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Evaluation of Mechanical properties of 3D Printed component

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ABSTRACT:

This study investigates the effects of infill density (20% and 40%) and patterns (Concentric and Hilbert Curve) on the mechanical performance of Fused Deposition Modeling (FDM) printed Polylactic Acid (PLA) parts. Specimens were tested for tensile strength (ASTM D638), compressive strength (ASTM D695), and impact resistance (ASTM D256). Results show that increasing infill density from 20% to 40% significantly enhances mechanical properties, with tensile strength rising from 24.2–28.4 MPa to 33.6–38.5 MPa. The Hilbert Curve at 40% infill yielded the highest tensile strength (38.5 MPa) and impact resistance (1.25 J), while the Concentric pattern at 40% infill exhibited superior compressive strength (61.3 MPa). These findings inform the optimization of 3D-printed PLA components for strength-critical applications.

Keywords: 3D Printing, Fused Deposition Modeling, Polylactic Acid, Infill Pattern, Infill Density, Mechanical Properties

Introduction:

Fused Deposition Modeling (FDM) is a widely used additive manufacturing technique that builds parts layer-by-layer from thermoplastic filaments like Polylactic Acid (PLA). PLA is favored for its biodegradability, low warping, and ease of printing, making it suitable for prototyping and functional components in automotive, medical, and consumer applications. However, the mechanical performance of FDM-printed parts depends on internal design parameters, particularly infill density and pattern.

Infill density, expressed as a percentage, determines the material fill within a part, balancing strength and material efficiency. Infill patterns, such as Concentric (aligned with part contours) and Hilbert Curve (space-filling, isotropic), influence load distribution. Prior studies (Chacón et al., 2017) show that higher infill density improves strength, while patterns like Hilbert Curve enhance isotropic behavior. This study investigates how these parameters affect tensile, compressive, and impact properties of PLA parts to optimize design for specific applications.

Nomenclature

- σ - Tensile strength (MPa)
- E - Impact energy absorption (J)
- C - Compressive strength (MPa)
- ρ - Infill density (%)

1.1 Objectives

- Evaluate tensile, compressive, and impact properties of PLA specimens with Concentric and Hilbert Curve infill at 20% and 40% density.
- Determine the optimal infill configuration for mechanical performance.
- Provide data to inform design decisions for FDM-printed PLA components.

2. Methodology

2.1 Materials and Equipment

PLA filament (1.75 mm, white, Creality) was selected for its printability and mechanical properties. A Creality K1 FDM printer (nozzle: 0.4 mm, layer height: 0.2 mm, nozzle temperature: 210°C, bed temperature: 60°C) was used, with Creality Slicer software to generate G-code. Mechanical testing employed a Universal Testing Machine (UTM) for tensile and compression tests and an Izod Pendulum Tester for impact tests.

2.2 Specimen Design

Specimens adhered to ASTM standards:

- Tensile (ASTM D638 Type V): Gauge length 7.62 mm, width 3.18 mm, thickness 3.2 mm.
- Impact (ASTM D256): 63 mm × 12.7 mm × 10 mm, V-notch (2 mm depth, 45°).
- Compression (ASTM D695): 2.5 cm × 2.5 cm × 2.5 cm cubes.
- Triplicates were printed for each combination of Concentric and Hilbert Curve patterns at 20% and 40% infill, totaling 36 specimens.

2.3 Printing and Testing

Printing parameters included 1.2 mm wall thickness, 3 top/bottom layers, 60 mm/s print speed, and brim adhesion. Specimens were cleaned of brim material and verified with digital calipers. Testing followed ASTM protocols:

- Tensile: 5 mm/min crosshead speed, measuring load vs. displacement.
- Impact: Izod V-notch, recording energy absorption in joules.
- Compression: Axial loading until deformation or fracture.

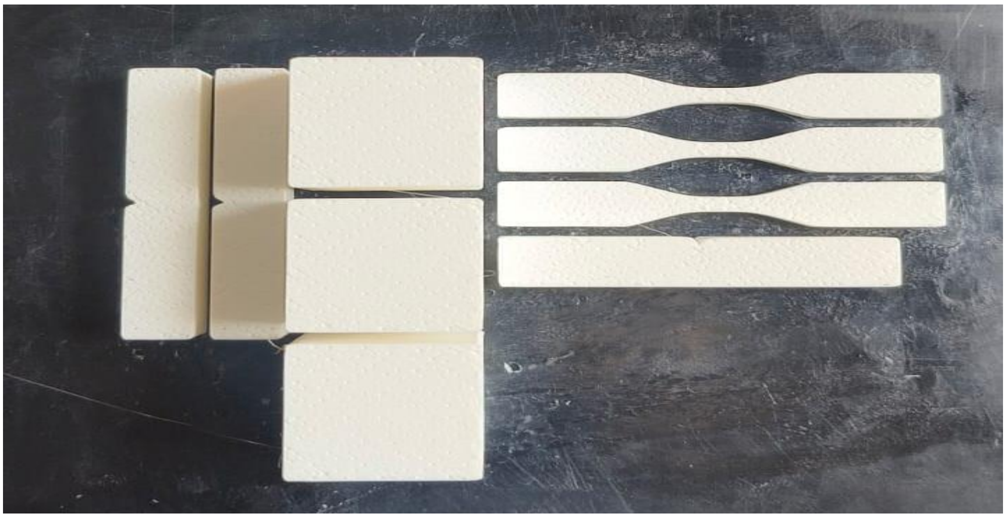

Fig. 1 - CAD models of tensile, impact, and compression specimens.

3.4 Comparative Analysis

Hilbert 40% infill excelled in tensile and impact performance due to its isotropic structure, while Concentric 40% was optimal for compression. These results confirm that infill density enhances mechanical properties, with patterns tailoring performance to specific loads.

3. Results and Discussion

3.1 Tensile Test Results

Tensile tests showed significant effects of infill density and pattern (Table 1). Hilbert Curve at 40% infill achieved the highest tensile strength (38.5 MPa), followed by Concentric at 40% (33.6 MPa). At 20% infill, Hilbert (28.4 MPa) outperformed Concentric (24.2 MPa). Higher density increased material volume, enhancing strength, while Hilbert's isotropic structure improved stress distribution, aligning with findings by Rajpurohit and Dave (2018).

Table 1 - Tensile Test Results

Pattern	Density	Tensile Strength (MPa)	Elongation at Break (%)
Concentric	20%	24.2	3.5
Concentric	40%	33.6	4.2
Hilbert	20%	28.4	4.8
Hilbert	40%	38.5	5.1

3.2 Impact Test Results

Impact tests indicated Hilbert 40% infill had the highest energy absorption (1.25 J), reflecting superior shock resistance (Table 2). Concentric at 20% infill was least resistant (0.85 J, brittle fracture). Hilbert's continuous paths likely enhanced energy dispersion, consistent with Dawoud et al. (2014).

Table 2 - Impact Test Results

Pattern	Density	Impact Strength (J)	Fracture Appearance
Concentric	20%	0.85	Brittle
Concentric	40%	1.10	Semi-ductile
Hilbert	20%	1.05	Ductile
Hilbert	40%	1.25	Ductile

3.3 Compression Test Results

Compression tests showed Concentric 40% infill with the highest compressive strength (61.3 MPa), due to radial reinforcement (Table 3). Hilbert patterns exhibited uniform deformation, while 20% infill specimens buckled. Increased density significantly improved load-bearing capacity, supporting Sood et al. (2010).

Table 3 - Compression Test Results

Pattern	Density	Compressive Strength (MPa)	Deformation Mode
Concentric	20%	43.7	Buckling
Concentric	40%	61.3	Shear
Hilbert	20%	48.9	Uniform
Hilbert	40%	54.2	Uniform

Result

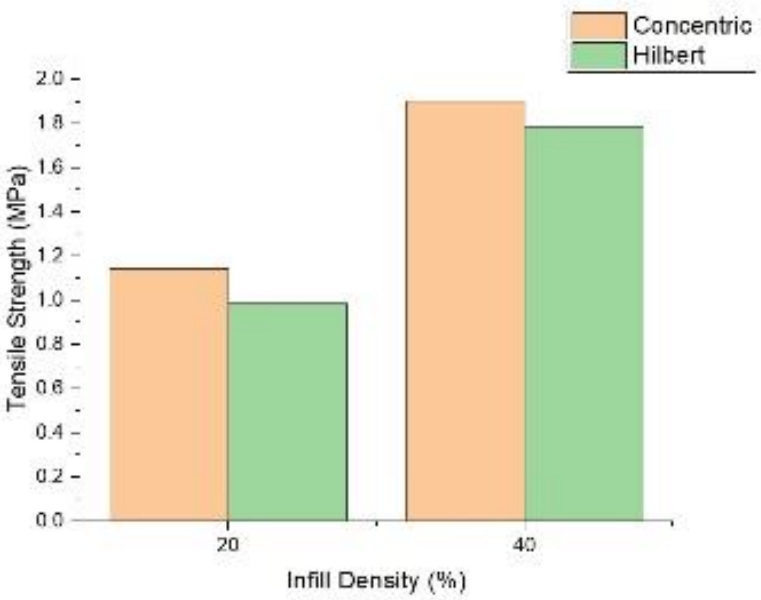

Fig. 2: Tensile strength comparison for Concentric and Hilbert Curve at 20% and 40% infill.

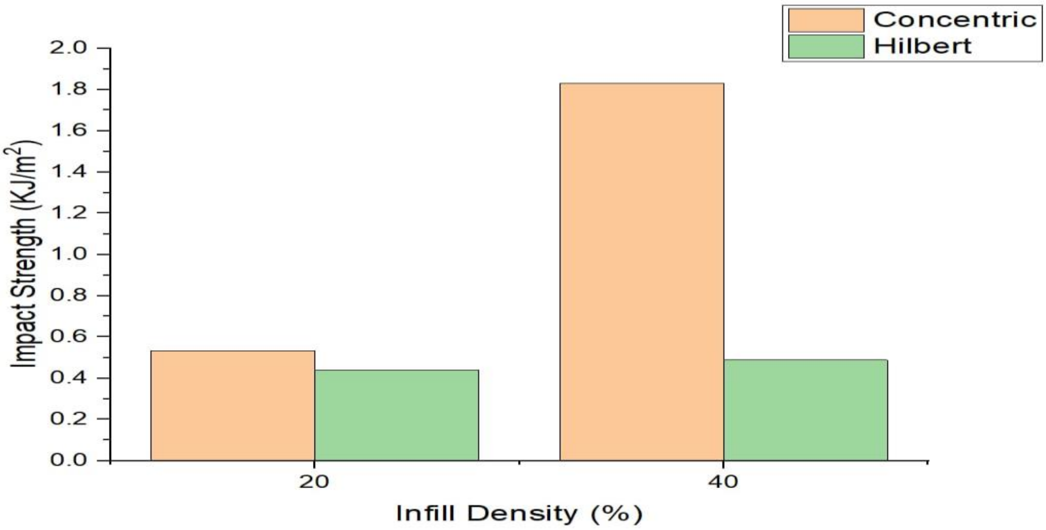

Fig. 3: Impact strength comparison for Concentric and Hilbert Curve at 20% and 40% infill.

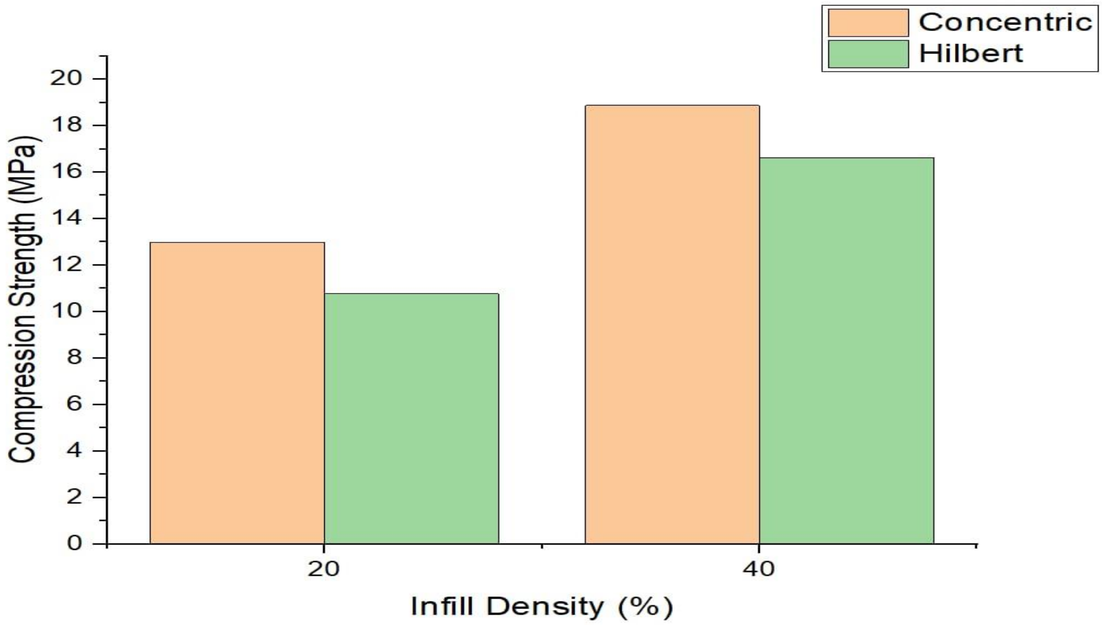

Fig. 4: Compression strength comparison for Concentric and Hilbert Curve at 20% and 40% infill.

4. Conclusion

This study demonstrates that infill density and pattern significantly affect the mechanical performance of FDM-printed PLA parts. Hilbert 40% infill is ideal for tensile and impact-critical applications, while Concentric 40% suits compressive loads. Future work should explore additional patterns (e.g., gyroid), materials (e.g., PETG), and microstructural analysis to further optimize 3D-printed components.

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