

COMPARATIVE EXPERIMENTAL STUDY ON THE COMPRESSIVE PERFORMANCE OF FDM-PRINTED PLA AND ABS USING DIFFERENT INFILL ARCHITECTURES

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ABSTRACT

This study presents an experimental investigation into the compressive behaviour of components fabricated by Fused Deposition Modelling (FDM) using polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS). The mechanical performance of FDM-printed parts is strongly influenced by internal infill architecture; however, limited experimental data exist comparing compressive responses under identical processing conditions. To address this gap, cube specimens with dimensions of $50 \times 50 \times 50$ mm were designed and manufactured using ten different infill patterns at a constant infill density of 40% and a layer height of 0.2 mm. All samples were printed using the same printer and slicing parameters to ensure consistency. Compression tests were conducted using a Universal Testing Machine to evaluate load-crosshead travel behaviour and compressive strength. The results demonstrate a significant dependence of compressive performance on infill geometry for both materials. For PLA specimens, the grid infill pattern exhibited the highest compressive strength, followed by trihexagon and triangle patterns. In contrast, ABS specimens achieved maximum compressive strength with the trihexagon infill, while cubic and gyroid patterns also showed favourable performance. Simple infill geometries such as concentric and line patterns consistently resulted in lower compressive strength for both materials. Overall, PLA samples exhibited higher compressive strength than ABS under identical printing conditions, whereas ABS showed greater deformation prior to failure, indicating a more ductile compressive response. The findings confirm that infill architecture plays a critical role in determining the compressive behaviour of FDM-printed components and provide practical guidelines for selecting suitable infill patterns in load-bearing applications.



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I. INTRODUCTION

Additive manufacturing also referred to as 3D printing is an approach to manufacturing whereby parts are built in layers through directly fabricating a computer-generated image. The technology has acquired a large significance because of its ability to create complicated forms, minimize waste of materials and quick prototyping, personalized manufacturing, and quick product development. In contrast to traditional subtractive manufacturing, additive manufacturing only forms material where it is needed and therefore is an efficient and flexible process of making complex parts with reduced lead times and tooling needs. Therefore, engineering, medical, automotive, aerospace, and consumer product applications of 3D printing have been widespread in the engineering field, medical field, automotive field, aerospace field, and consumer product industry [1],[2]. Of the several additive manufacturing process Fused Deposition Modelling (FDM) is one of the most popular process due to its simplicity, low cost, and compatibility with a vast variety of thermoplastic substances.

A FDM process is done by feeding a continuous strand of a thermoplastic material into a heating nozzle where it melts and is squirted onto a build platform in a pattern. The molten material is immediately solidified upon deposition and another layer is deposited on top of the previous one until a three dimensional object is formed. Computer-aided manufacturing software manages the whole process transforming the digital model into machine-readable instructions to fabricate the part layer by layer [3],[4]. Among the most popular materials used in FDM printing are Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS) that have appropriate mechanical characteristics, can be easily obtained, and have numerous applications. PLA is a renewable based biodegradable thermoplastic, which is commonly used in rapid prototyping and low-load applications due to its good dimensional stability and easy printing. ABS, in turn, is a thermoplastic that is made of petroleum, is tough, has a greater impact strength, and has better resistance to higher temperatures than PLA.

The materials are usually used in the production of functional parts, housings, fixtures, and mechanical parts with the FDM process [3],[4]. A number of internal and external process parameters are very sensitive in determining the mechanical behaviour of FDM-printed components. The infill density, infill pattern, raster orientation, the layer thickness, printing speed and extrusion temperature are some of the parameters that influence the strength, stiffness, and deformation behaviour of the printed parts. One of the critical parameters that determine the mechanical performance is the infill structure among many others. The internal geometry of the printed part is also defined by the infill pattern which defines how the loads are distributed in the entire structure when the part is exposed to external forces. The various infill patterns also give different load paths and stress distributions which directly influence the compressive and tensile properties as well as the impact properties of the component [5],[6]. The effect of infill pattern and density on the mechanical properties of FDM-printed components has been studied by a number of researchers. It has been stated that the tendency of increasing the infill density tends to enhance the strength and stiffness, and the infill pattern may strongly change the deformation behaviour and failure of the printed structures. Some patterns, including grid, triangular, cubic, gyroid and trihexagonal structure have varying mechanical behaviors to compressive loading and tensile loading.

Consequently, it is necessary to choose an appropriate infill structure to maximize the mechanical behavior of components fabricated by FDM to certain engineering applications [5],[6]. Although the literature on the mechanical behaviour of FDM-printed polymers continues to expand, not much is known regarding the compressive behaviour of various infill structures that were produced at the same conditions of processing. To have a deeper insight into the impact of infill geometry on compressive strength and deformation behaviour, a systematic experimental study is needed especially in the case of widely used material like PLA and ABS. The aim of the current work is to experimentally test compressive behaviour of FDM-printed PLA and ABS specimens printed at the same infill density and layer height using various infill structures. The research problem will be to determine what infill pattern gives the best compressive strength to each material and to determine the mechanical performance of PLA and ABS made under the same printing conditions. The outcomes of this study should offer some useful guidelines on the choice of the appropriate infill structure when designing load-bearing FDM-printed components.

II. LITERATURE REVIEW

The mechanical behaviour of the polymers produced through Fused Deposition Modelling (FDM) process has been studied in a number of studies. In [7], the authors compared the physical and mechanical properties of PLA, ABS, and nylon 6 made with the help of FDM and injection moulding. Their contribution accentuated the effect of manufacturing process on the performance of the material and demonstrated that FDM-produced components have varied mechanical properties as compared to those produced in a conventional manufacturing process. According to [8],[9] examined how the tensile and dynamic mechanical property of a PLA material is influenced by the parameters of FDM processes. Through their experimental study, they proved that printing parameters, e.g., layer thickness and raster orientation, have great effects on the mechanical response of printed parts. In [10] explored anisotropy properties of 3D printed PLA and ABS and found out that the orientation of the prints had significant influence on tensile behaviour and failure properties of the materials.

According to [11] also studied the impact of specimen thickness on mechanical behaviour of PLA made through FDM and discovered that the stronger tensile strength occurred in thicker specimens. For [5] have created mechanical models to estimate tensile strength and elasticities of FDM-printed PLA, with the focus on the effect of printing orientation and thickness of the layer on material behaviour. In [12],[13] examined how the type and density of infills determine the tensile strength of PLA and found that the higher the infill density, the higher the strength of all infill patterns. In [14],[15], the mechanical properties of FDM-printed PLA parts prior to and following thermal treatment were studied and it was found that heat treatment can alter the mechanical response of printed parts. According to [16, 17] have examined the effect of printing parameters including infill shape, orientation, and raster angle on mechanical properties of plastic parts made with the help of FDM technology. Based on [9] experimented the tensile behaviour of multi-polymer sandwich structures that were designed using FDM and showed that which material combination was used greatly influenced the mechanical behaviour.

According to [18-20] investigated the effect of slicing parameters to determine the quality of surface and mechanical properties of the CF/PLA composite developed by FDM. The influence of raster orientation, infill rate, and infill pattern on the mechanical properties of FDM-printed components was studied by [11] and it was found that the higher the rate of infill, the higher the stiffness and strength of the part. Based on [12] examined effect of infill pattern and infill density on the impact strength of PLA parts and determined that infill pattern of zigzag and concentric gives superior impact resistance. The effect of the parameters of FDM process on tensile properties of ULTEM 9085 was investigated by [13] with a dominant influence of raster angle on tensile strength. Based on [15],[17] examined mechanical behaviour of honeycomb sandwich structure made by FDM and showed that internal geometry plays a significant role on compressive and flexural behaviour. According to [18] determined the impact of raster angles on the mechanical properties of the FDM-printed parts and found out better strength when the raster angle was 45 plus or minus. In [19] suggested a process of forecasting the final tensile strength of FDM-printed PLA at varying printing orientations, whereas by [20] examined the mechanical behaviour of PLA-graphene filaments to be used in FDM.

Despite the fact that tensile, flexural, and impact behaviour of FDM-printed parts have received a lot of work, little experimental evidence exists on compressive behaviour of PLA and ABS structures printed using various infill patterns with the same processing conditions. The proposed work will fill this gap by experimentally testing the compressive behavior of different infill structures made through the FDM process.

III. MATERIALS AND METHODS

III.1 MATERIALS

The two materials that will be utilized in this research are Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS). PLA is a renewable thermoplastic biodegradable material and is commonly available in FDM printing because of its processing and dimensional characteristics. ABS is a thermoplastic made of petroleum, which is tough, resistant to impact and capable of withstanding higher temperatures hence suitable in functional and load bearing applications. The samples were cube-shaped specimens which had been manufactured deliberately to be used in compression testing through the Fused Deposition Modelling (FDM) process. Each of the samples was a solid cube with 50 mm x 50 mm x 50 mm dimensions constructed in SolidWorks 2019 and printed by X-MAX WOL 3D printer. There were two types of thermoplastics Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS). All the samples were printed by the same parameters to be comparable with the same infill density of 40 percent and layer height of 0.2 mm, with QIDI TECH V5.5.2 slicing software. The structure that defined the samples was the infill structure, and ten types were regarded, which included concentric, lines, grid, cubic, cubic subdivision, gyroid, triangle, trihexagon, octet, and cross 3D. In the case of each material, a single specimen was fabricated of each infill pattern, and it produced 10 PLA samples and 10 ABS samples, and altogether 20 samples. These were compression tested using a Universal Testing Machine (UTM) in order to test the behavior of load-crosshead travel and compressive strength.

III.2 EQUIPMENT

The construction of specimens was performed with the help of X-MAX WOL 3D printer that uses Fused Deposition Modelling technology.



Figure 1: X-MAX WOL 3D Printer.
Source: Authors, (2026).

A Universal Testing Machine (UTM) having maximum capacity of 600 kN was used to perform compression testing.



Figure 2: Universal Testing Machine.
Source: Authors, (2026).

III.3 SPECIMEN DESIGN AND MANUFACTURING

III.3.1 Specimen Modelling

The design of a cube specimen was done through SolidWorks 2019 software with a dimension of 50 mm by 50 mm by 50 mm. The sketch and boss-extrude feature was used to create the model and send it in STL format to slice.

III.3.2 Slicing Parameters

QIDI TECH V5.5.2 slicing software was used to slice the STL file. All specimens were kept at a constant infill density of 40% and at a constant height of layer of 0.2 mm. Patterns of infills that were taken into account in the current paper included concentric, lines, grid, cubic, cubic subdivision, gyroid, triangle, trihexagon, octet, and cross 3D.

III.3.3 Printing Process

The cuts in the models were transformed into G-code files and sent to the X-MAX WOL 3D printer. The specimens were made via FDM process under the same printing conditions of the PLA material and the ABS material.



Figure 3: Lines Pattern, Concentric Pattern, Grid Pattern.

Source: Authors, (2026).

Table 1: Printing Parameters of PLA.

MATERIAL	INFILL STRUCTURE	PRINTING TIME	WEIGHT IN GRAMS(g)
PLA	Concentric	3h 25min	41.5g
PLA	Gyroid	5h 05min	44.0g
PLA	Grid	3h 38 min	43.6g
PLA	Lines	3h 48min	42.9g
PLA	Cubic	3h 18 min	42.7g
PLA	Cubic Subdivision	3h 12 min	39.2g
PLA	Triangle	3h 08 min	42.8g
PLA	Trihexagonal	3h 32 min	43.1g
PLA	Octet	3h 37 min	43.4g
PLA	Cross 3D	3h 28 min	45.2g

Source: Authors, (2026).

Table 2: Printing Parameters of ABS.

MATERIAL	INFILL STRUCTURE	PRINTING TIME	WEIGHT IN GRAMS(g)
ABS	Concentric	6h 38 min	62.1g
ABS	Gyroid	8h 05min	66.8g
ABS	Grid	6h 50 min	64.6g
ABS	Lines	6h 58 min	64.9g
ABS	Cubic	6h 55 min	65.3g
ABS	Cubic Subdivision	6h 18 min	48.5g
ABS	Triangle	6h 49 min	65g
ABS	Trihexagonal	6h 52 min	64.7g
ABS	Octet	6h 45 min	65.2g
ABS	Cross 3D	7h 42 min	54.1g

Source: Authors, (2026).

III.3.4 Compression Test Procedure

A Universal Testing machine was used to carry out compression tests. The specimens were put between two compression platens and a compressive load was exerted on the specimen at a steadily increasing compressive load until a failure occurred. Each specimen was loaded and cross head travel (CHT) to determine compressive strength and deformation behaviour was measured.

Table 3: Articles Published in 2024-2025.

Areas	Articles 2024	Articles 2025
Engineering	60	71
Biotechnology	12	9
Computing	27	23
Total	99	103

Source: Authors, (2026).

IV. RESULTS AND DISCUSSIONS

The compressive behaviour of FDM-printed PLA and ABS specimens was evaluated under identical processing and testing conditions to investigate the influence of infill architecture on mechanical performance. Load–crosshead travel responses and compressive strength values obtained from the compression tests are presented and analyzed for both materials.

IV.1 COMPRESSIVE BEHAVIOUR OF PLA SPECIMENS

The load–crosshead travel responses of PLA specimens exhibited noticeable variation depending on the infill pattern used. Infill structures with interconnected and multidirectional geometries generally demonstrated higher load-bearing capacity and improved resistance to compressive deformation compared to simpler geometries.

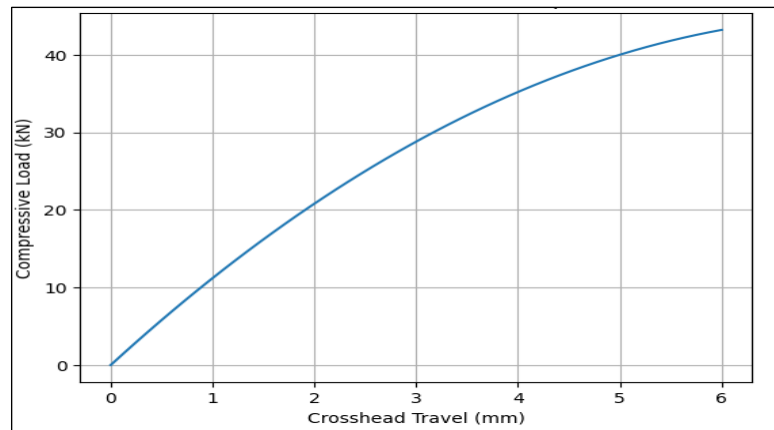


Figure 4: Load versus Crosshead Travel Curve for PLA Specimen with Grid Infill Pattern.

Source: Authors, (2026).

The Figure 4 demonstrates a progressive increase in compressive load with increasing crosshead travel until the maximum load is attained. This behavior indicates gradual deformation of the internal grid structure prior to failure. The high peak load observed confirms that the grid infill provides effective load distribution and structural stability under compressive loading.

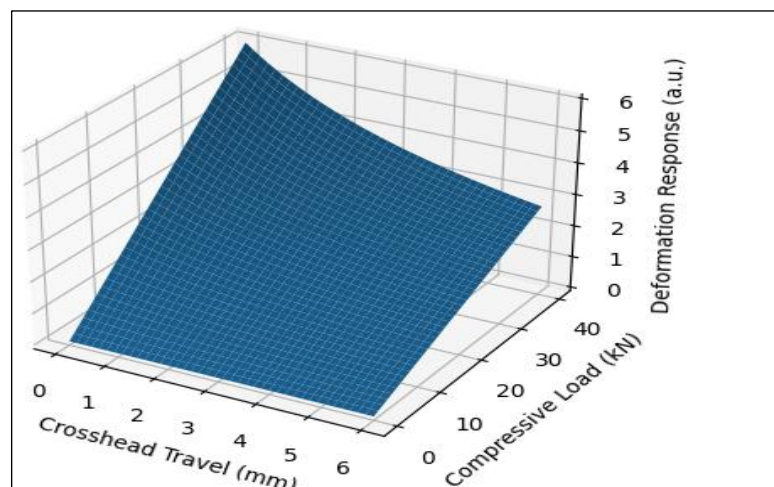


Figure 5: Load versus Crosshead Travel Curve for PLA Specimen with Line Infill Pattern.

Source: Authors, (2026).

The Figure 5 demonstrates a lower peak load accompanied by larger deformation when compared to the grid infill pattern. The predominantly one-directional internal structure of the line infill limits its ability to resist compressive stresses, resulting in reduced compressive strength and earlier onset of failure. The quantitative results obtained from the compression tests of all PLA specimens are summarized in Table 1. The data reveal a strong dependence of compressive strength on infill geometry.

Table 4: Compression Test Results of PLA Specimens with Different Infill Patterns.

Infill Pattern	Load (kN)	Compressive Strength (MPa)
Concentric	15.15	4.87
Cross 3D	35.25	13.56
Cubic Subdivision	18.48	8.64
Cubic	35.79	10.33
Grid	67.50	23.66
Lines	50.88	14.68
Octet	47.40	16.91
Gyroid	36.90	11.49
Triangle	65.01	19.33
Trihexagon	62.97	22.07

Source: Authors, (2026).

The table demonstrates that the grid infill pattern exhibits the highest compressive strength among the tested PLA specimens, followed by trihexagon and triangle infill structures. In contrast, the concentric infill pattern shows the lowest compressive strength. These findings highlight the importance of complex and interconnected internal geometries in enhancing compressive resistance of PLA components fabricated using FDM.

IV.2 COMPRESSIVE BEHAVIOUR OF ABS SPECIMENS

Similar to PLA, the compressive response of ABS specimens was significantly influenced by the infill architecture. However, ABS specimens generally showed lower peak compressive strength and greater deformation prior to failure, indicating a more ductile compressive behavior.

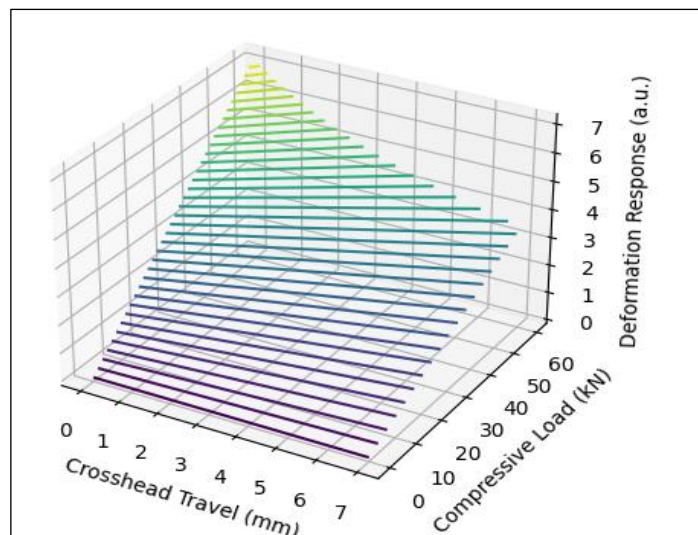


Figure 6: Load versus Crosshead Travel Curve for ABS Specimen with Trihexagon Infill Pattern.

Source: Authors, (2026).

The figure demonstrates a gradual increase in load with increasing crosshead travel until the peak load is reached. The smooth load–displacement curve suggests uniform deformation of the internal trihexagon structure. The high peak load achieved indicates that the trihexagon infill geometry effectively distributes compressive stresses and provides enhanced structural integrity for ABS specimens. The compressive strength values and peak load data for all ABS specimens are presented in Table 5.

Table 5: Compression Test Results of ABS Specimens with Different Infill Patterns.

Infill Pattern	Peak Load (kN)	Compressive Strength (MPa)
Concentric	12.33	4.48
Cubic Subdivision	18.00	8.22
Cubic	32.79	10.91
Grid	21.06	7.01
Gyroid	32.01	10.47
Lines	32.67	10.87
Octet	28.14	8.12
Triangle	25.80	7.34
Trihexagon	59.34	21.97

Source: Authors, (2026).

The table demonstrates that the trihexagon infill pattern yields the highest compressive strength among the ABS specimens, followed by cubic and gyroid infill structures. The concentric infill pattern exhibits the lowest compressive strength, reflecting its limited load-bearing capability. These results confirm that more complex infill geometries improve compressive performance in ABS materials.

IV.3 COMPARATIVE ANALYSIS OF PLA AND ABS

A comparative evaluation of PLA and ABS specimens printed with identical infill patterns shows clear material-dependent differences in compressive behavior.

Table 6: Comparative Compressive Strength of PLA and ABS Specimens with Identical Infill Patterns.

Infill Pattern	PLA Compressive Strength (MPa)	ABS Compressive Strength (MPa)
Concentric	4.87	4.48
Cubic	10.33	10.91
Grid	23.66	7.01
Gyroid	11.49	10.47
Lines	14.68	10.87
Triangle	19.33	7.34
Trihexagon	22.07	21.97

Source: Authors, (2026).

The table demonstrates that PLA specimens generally exhibit higher compressive strength than ABS specimens under the same printing and testing conditions. This behavior can be attributed to the higher stiffness of PLA. Conversely, ABS specimens show greater deformation before failure, indicating improved ductility under compressive loading. These observations emphasize that both material selection and infill architecture must be considered when designing load-bearing FDM-printed components.

V. CONCLUSIONS

This study experimentally investigated the compressive behaviour of FDM-printed PLA and ABS components manufactured using different infill architectures under identical processing conditions. All specimens were fabricated with a constant infill density of 40% and a layer height of 0.2 mm, allowing a direct comparison of the influence of infill geometry on compressive performance. The results demonstrate that infill architecture has a significant effect on the compressive strength and deformation behaviour of both materials. For PLA specimens, the grid infill pattern exhibited the highest compressive strength, followed by trihexagon and triangle infill structures, while the concentric infill pattern showed the lowest compressive resistance. In the case of ABS specimens, the trihexagon infill pattern achieved the maximum compressive strength, with cubic and gyroid infill patterns also providing relatively good performance. A comparative assessment revealed that PLA generally exhibited higher compressive strength than ABS when printed with identical infill patterns and process parameters. However, ABS specimens showed greater deformation prior to failure, indicating a more ductile response under compressive loading. These differences are attributed to the inherent material characteristics of PLA and ABS. Overall, the findings confirm that both material selection and infill architecture play a critical role in determining the compressive performance of FDM-printed components. The results provide practical guidance for selecting appropriate infill patterns when designing load-bearing parts using the FDM process.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: M. Jayakrishna and M. Vijay.

Methodology: M. Jayakrishna and M. Vijay.

Investigation: M. Jayakrishna and M. Vijay.

Discussion of results: M. Jayakrishna and M. Vijay.

Writing – Original Draft: M. Jayakrishna

Writing – Review and Editing: M. Jayakrishna and M. Vijay.

Resources: M. Jayakrishna and M. Vijay.

Supervision: M. Vijay

Approval of the final text: M. Jayakrishna, M. Vijay.

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