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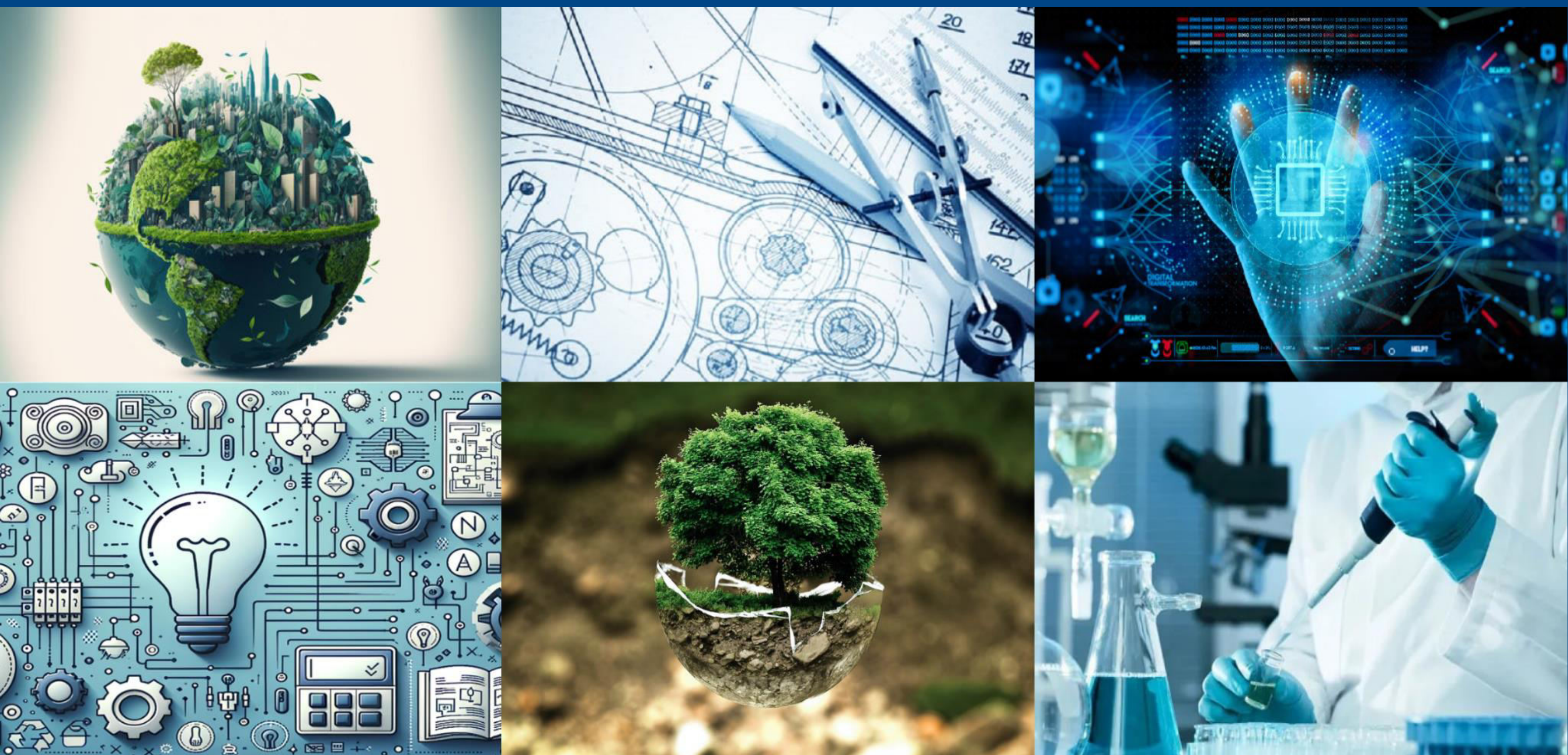

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Experimental Characteristics of 3D Printed Carbon Fiber Reinforced PLA Composites

Sangilimuthukumar Jeyaguru[1], Mohan Raj S[1], Sakthivel Murugan M[1], Sakthivel S[1], Raja M[1]

Department of Mechanical Engineering, Francis Xavier Engineering College, Tirunelveli, Tamil Nadu, India

ABSTRACT: 3D printing using composite materials has revolutionized modern manufacturing, particularly for applications requiring high strength-to-weight ratios. This study explores the experimental characteristics of carbon fiber-reinforced PLA (Polylactic Acid) composites fabricated via fused deposition modeling (FDM). The effect of carbon fiber reinforcement on mechanical properties such as tensile strength, flexural strength, impact resistance, and thermal behavior was investigated. Comparative analysis between neat PLA and carbon fiber-reinforced PLA revealed significant enhancements in strength and stiffness, while maintaining the printability and biodegradability of PLA. The study concludes that short carbon fiber-reinforced PLA composites hold immense potential for functional prototyping and lightweight structural applications.

I. INTRODUCTION

Additive manufacturing, commonly known as 3D printing, has become an innovative approach for creating complex geometries with reduced material wastage. Among various 3D printing techniques, **Fused Deposition Modeling (FDM)** is the most widely used due to its affordability and ease of use. However, the mechanical properties of standard FDM materials like PLA are limited, which restricts their use in load-bearing applications.

To overcome these limitations, reinforcing polymers with carbon fibers has become a promising solution. **Carbon fiber-reinforced PLA (CF-PLA)** is a hybrid material that combines the lightweight, biodegradable nature of PLA with the high stiffness and strength of carbon fibers. This study focuses on:

- Evaluating the **mechanical behavior** of 3D printed CF-PLA.
- Comparing CF-PLA with pure PLA under similar printing conditions.
- Studying the **thermal and morphological** characteristics using DSC and SEM.

II. MATERIALS AND METHODS

2.1 Material Selection

- **PLA (Polylactic Acid)**: Commercial-grade filament with 1.75 mm diameter.
- **Carbon Fiber Reinforced PLA (CF-PLA)**: Contains ~15% short carbon fibers dispersed within the PLA matrix.

2.2 3D Printing Parameters

- **Printer Used**: Creality Ender 5 Pro (FDM type)
- **Nozzle Diameter**: 0.4 mm
- **Layer Height**: 0.2 mm
- **Infill Density**: 100%
- **Printing Speed**: 60 mm/s
- **Nozzle Temperature**: 210°C for PLA, 220°C for CF-PLA
- **Bed Temperature**: 60°C

2.3 Mechanical Testing

Standard ASTM methods were followed:

- **Tensile Test (ASTM D638)**: UTM used at a crosshead speed of 5 mm/min.

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- **Flexural Test (ASTM D790)**: Three-point bending test setup.
- **Impact Test (ASTM D256)**: Izod method.
- **Hardness Test**: Shore D scale hardness tester.

2.4 Thermal and Morphological Analysis

- **DSC (Differential Scanning Calorimetry)**: To find the glass transition and crystallization temperature.
- **SEM (Scanning Electron Microscopy)**: To observe fiber-matrix bonding and fracture surfaces.

III. RESULTS AND DISCUSSION

3.1 Tensile Properties

Material	Ultimate Tensile Strength (MPa)	Young's Modulus (GPa)
Neat PLA	54.2	2.3
CF-PLA	72.8	4.1

The addition of carbon fibers increased the tensile strength by **34%** and stiffness by **78%**. This is due to the high load transfer capability of carbon fibers within the matrix.

3.2 Flexural Strength

CF-PLA exhibited **flexural strength of 112 MPa**, compared to **PLA's 84 MPa**, confirming improved resistance to bending loads.

3.3 Impact Strength

Although the tensile and flexural properties improved, the **impact resistance** slightly decreased due to the brittle nature of carbon fibers:

- **PLA**: 25.4 kJ/m²
- **CF-PLA**: 21.7 kJ/m²

This trade-off is typical for fiber-reinforced thermoplastics.

3.4 Hardness Test

The Shore D hardness of CF-PLA was measured at **80**, compared to **72** for PLA, indicating better surface durability and wear resistance.

IV. THERMAL ANALYSIS

4.1 Differential Scanning Calorimetry (DSC)

- **Glass Transition Temperature (Tg)**:
  - PLA: 58.4°C
  - CF-PLA: 61.7°C
- **Crystallization Peaks** were sharper for CF-PLA, suggesting carbon fibers act as nucleating agents, enhancing thermal stability.

4.2 SEM Analysis

SEM images of fracture surfaces showed:

- **Good interfacial bonding** between carbon fibers and PLA.
- Presence of **fiber pull-out zones**, indicating effective energy dissipation during failure.
- Improved layer adhesion in CF-PLA samples.

V. CONCLUSION

This experimental study shows that 3D printed CF-PLA composites exhibit:

- **Higher mechanical strength and modulus**
- **Improved surface hardness and thermal resistance**

- **Reduced impact toughness due to fiber brittleness**

These composites are suitable for applications such as drone frames, automotive brackets, custom fixtures, and lightweight jigs. The findings support the use of CF-PLA as a sustainable and functional material in structural FDM-based manufacturing.

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