ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Volume 11 Issue 5 May 2024

Identification of Bending Behaviour of a 3-D Printed Composite Polymer Reinforced with Carbon Fiber

[1] Rishith Harish, [2] K Siddhartha Shankar, [3] Dr. Sangamesh C M

[1] [2] Student, PES University, 100 Feet Ring Road, Banashankari Stage III, Dwaraka Nagar, Banashankari, Bengaluru, Karnataka 560085

[3] Assistant Professor, PES University, 100 Feet Ring Road, Banashankari Stage III, Dwaraka Nagar, Banashankari, Bengaluru, Karnataka 560085

Corresponding Author Email: [1] rishithharish1@gmail.com, [2] kurumalasiddu2002@gmail.com, [3] sangameshm@pes.edu

***Abstract*— The 3D printing, has emerged as a disruptive technology capable of revolutionizing various industries. It adopts additive processes to build objects through sequential addition of layers. The implementation of a layer-by-layer approach offers an unparalleled degree of adaptability in design, enabling the creation of intricate and intricate structures that were previously challenging or unachievable.**

The study in this paper is to the investigate the fundamental comprehension of the flexing characteristics of the 3D-printed composite, the composite material formed by the combination of additive manufacturing's flexibility, carbon fiber's robustness and endurance is exceptionally versatile and valuable for creating customized and long-lasting solutions. The significant benefits such as corrosion resistance, design adaptability, long-lasting performance, lightweight construction, and high strength.

***Keywords*— 3D printing, Design adaptability, Bending behaviour, Composite Polymer, Carbon fiber.**

I. INTRODUCTION

3D printing, also known as additive manufacturing, allows for the step-by-step production of objects using digital models. This technique is particularly advantageous in composite manufacturing, as it enables the precise conversion of intricate designs into physical structures. The present study emphasis on synthesis of 3D-printed composite polymer composites reinforced with the carbon fiber.

Composite materials are widely acknowledged and esteemed for their remarkable durability. The combination of different materials provides a strength that often surpasses that of each individual component. A notable advancement in composite materials involves the integration of carbon fiber reinforced polymers (CFRPs). The carbon fibers in these composites possess remarkable strength and rigidity, while the polymer matrix functions as a binding agent, ensuring the security and stability of the fibers while also offering a certain degree of flexibility. This study primarily investigates the production of 3D-printed composite polymer composites that are strengthened with carbon fiber. It specifically examines how the addition of carbon fiber and the density of the filler material affect the bending properties of polymer composites based on PLA. Further, the applications in automotive industry, biomedical engineering and aerospace industrial engineering stands to benefit from the progress of composite materials. The study intends to demonstrate occurrence of bending loads in industrial environments and seeks to provide crucial insights that can guide the design and application of 3D-printed composite polymer composites. The research aims to analyze the effect of adding carbon fiber and adjusting fill density on the flexural behaviour, in order to understand the intricate relationship between these variables. The ultimate objective is to uncover the possible uses of the material, especially in industries where durability, flexibility, and mechanical robustness are crucial for achieving success. Finally, the study seeks to combine these two materials in order to leverage their synergistic effects and produce a composite material that demonstrates superior adaptability and mechanical strength.

II. OBJECTIVES

Step 1: Synthesis of carbon fiber reinforced PLA based polymer filaments for 3D printing applications.

Step 2: 3D printing of polymer composite parts using fused deposition modelling process.

Step 3: Evaluation of flexural behaviors of composite parts as per ASTM standards.

Step 4: To study the effect of infill density on the flexural properties of 3D printed PLA parts and composite parts.

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Volume 11 Issue 5 May 2024

Experimental Steps

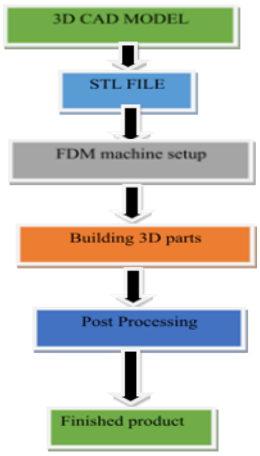

Figure 1. Steps of additives manufacturing process

III. MATERIAL SELECTION

Matrix Material: Polylactic acid, or PLA, stands out as a matrix material for the preparation of composites, particularly in the realm of 3D printing, due to its exceptional material properties, feasibility for 3D printing via Fused Deposition Modeling (FDM), and widespread application in various industrial sectors. PLA was chosen as a matrix material due to its unique combination of properties that make it ideal for additive manufacturing and broader engineering applications. One of the most important factors to consider when choosing PLA is its biodegradability and bio-sourced nature. PLA is made from renewable resources like corn starch or sugarcane, making it a greener alternative to traditional petroleum-based plastics. Importantly, PLA has a low melting temperature, making it ideal for 3D printing processes such as FDM. PLA's low melting point allows it to be easily extruded and deposited layer by layer during the printing process, allowing the creation of intricate and precise geometries. It is a practical choice for industries looking for efficient and cost-effective solutions.

Table 1. Properties of PLA Material

Property	Value
Tensile strength (MPa)	2550
Tensile modulus (GPa)	135
Elongation (%)	2.1
Density (g/cm^3)	180
Carbon content (%)	93

Figure 2. Photograph of PLA filaments

Reinforcement Material: The incorporation of carbon fiber as a reinforcement material in poly (lactic acid) (PLA)-based 3D printed composites is a strategic choice grounded in the desire to synergize the exceptional properties of both materials, thereby creating a composite material that surpasses the individual strengths of its constituents.

This attribute is particularly advantageous in engineering applications where lightweight materials with high strength are highly sought after, such as in aerospace and automotive industries. Carbon fiber reinforcement enhances the fatigue resistance of PLA-based composites, crucial in applications subjected to cyclic loading or stress. The composite can withstand repetitive forces without experiencing premature failure, benefiting industries such as automotive and sports equipment where components endure cyclic stresses. The justification for employing carbon fiber as a reinforcement material in PLA-based 3D printed composites rests on its superior strength-to-weight ratio, high modulus of elasticity, thermal conductivity, tailorable mechanical properties, enhanced fatigue resistance, structural performance and overall durability. This strategic combination of PLA and carbon fiber harnesses their synergies, resulting in a composite material that extends the application potential of 3D printed components across diverse industries, from aerospace to consumer electronics.

Figure 3. Photograph of continuous carbon fiber

Table 2. Properties of carbon fiber material

Properties	Values
Young's Modulus (MPa)	3600
Tensile Strength (MPa)	70
Elongation at break (%)	2.4
Flexural Strength (N/mm^2)	98
Impact strength (kJ/m^2)	16.5
Notched impact strength (kJ/m^2)	3.3
MFI (g/10 min)	3–6
Density (g/cm^3)	1.25
Moisture absorption (%)	0.3

IV. EXPERIMENTAL RESULTS AND DISCUSSION

A. FDM Filament Analysis

The Fused Deposition Modeling (FDM) process entails the use of a filament or wire, usually composed of thermoplastic material, as the main substance. The filament is introduced into a nozzle or extrusion head, where it is heated to a semi-liquid or molten state just above its melting point. The printers are equipped with a sealed chamber that can hold up to 300cm³, providing a regulated environment that is suitable for the printing process. The layer thickness was adjusted to 0.1mm to achieve greater intricacy, albeit at the expense of longer printing duration. The shell thickness, which impacts the overall strength, was established at 0.4mm. The top and

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Volume 11 Issue 5 May 2024

bottom layer thickness were both adjusted to 1.2mm in order to achieve a uniform and robust surface finish. The printer's movement during the printing process was regulated by a print speed of 5mm/s, which had an impact on both the duration and quality of the printing. The print was oriented at a 45-degree angle, which impacted the surface finish, support structures, and overall print quality. The nozzle temperature for PLA material was consistently set at 240°C, whereas for other materials, it was adjusted according to their individual specifications. The bed temperature was maintained at a constant 80°C throughout the entire printing process to ensure optimal adhesion and minimize the occurrence of warping. Through careful parameter selection and optimization, we successfully developed precise and top-notch 3D models using a PLA matrix and carbon fiber filament. The selected concentric infill pattern, set at a density of 100 percent, guarantees the strength and structural soundness of the printed components, rendering them appropriate for their intended use. To achieve the desired diameter of 1.75 millimeters, the subsequent step involved drawing the filament to the desired length. The extrusion parameters that were used in this investigation were optimized in order to produce filaments that had a smooth texture and were free of any surface defects, pores, melt fracture, or thread-like surface formations.

Figure 4. FDM machine used for printing

Table 3. Technical specifications of Prusa i3 FDM printer

Technology	Fused Deposition Modelling
Print Size	160mm * 160mm * 180mm
Compatible Materials	ABS, PC, PLA, PET-G etc.
Print Resolution	0.1 mm/100 Microns
Hot-end Type	Single Extruder
Nozzle-Type	Brass
Nozzle Max. Temp.	260°C
Max. Bed Temp.	100°C
Working Ambient Temp.	5-40°C
Connectivity	SD-Card/USB
Power Current: 5-6 Amp.	Input Voltage: 220 V,50Hz

(a) PLA **(b) PLA/CF composites**

Figure 5. Photographs of FDM printed filaments

Figure 6. Picture of PLA+Carbon fiber FDM filament

B. Dimensional Accuracy of 3D Printed Specimens

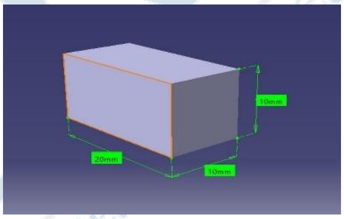

Figure 7. CAD model of the specimens used for measurement of dimensional accuracy

In Figure, the process of fabricating rectangular components using the Fused Deposition Modeling (FDM) technique with a PLA matrix and carbon fiber reinforcement is illustrated. These components, designed with dimensions of 10x10x20 mm, underwent fabrication with a focus on achieving high dimensional accuracy. When it comes to neat PLA, it is well- known for its strength, flexibility, and ability to withstand temperatures ranging from -20 degrees Celsius to 80 degrees Celsius. The shrinkage that PLA typically experiences is approximately 0.8%. The FDM-printed PLA and its carbon fiber-reinforced composites were designed with the intention of replicating the original part's overall volume of 2000 mm3, which was the volume of the original structure. According to the results of the volume analysis, the volume of neat PLA was found to be 2008.5 mm3, which is a deviation of approximately 0.42% from the initial volume of 2000 mm3. After the incorporation of carbon fiber, the volume of PLA composites was determined to be 2004.4 mm3 after an additional measurement. Taking into consideration the original volume, which was 2000 mm3, and the volume of the neat PLA, which was 2008.5 mm3, the variation in volume was 0.22% and 0.20%, respectively.

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Volume 11 Issue 5 May 2024

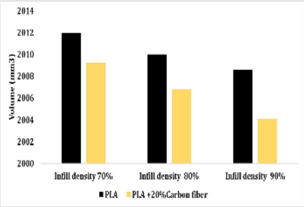

Figure 8. Variation of volumetric error with increase in infill density for PLA and PLA+ carbon fiber composites

Table 4. Volumetric error with increase in infill density for PLA and PLA +carbon fiber composites

Material	Infill density 70%	Infill density 80%	Infill density 90%
PLA	2012.2	2010.3	2008.6
80% PLA + 20% CF	2009.2	2006.8	2004.1

C. Flexural Strength

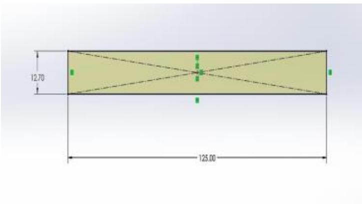

Figure 9. Specimen Dimensions

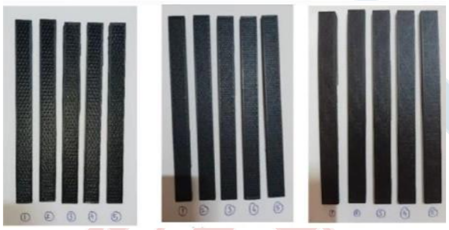

Figure 10. Photograph of 3D printed flexural test specimens

With the purpose of determining the effects of incorporating carbon fiber into PLA, flexural tests were carried out. In order to ascertain the flexural strength of the material, a flexural test was carried out in accordance with the ASTM D790 standard, with the crosshead speed being set at 3 millimeters per minute. In addition, the incorporation of carbon fiber into PLA has resulted in a significant extension of the material's flexural strength, which has been increased to 55 MPa. When compared to PLA in its natural state, this enhancement results in a relative strength improvement of approximately 40.3%. There is a correlation between the toughening effects that carbon fibers induce and the improved flexural strength of the material. Increasing the infill density has a direct positive relationship with the flexural strength of both PLA material and PLA material that is reinforced with carbon fiber filament. The streamlined internal structure, which minimizes vulnerabilities, enhances the materials' capacity to withstand bending forces with greater efficiency.

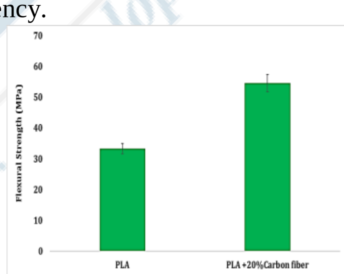

Figure 11. Variation of flexural strength of PLA and PLA+Carbon fiber composites

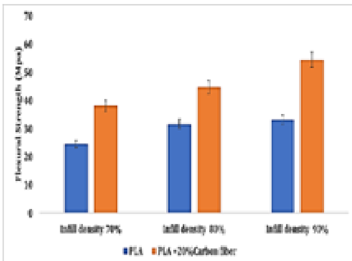

Figure 12. Effect of infill density on flexural strength of PLA and PLA+Carbon fiber composites

Table 5. Infill density effect on flexural strength of PLA and PLA+Carbon fiber composites

Material	Infill density70%	Infill density80%	Infill density 90%
PLA	24.5	31.7	33.2
80% PLA + 20%CF	38.1	44.8	54.5

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Volume 11 Issue 5 May 2024

D. Shore D Hardness Test

Table 6. Shore D Hardness Test

Filament: PLA	Durometer Scale	Filament: PLA+CF (20%)	Durometer scale
70% - Infill density	72	70% - Infill density	65
80% - Infill density	78	80% - Infill density	71
90% - Infill density	83	90% - Infill density	74

Shore D hardness, a metric measuring material hardness, is frequently used to assess rigid polymers hardness. When PLA (polylactic acid) is reinforced with carbon fiber, the material becomes more rigid and harder as a result of the carbon fiber addition.

V. CONCLUSION

The current investigation delved into the impact of carbon fibers on the dimensions and flexural properties of PLA composites produced through fused deposition modeling (FDM). The composite fabrication involved FDM printing of PLA and carbon fiber reinforced PLA composites under optimum process conditions and varied infill density. Dimensional analysis of PLA and its composites, incorporating carbon fibers, revealed substantial improvements in dimensional accuracy. It has been established that an optimal carbon fiber content is crucial to achieving a volume comparable to that of the original material. The PLA/carbon fiber composite showcased the highest flexural strength at 62 MPa, marking a notable 58.2% improvement compared to neat PLA and the PLA/carbon fiber composite, respectively. When subjected to bending forces, the pure PLA material exhibited brittle failure, while the primary cause of failure for both composites was the breakage of carbon fibers. The study underscores the significant influence of carbon fiber reinforcement on the dimensional accuracy and flexural strength of PLA composites, demonstrating its potential for enhancing the mechanical properties of 3D-printed materials. Increase in the infill density increases the flexural strength of the PLA parts and composites remarkably.

REFERENCES

[1] Goh, G. D., et al. (2018). Additive Manufacturing in Polymer and Ceramic Processing.
[2] Singh, S., et al. (2019). Recent Developments in 3D Printing of Fiber-Reinforced Polymer Composites.
[3] Sood, A. K., et al. (2019). 3D Printing for Composite Materials: A Review.
[4] Wong, K. V., et al. (2019). A Review of Additive Manufacturing.
[5] Zaldivar, R. J., et al. (2016). Additive Manufacturing of Carbon Fiber-Reinforced Plastic Composites.
[6] Gu, D., & Zhang, H. (2015). Fused Deposition Modeling of High-Performance Poly (etheretherketone) Composite Structures.