



INVESTIGATING THE MECHANICAL PROPERTIES OF PLA BASED 3D PRINTED MATERIALS WITH DIFFERENT INFILL PATTERNS

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ABSTRACT:

This investigates the influence of different infill patterns on the mechanical properties of Polylactic acid based on 3D printed materials. Fused Deposition Modelling is a widely used Additive Manufacturing technique that offers cost-effectiveness, design flexibility, and minimal material wastage. PLA is a popular Thermoplastic polymer used in 3D printing due to its Biodegradability, Renewability, and ease of processing. However, the Mechanical performance of PLA-based printed parts largely depends on the process parameters, especially the infill pattern. Various infill patterns, including Honeycomb, Gyroid, concentric, are examined for their effects on Tensile strength, Flexural strength, Impact Strength. The mechanical behaviour of PLA-based 3D printed materials is highly sensitive to the chosen infill pattern, along with density and orientation. The ideal choice of infill pattern depends on the intended application and specific loading requirements. This work highlights the importance of understanding infill patterns to enhance the performance of PLA components and broaden their applicability in engineering and industrial domains.

Key Words: 3D Printing, Fused Deposition Modelling, Polylactic acid, Infill Patterns, Mechanical properties.

1. INTRODUCTION:

Additive Manufacturing, commonly known as 3D printing, is a modern technology used to create three-dimensional objects directly from digital designs. Unlike traditional manufacturing methods that remove material by cutting or machining, 3D printing builds objects layer by layer, which reduces material waste, saves time, and lowers production costs. Because of these advantages, it is widely used in industries such as automotive, aerospace, medical, and product development. One of the most popular 3D printing methods is FDM, where a thermoplastic filament is heated and extruded through a nozzle to form objects layer by layer. FDM printers are affordable, easy to operate, and suitable for producing prototypes and test specimens, especially in academic and research work. PLA is one of the most commonly used materials in FDM printing because it is biodegradable, environmentally friendly, and easy to print. It provides good surface finish, dimensional accuracy, and sufficient strength for many applications. In FDM printing, the internal structure of a part is controlled by the infill pattern and density, which affect its strength, weight, and material usage. This study focuses on infill patterns like Gyroid, Honeycomb, and Concentric and evaluates their mechanical performance using tensile, flexural, and impact tests to identify the most efficient and strong design.

2. LITERATURE REVIEW:

This study examined the mechanical behavior of 3D-printed PLA made using FDM technology. It focused on how infill density, print orientation, pull rate, and material composition affect strength. The results showed that increasing infill density from 15% to 100% greatly improved tensile strength because there were fewer internal gaps and better load support. Print orientation also strongly influenced performance. Adding carbon black nanoparticles made PLA electrically conductive, but reduced its strength due to weak layer bonding and brittleness. The study highlights the need to carefully choose printing settings for strong and functional parts [1]. studied how different 3D printing parameters affect the mechanical and surface properties of PLA parts made using MEX



technology. Using the Taguchi optimization method, they analyzed infill density, layer thickness, raster angle, printing speed, and wall thickness. The results showed that infill density had the greatest effect on strength, while layer thickness mainly influenced surface finish and impact resistance. Increased wall thickness improved bending and compressive strength, helping identify optimal printing settings [2]. compared the mechanical properties of PLA, ABS, and epoxy resin parts produced by different 3D printing techniques. They evaluated tensile strength, impact strength, and fatigue life. PLA showed the highest tensile strength and stiffness but behaved in a brittle manner. ABS had better impact resistance, while epoxy resin showed high ductility but poor fatigue life. The study also found that sharp notches significantly reduced the fatigue life of epoxy. SEM analysis was used to study fracture behavior. This research helps engineers choose suitable materials based on performance needs [3]. Investigated how different infill patterns influence the strength of FDM-printed PLA parts. Patterns such as concentric, gyroid, 3D honeycomb, and rays were examined using a G-code-based cross-sectional area analysis method. Tensile testing showed that the concentric pattern provided uniform material distribution and consistent mechanical performance. The rays pattern showed higher porosity and earlier failure. The study concluded that local weak cross-sections significantly affect strength, emphasizing careful infill pattern selection [4]. Investigated the mechanical behavior of PLA/Cu composite parts made using FDM by studying different infill patterns and densities from 10% to 90%. Tensile tests showed that the line pattern at 90% density achieved the highest tensile strength and Young's modulus. Triangle patterns at medium densities showed weak performance due to internal voids and poor bonding. SEM and EDX analysis confirmed uniform copper distribution in stronger samples. The study highlights that proper infill design significantly improves strength and functionality [5]. Investigated the effect of infill density and infill geometry on the tensile strength of PLA parts fabricated using FDM. Three patterns grid, triangle, and gyroid were tested at four different density levels. The results showed that tensile strength consistently increased with higher infill density for all geometries. Among the tested patterns, the grid infill provided the highest tensile strength due to improved alignment of internal structures with the applied load. The study emphasizes that selecting suitable infill geometry and density is essential to achieve strong parts while maintaining material efficiency in practical applications [6]. Analyzed the tensile properties of PLA components printed with five different infill patterns and validated the findings using finite element analysis in ANSYS. The patterns included gyroid, circular, rhombille, truncated octahedron, and honeycomb. Experimental results showed that the honeycomb pattern achieved the highest tensile strength and hardness because of uniform stress distribution and efficient load transfer. Increasing infill density improved strength but also increased material consumption. The FEA simulation closely matched experimental results, confirming its reliability. The study highlights the importance of infill design and supports simulation tools for optimizing mechanical performance [7]. Examined the effect of ten different infill patterns on the tensile behavior of PLA parts produced under constant printing conditions. The results demonstrated that infill geometry plays a major role in determining mechanical strength. The concentric infill pattern showed the highest tensile strength because it aligned well with the direction of applied load, enabling better stress distribution. Triangle and grid patterns exhibited lower strength due to weaker bonding between layers. Stress-strain analysis confirmed improved ductility in concentric designs. The study concludes that proper infill selection enhances strength without increasing material use or print time [8]. Investigated the impact of complex infill patterns on the mechanical properties of PLA parts printed at a constant density. Five patterns were analyzed: honeycomb, 3D honeycomb, gyroid, stars, and Hilbert curve. The honeycomb pattern achieved the highest tensile strength and elongation due to strong internal connectivity and minimal air gaps. In contrast, the Hilbert curve showed the weakest mechanical performance because of larger voids and sharp internal turns microscopic examination supported these results by revealing better bonding in honeycomb structures. The research emphasizes that selecting suitable infill geometry significantly improves strength and reliability [9]. conducted an experimental investigation on PLA parts fabricated with six different



infill patterns using FDM. Mechanical properties including tensile strength, elongation, Young's modulus, and energy absorption were evaluated. The triangular infill pattern exhibited the highest tensile strength and stiffness, making it ideal for load-bearing applications. The wiggle pattern showed greater elongation and energy absorption, indicating improved flexibility. Honeycomb provided a balanced combination of strength and material efficiency. The study concludes that infill pattern selection should be based on application requirements to achieve optimal mechanical performance [10]. Developed toughened PLA–natural rubber blends for FDM printing and studied the effect of rubber content and infill pattern. Adding up to 20% natural rubber greatly increased elongation and impact resistance, reaching about 440% elongation at the highest content. Parallel infill showed better tensile strength and toughness than grid due to improved load transfer. Although stiffness decreased with rubber addition, ductility improved significantly. The study shows that combining material modification and infill design expands PLA applications [11]. Examined how infill density affects tensile properties of antibacterial PLA, Tough PLA, and ABS-X using triangular infill from 20% to 100%. Tensile strength and modulus decreased almost linearly with lower infill density. At full density, antibacterial PLA showed the highest strength, while Tough PLA demonstrated better ductility at lower densities. The study confirms that infill density strongly controls stiffness and load capacity, sometimes more than material type, helping designers balance weight and strength [12]. Compared natural PLA and advanced PLA-X under different printing parameters. They studied infill density, layer thickness, moisture condition, and infill pattern. Results showed that 100% infill and thinner layers produced maximum strength and stiffness. Standard PLA had higher tensile strength, while PLA-X offered better ductility and energy absorption. Circular infill aligned with load improved performance, especially for PLA-X. The study suggests PLA-X for flexible uses and PLA for high-strength applications [13]. Investigated the combined effect of infill pattern and layer thickness on tensile strength of FDM- printed PLA. Results showed that infill geometry had a stronger influence than layer thickness. Patterns with better internal bonding provided improved stress distribution and load capacity. Thinner layers enhanced interlayer adhesion, further increasing strength. The study highlights the importance of optimizing both design and process parameters together to improve mechanical performance while maintaining printing efficiency [14]. Analyzed the effect of infill density from 20% to 80% on impact strength and fracture toughness of PLA specimens. Mechanical performance increased significantly with higher density due to reduced voids and better bonding. The best results were achieved at 80% infill, though material use and printing time also increased. The study emphasizes the trade-off between strength and production efficiency, guiding engineers in selecting suitable infill levels [15]. Studied bending and fatigue behavior of FDM-printed PLA under cyclic loading. PLA parts performed well under low-stress fatigue but failed at higher stresses due to cracks at interlayer boundaries. Infill density and raster orientation strongly influenced fatigue life. The research highlights the effect of mechanical anisotropy in FDM parts and provides valuable insights for designing PLA components used in cyclic or structural loading conditions [16]. Examined how infill density and printing orientation affect bending strength of PLA parts. Increasing infill density improved flexural strength and stiffness by reducing internal voids. Printing orientation significantly influenced deformation and crack growth, with layers aligned parallel to bending load showing better performance. The study stresses the importance of considering anisotropy in FDM designs and offers guidance for applications requiring strong bending resistance [17]. Studied how FDM printing parameters affect the tensile strength of PLA parts using the Taguchi design of experiments. They focused on infill pattern, layer thickness, and printing speed. Results showed that infill pattern had the greatest impact on strength, followed by layer thickness, while printing speed had less effect. Thinner layers improved interlayer bonding. Using Taguchi optimization, the best parameter combination was identified, producing stronger parts with minimal trials. The study highlights that optimizing printing parameters enhances PLA part performance and reliability [18]. Studied how infill density and geometry affect the mechanical properties of FDM-printed PLA parts. Higher infill density increased



tensile strength and stiffness, while certain infill geometries improved strength-to-weight efficiency. The direction of material deposition relative to the load also influenced performance. The study shows that careful selection of infill design and density can optimize strength without needing full solid infill, reducing material usage and print time. These findings provide practical guidance for efficient and strong PLA part design [19]. Studied tensile behavior of FDM- printed PLA using experiments, finite element analysis, and neural network modelling. Different infill patterns and densities were tested, with triangular infill giving the best strength-to-weight ratio at lower densities. The simulations accurately predicted stress distribution and failure points. A neural network model was created to estimate tensile properties from printing parameters. This approach reduces the need for extensive physical testing and supports efficient, data-driven design optimization of PLA parts [20].

3. METHODOLOGY:

This study was conducted to evaluate the influence of internal infill behavior on the mechanical performance of PLA components fabricated using FDM. Commercial-grade PLA filament was selected due to its biodegradability, dimensional stability, and widespread use in additive manufacturing. To ensure material consistency, all specimens were produced from the same filament batch. Standardized test samples were designed in accordance with internationally recognized ASTM specifications for tensile, flexural, and impact testing. The geometries were developed using Catia software and converted into printable formats through slicing software for toolpath generation. All specimens were fabricated under controlled processing conditions to ensure uniformity and repeatability. Printing parameters and build orientation were maintained constant throughout the study so that any variation in mechanical performance could be attributed solely to differences in infill configuration. Multiple infill geometries were selected based on their structural characteristics and industrial relevance, and each pattern was evaluated at different density levels. Mechanical characterization was performed using calibrated testing equipment to determine tensile strength, stiffness, bending resistance, and impact energy absorption. The experimental results were systematically recorded and comparatively analyzed to establish correlations between internal structure and mechanical response.

Selection of ASTM Standard specimens:

Tensile Test - ASTM D638: This standard specifies the dimensions and shape of plastic tensile specimens. It ensures uniform stress distribution in the gauge section when the specimen is pulled.

Purpose: To determine Tensile strength, Elongation, Tensile Modulus.

Flexural Test - ASTM D790: This standard defines the size of rectangular specimens used in bending tests. It ensures proper support span and load application during bending.

Purpose: To measure flexural strength of the specimen.

Impact Test - ASTM D256: This standard defines the size of rectangular specimens used in bending tests. It ensures proper support span and load application during bending.

Purpose: To measure flexural strength and bending resistance of the specimen.

4. EXPERIMENTATION:

The experimental study was conducted to understand how different internal infill patterns affect the mechanical performance of 3D-printed PLA specimens. After fabrication, all samples were tested using standard mechanical testing procedures under controlled laboratory conditions to ensure accurate, reliable, and consistent results. Before testing, each specimen was carefully inspected for visible surface defects such as cracks, poor layer bonding, or printing irregularities, and its dimensions were measured to confirm compliance with standard specifications. Tensile testing was performed using a Tensometer, where

each specimen was firmly gripped and pulled in one direction until fracture occurred. During the test, the applied load and corresponding extension were continuously recorded to determine tensile strength, stiffness, and elongation at break. Flexural testing was conducted using a three-point bending setup in which the specimen was supported at both ends and loaded gradually at the center to evaluate bending strength and rigidity. Impact testing was carried out using a pendulum impact machine to measure the energy absorbed by the material under sudden loading conditions. All experiments were performed under identical environmental and operational conditions to minimize external influences. The collected data were systematically recorded, analyzed, and compared to clearly understand how variations in internal infill design influence the strength, stiffness, and fracture behavior of the 3D-printed PLA components.

Table 1: 3D printing parameters configuration

S.NO	PARAMETERS	VALUES
1.	Material	PLA
2.	Filament diameter	1.75mm
3.	Nozzle diameter	0.4mm
4.	Nozzle temperature	220 °C
5.	Bed temperature	55 °C
6.	Layer height	0.2mm
7.	Printing speed	100mm/s
8.	Bluid orientation	Flat
9.	Slicing software	Bambu P1S

Table 2: Mechanical test

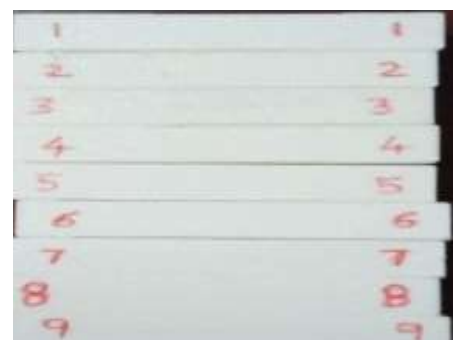
S.NO	INFILL PATTERNS	INFILL DENSITY	THICKNESS	
			TENSILE & FLEXURAL TEST	IMPACT TEST
1.	GYROID	75%	3 mm	10 mm
		80%		
		85%		
2.	HONEY COMB	75%	3 mm	10 mm
		80%		
		85%		
3.	CONCENTRIC	75%	3 mm	10 mm
		80%		
		85%		



Tensile Test Printed Specimen



Flexural Test Printed Specimen



Impact Test Printed Specimen

5. RESULTS AND DISCUSSION:

The experimental results clearly show that infill density and infill pattern strongly influence the mechanical performance of PLA specimens. Tensile strength increased steadily as the infill density increased from 75% to 85% for all patterns.

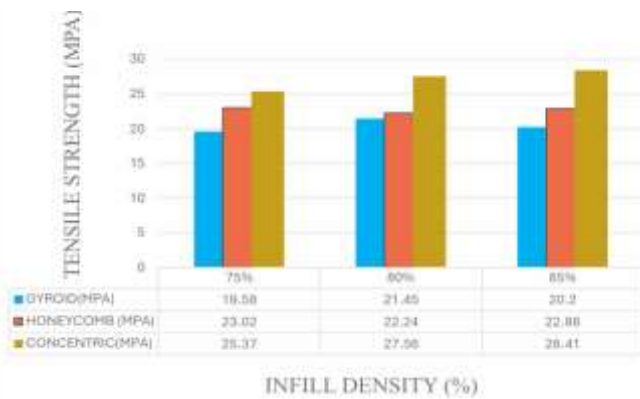
Tensile specimen: The results show that tensile performance is strongly influenced by infill geometry and density. The Concentric pattern at 85% infill exhibited the highest tensile strength of 28.41 MPa, indicating efficient load transfer due to aligned filament paths. The highest tensile modulus of 326 MPa was observed for the Honeycomb pattern at 85% infill, demonstrating superior



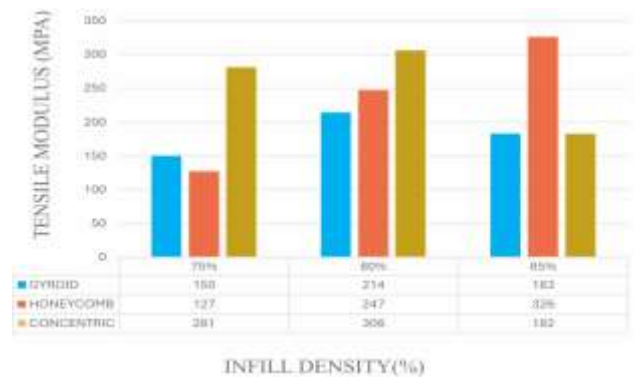
stiffness. The Gyroid pattern showed moderate tensile behaviour compared to the other structures. In general, increasing infill density improved tensile strength, although the improvement was not strictly linear.

Flexural specimen: The highest flexural strength (161.13 MPa) was obtained for the Gyroid pattern at 85% infill density. This suggests that the continuous internal geometry of the gyroid structure enhances resistance. Concentric and Honeycomb patterns showed stable but comparatively lower flexural performance. Flexural behaviour was influenced more by internal geometry than by density alone.

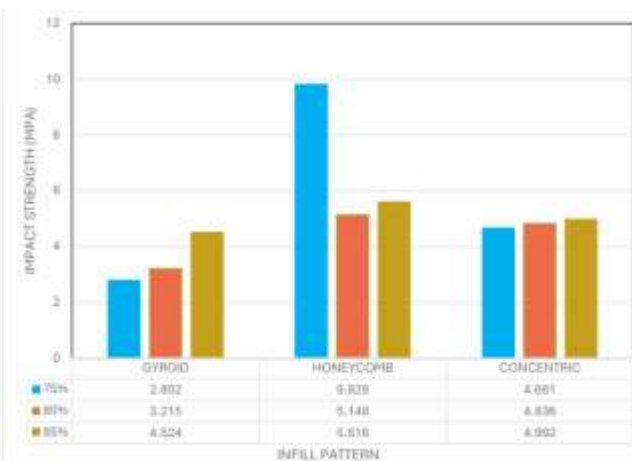
Impact specimen: Impact testing revealed that the Honeycomb pattern at 75% infill achieved the highest impact strength of 9.828 kJ/m². The cellular structure effectively absorbed and distributed sudden loads. Gyroid and Concentric patterns showed moderate impact resistance, with improved performance at higher densities.



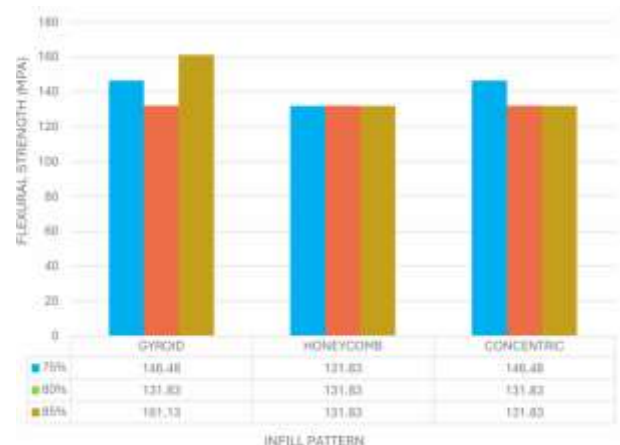
Graph 1: Tensile strength vs Infill density



Graph 2: Tensile modulus vs Infill density



Graph 3: Infill pattern vs Impact strength



Graph 4: Infill pattern vs Flexural strength

Table 3: Maximum Mechanical properties for different infill patterns

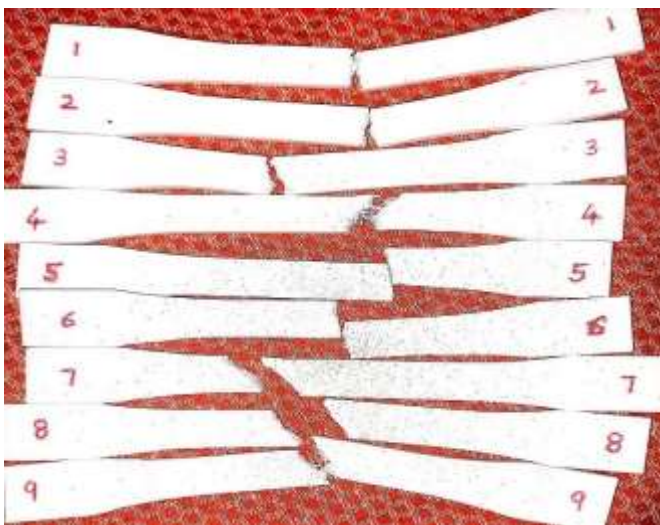
INFILL PATTERN	TENSILE SPECIMEN			FLEXURAL SPECIMEN		IMPACT SPECIMEN	
	Max Density (%)	Max Tensile Strength (mpa)	Max Tensile Modulus (mpa)	Max Density (%)	Max Flexural Strength (mpa)	Max Density (%)	Max Impact Strength (mpa)
GYROID	80	21.45	214	85	161.13	85	4.524
HONEY-COMB	75	23.02	127	75	131.83	75	9.828
CONCENTRIC	85	28.41	182	75	146.48	85	4.992

Table 4: Tensile test results Table 5: Flexural and Impact test results

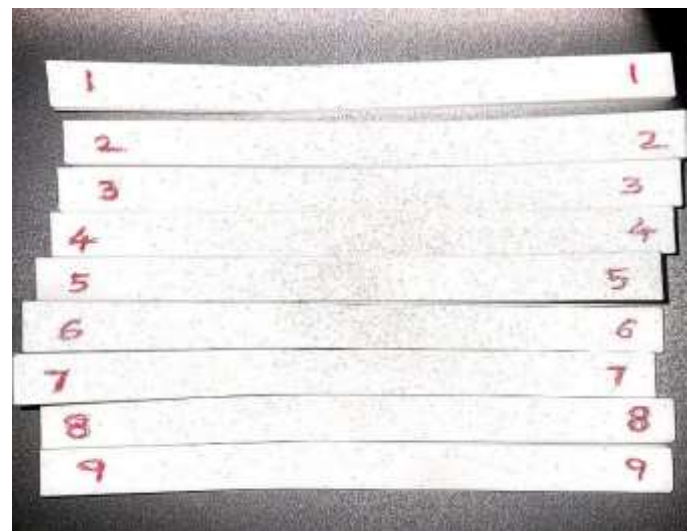
S.NO	INFILL PATTERN	INFILL DENSITY (%)	LOAD (N)	ELONGATION (mm)	TENSILE STRENGTH (mpa)	TENSILE MODULUS (mpa)
1.	GYROID	75%	1250	7.5	19.58	150
2.		80%	1370	5.7	21.45	214
3.		85%	1290	6.7	20.20	183
4.	HONEY COMB	75%	1470	10.5	23.02	127
5.		80%	1420	5.3	22.24	247
6.		85%	1460	4.0	22.86	326
7.	CONCENTRIC	75%	1620	5.2	25.37	281
8.		80%	1750	5.6	27.56	306
9.		85%	1760	8.9	28.41	182

S.NO	INFILL PATTEN	INFILL DENSITY %	LOAD (N)	ELONGATION (mm)	FLEXURAL STRENGTH (mpa)	IMPACT STRENGTH (KJ/m ²)
1.	GYROID	75%	100	9.0	146.48	2.802
2.		80%	90	9.7	131.83	3.215
3.		85%	110	10.0	161.13	4.524
4.	HONEY	75%	90	11.3	131.83	9.828
5.		80%	90	12.3	131.83	5.148
6.		85%	90	15.4	131.83	5.616
7.	CONCEN-TRIC	75%	100	15.8	146.48	4.681
8.		80%	90	11.1	131.83	4.836
9.		85%	90	10.4	131.83	4.992

Failure Parts of Tested Specimen of Tensile, Flexural, & Impact:



a.) Tensile part



b.) Flexural part



c.) Impact part

6. CONCLUSION:

This project examined how different infill patterns and densities affect the mechanical properties of PLA components produced using FDM 3D printing. Three infill patterns Gyroid, Honeycomb, and Concentric were tested at 75%, 80%, and 85% infill densities under tensile, flexural, and impact loading conditions. The Concentric pattern at 85% infill exhibited the highest tensile strength of 28.41 MPa, indicating superior resistance to axial loads. The highest tensile modulus of 326 MPa was achieved by the Honeycomb pattern at 85% infill, demonstrating greater stiffness. In flexural testing, the Gyroid pattern at 85% infill showed the maximum flexural strength of 161.13 MPa, confirming better bending resistance. Impact testing revealed that the Honeycomb pattern at 75% infill achieved the highest impact strength of 9.828 kJ/m², showing enhanced energy absorption capability. The results indicate that mechanical performance depends on both internal geometry and material density. Concentric infill is suitable for load-bearing structural components, Honeycomb is preferable for impact-resistant parts and stiff structures, and Gyroid is effective for components subjected to bending stresses. These findings provide useful guidelines for optimizing infill selection in lightweight automotive parts, protective housings, consumer products, and functional engineering prototypes manufactured using FDM technology.

FUTURE SCOPE:

Future research can expand this study by examining additional infill patterns and a wider range of infill densities to identify the most efficient internal structures for specific engineering applications. Testing lower densities such as 20%, 40%, and 60%, as well as fully solid structures, would provide a better understanding of mechanical behaviour from lightweight to dense configurations. The use of alternative PLA materials, including reinforced or recycled PLA, can also be explored to evaluate improvements in strength and sustainability. Furthermore, integrating Finite Element Analysis (FEA) with experimental testing can help predict stress distribution, deformation, and failure behaviour before physical trials. Comparing simulation results with experimental data would enhance design accuracy, reduce testing time, and optimize overall structural performance.

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