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# MECHANICAL TESTING OF 3D-PRINTED PLA SPECIMENS WITH DIFFERENT INFILL PATTERNS FOR HEALTHCARE APPLICATIONS

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## ABSTRACT:
Polylactic acid (PLA), a thermoplastic poly-ester made from renewable resources, finds frequent applications in healthcare and packaging industries. Additive manufacturing processes have transformed the production of medical devices, such as orthopaedic splints, owing to reduced costs, and customization. Varying the infill patterns and density of 3D-printed devices have high influences on the strength, flexibility, weight, and comfort. Alter the 3D printing parameters also helps minimize material use and cost while enhancing durability and improving stress distribution. In the proposed study, four infill patterns like Grid, Gyroid, Tri-hexagon, and Honeycomb are examined. PLA samples are 3D printed using Fused Deposition Modelling (FDM) with these varying patterns. The mechanical properties of the printed samples are evaluated in accordance with ASTM standards D638, D695, and D256 for tensile, compressive, and impact tests respectively. The aim is to assess the contributions of these infill patterns to material strength, ductility, and energy absorption from mechanical testing. These findings aim to guide the optimization of infill parameters for PLA in healthcare applications. This work underscores the potential of 3D printing to revolutionize healthcare by enabling cost-effective, lightweight, and custom solutions tailored to individual needs.
**Keywords**: 3D printing, additive manufacturing, polylactic acid (PLA), infill patterns, mechanical testing, healthcare applications.

## INTRODUCTION:
3D printing, a prominent additive manufacturing technology, has transformed the production of thermoplastic and biocompatible materials. Its layer-by-layer fabrication process allows for the creating intricate geometries that are otherwise impossible to achieve with traditional manufacturing methods. Among the various 3D printing techniques, Fused Deposition Modelling (FDM) stands out due to its simplicity, cost-effectiveness, and ability to produce functional components across industries such as healthcare, automotive, and aerospace [1][6][12].
Poly(lactic acid) (PLA), a biodegradable polymer derived from renewable resources like corn starch, is notable for its eco-friendly properties, biocompatibility, and mechanical stability. PLA is widely utilized in healthcare applications, including implants, sutures, and tissue scaffolds, owing to its ability to degrade safely within biological systems [2].
The mechanical performance of 3D-printed components is heavily influenced by the infill pattern, which defines the internal structure of the printed parts. This parameter directly affects strength, weight, and material efficiency, making the selection of an appropriate infill pattern crucial for applications that require durability and optimized performance [3][4][5].

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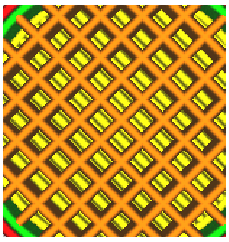
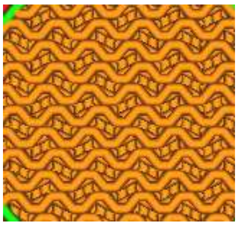
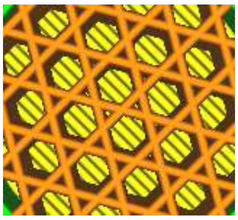
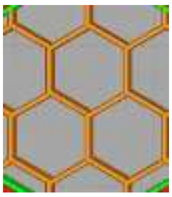
**EXPERIMENTAL WORK:**

The challenge lies in identifying the optimal infill pattern that can balance mechanical performance with material usage and printing time. There is a lack of comprehensive data on how different infill patterns affect the impact resistance. This gap necessitates systematic experimentation to provide insights into the mechanical behaviour of 3D-printed specimens with various infill patterns.

**SELECTION OF INFILL PATTERN:**

Four distinct infill patterns were chosen for evaluation based on their structural characteristics and potential impact on mechanical properties:

Table 1. Selected infill pattern

| | PATTERN | REASON |
|---|---|---|
| Grid |  | • Features a simple square structure, providing uniform strength distribution and reduced printing time.<br>• It balances mechanical strength with material efficiency, making it ideal for general-purpose applications. |
| Gyroid |  | • Features a simple square structure, providing uniform strength distribution and reduced printing time.<br>• It balances mechanical strength with material efficiency, making it ideal for general-purpose applications. |
| Tri-hexagonal |  | • Combines triangular and hexagonal geometries to enhance load distribution and improve structural stability.<br>• Ideal for components subjected to compressive and flexural loads. |
| Honeycomb |  | • Inspired by natural hexagonal designs, efficiently distributes loads while minimizing material usage.<br>• Widely used in weight-sensitive applications requiring energy absorption and strength. |

Selecting grid, gyroid, tri-hexagon, and honeycomb structures for this study, because these geometries are often chosen for their unique properties, practical applications, and ability to fulfill certain functional criteria. Each structure offers an exceptional balance of mechanical performance, material efficiency, and manufacturability, making them ideal for comparative studies.

**D-PRINTING:**

The specimens were designed following ASTM standards for mechanical testing, specifically ASTM D638 for tensile tests(a), D695 for compressive tests(b), and D256 for impact tests(c). Precise 3D

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models of the test specimens were created using SolidWorks. Once finished, the 3D models were exported in .stl format, a standard file format compatible with slicing software. The .stl files were imported into slicing software Cura, for further processing and G-code generation.

Table 2. Printing Parameters

| | |
|---|---|
| Layer Thickness | 0.2 mm |
| Nozzle diameter | 0.6 mm |
| Nozzle Temperature | 200 °C |
| Bed Temperature | 60 °C |
| Printing Speed | 100 mm/s |
| Infill Density | 80 % |

The specimens were fabricated using a Fused Deposition Modelling (FDM) 3D printer with PLA (Polylactic Acid) filament. Each specimen was printed layer by layer following the predefined infill patterns and density.

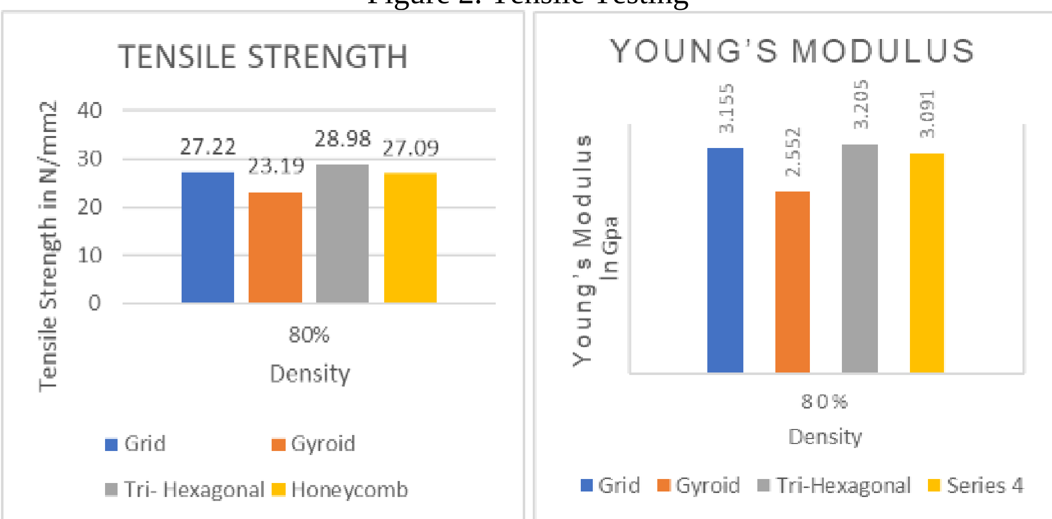
Figure 1. Dimension as per ASTM standard

**RESULT AND DISCUSSION :**

**TENSILE TESTING**

Tensile Testing is essential to assess a material's ability to endure tensile forces and determine critical properties such as ultimate tensile strength, yield strength, elastic modulus, and elongation at break. This is particularly important for materials used in structural applications subjected to tension or stretching forces. A Universal Testing Machine (UTM) is a versatile apparatus capable of conducting tensile tests. During a tensile test, the specimen is securely clamped at both ends within the machine's grips. A controlled tensile load is then applied by pulling the specimen constantly until it fractures.

Figure 2. Tensile Testing




Graph 1&2. Tensile Strength in $N/mm^2$ and Young's Modulus in Gpa

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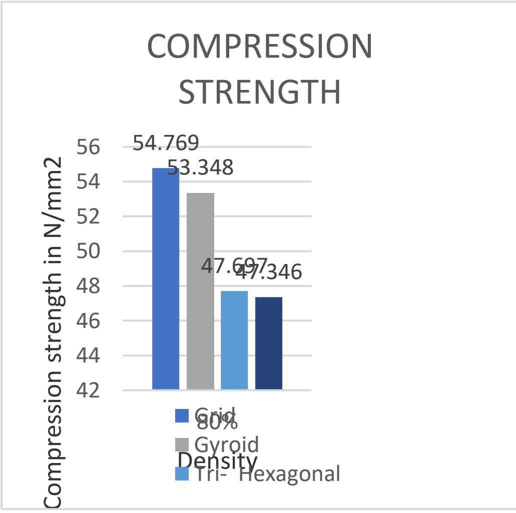
The tensile test results reveal that Young's Modulus is greatly influenced by the infill pattern. Among the tested patterns, the gyroid infill exhibited the lowest Young's Modulus value (23.19), while the tri-hexagonal pattern achieved the highest value (28.98). The tri-hexagonal pattern, known for its superior structural support, demonstrated higher Young's Modulus values compared to less dense configurations like the gyroid. This highlights that the geometry of the infill plays a crucial role in determining the material's mechanical properties, with structurally efficient patterns resulting in greater stiffness and strength.

**COMPRESSION TESTING:**

To evaluate a material's behaviour under compressive loads, determine its compressive strength, and analyse its deformation characteristics, compression testing is essential. This is particularly critical for packaging materials, which primarily endure compressive stresses.

A Universal Testing Machine (UTM) is used a cylindrical specimen is prepared according to standardized dimensions and positioned between the machine's compression platens. A compressive force is then gradually applied until the material deforms, fractures, or reaches a predefined limit. During the test, data is recorded to determine key parameters such as compressive strength, modulus of elasticity, and failure strain.




Graph 3. Compression strength

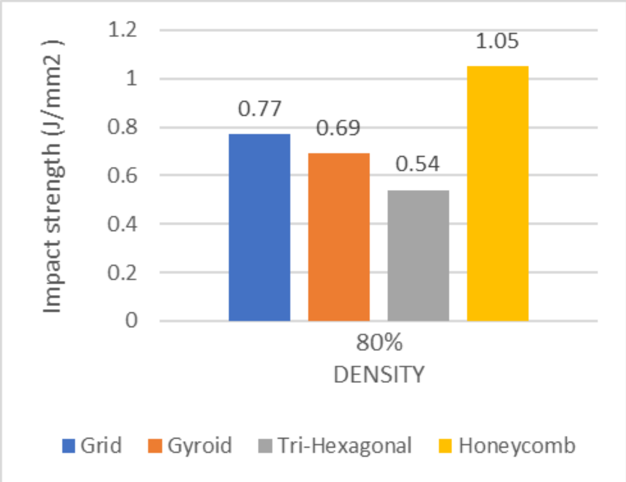
The results demonstrate that the infill pattern significantly influences the material's mechanical properties. Among the tested patterns at 80% density, the grid infill exhibited the highest compressive strength (54.769), followed closely by the gyroid pattern (53.348). These findings indicate that the grid and gyroid patterns better resist compressive forces.

**IMPACT TESTING :**

Figure 3. Impact Testing

Impact testing evaluates a material's impact resistance and determines its toughness, energy absorption, and fracture behaviour under sudden or dynamic loads. This is particularly crucial for materials used in automotive, aerospace, and other safety-critical applications.

An Izod Impact Tester, equipped with a hammer, is commonly used for this test. A notched specimen is prepared to standard dimensions and positioned vertically within the machine. The hammer is then released to strike the specimen at high velocity. The energy absorbed during fracture is measured and recorded, typically in joules.




Graph 4. Impact strength in J/mm$^2$

The results show that the infill pattern plays a significant role in the material's energy absorption properties. At 80% density, the honeycomb pattern achieved the highest energy absorption value (1.05), demonstrating its superior ability to absorb impact. This highlights the honeycomb pattern's effectiveness for energy absorption, likely due to its optimized structural geometry. In contrast, the tri-hexagonal pattern, despite its strength, proved less effective in this aspect.

**CONCLUSION:**

The study reveals that selecting an appropriate infill pattern is critical for achieving desired mechanical properties in healthcare applications, particularly in orthopaedics, where strength, stiffness, and energy absorption are vital. In summary, the optimal infill pattern should be chosen based on the intended healthcare application. The tri-hexagonal pattern is best suited for applications prioritizing stiffness and strength, while the honeycomb pattern is ideal for energy absorption and impact mitigation. The grid and gyroid patterns provide a balanced combination of strength and energy absorption, making them versatile for various applications.

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