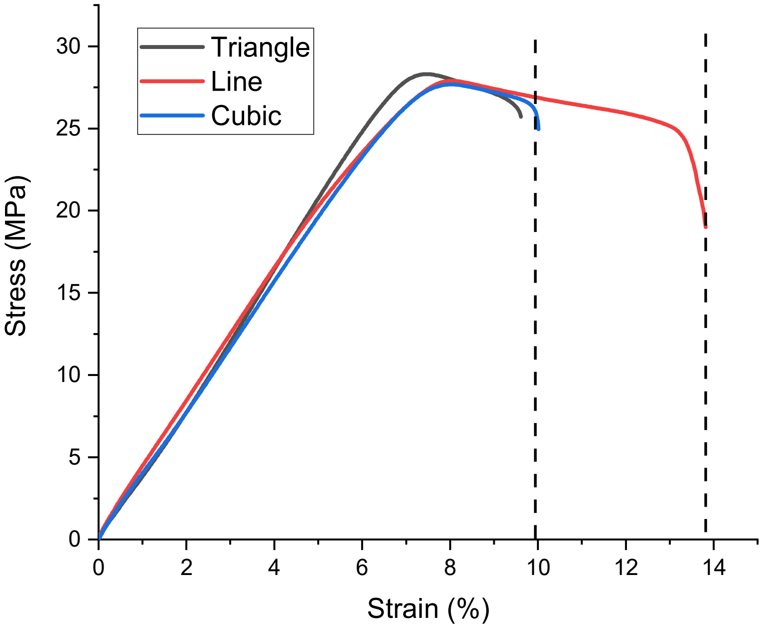

Figure 7. Stress vs Strain for infill pattern variations

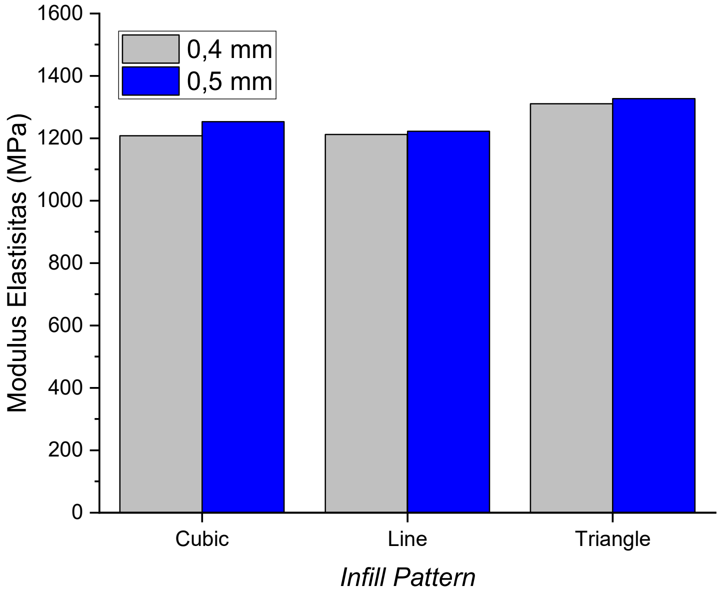

Figure 8. Differences in sample elastic modulus

Figure 8 shows the average elastic modulus from tensile testing. The results indicate that the highest elastic modulus was observed with an infill line width of 0.5 mm and a triangle printing pattern, with a value of 1326.598 MPa, whereas the lowest elastic modulus was found with an infill line width of 0.4 mm and a cubic pattern, with a value of 1208.121 MPa. From the tensile testing results, it can be concluded that 3D printing can be used for the production of prosthetic legs or arms, considering the pattern and line width to enhance tensile strength. Improvements in print quality can be achieved through post-processing treatments such as annealing [14], [15], [16].

4. CONCLUSION

Tensile testing on 3D printing samples with variations in infill patterns and line widths has been conducted. Based on the analysis, it was concluded that the highest tensile strength was found in the infill line pattern with an infill line width of 0.5 mm, with an average tensile strength value of 28.85 MPa. The lowest tensile strength was observed in the infill cubic pattern with an infill line width of 0.4 mm. The uniform direction of the line pattern results in higher tensile strength. The highest elastic modulus was found in the triangle pattern with an infill line width of 0.5 mm. The highest strain was observed in the line pattern with an infill line width of 0.5 mm. These research findings can serve as a reference for printing with FDM 3D printers for prosthetic production.

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