



## Natural Fiber Reinforced PLA Filament Using *Luffa Cylindrica*

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### Abstract

Fused Deposition Modeling commonly uses polylactic acid due to its biodegradability and ease of processing; however, PLA is brittle and has limited mechanical strength, which restricts its use in load-bearing applications. Reinforcing PLA with natural fibers offers a sustainable approach to enhance mechanical performance. *Luffa cylindrica*, a lightweight lignocellulosic fiber, shows potential as a reinforcement, although its application in additive manufacturing is limited. This study develops and evaluates *Luffa cylindrica* reinforced PLA composite filaments for FDM printing. Dried *luffa* fibers were subjected to alkaline (NaOH) treatment, followed by drying, grinding, and pulverization using a 7000 RPM pulverizer, and sieving to obtain uniform powder. The powder was mixed with PLA pellets at 2% and 3% weight fractions and extruded into composite filaments. Standard specimens were printed using FDM and tested for tensile, compression, flexural, and shear properties. The results showed improved tensile and compressive strength at 3% reinforcement, while 2% fiber exhibited better flexural and shear behavior. The study demonstrates the potential of *Luffa cylindrica* as a sustainable reinforcement for PLA composites in additive manufacturing.

**Keywords:** *Luffa cylindrica*; PLA Composites; FDM Printing; Natural Fiber Reinforcement; Sustainable.

### 1. Introduction

Additive manufacturing (AM), particularly Fused Deposition Modeling has gained widespread attention due to its ability to fabricate complex geometries with minimal material waste. Polylactic acid is one of the most commonly used thermoplastics in FDM because of its biodegradability, low cost, and ease of processing. However, PLA suffers from inherent brittleness and limited mechanical strength, restricting its application in structural and load-bearing components. To overcome these limitations, researchers have explored the incorporation of natural fibers into PLA matrices to form composite materials. Natural fibers offer advantages such as low density, biodegradability, renewability, and cost-effectiveness. Among them, *Luffa cylindrica* has attracted attention due to its porous, fibrous, and lightweight structure, which makes it a promising reinforcement material. Despite its potential, limited studies have been conducted on the use of *Luffa cylindrica* in additive manufacturing applications. This study aims to bridge this gap by developing and

evaluating *Luffa cylindrica* reinforced PLA composite filaments and analyzing their mechanical performance.

### 2. Literature Review

Natural fiber-reinforced polymer composites have garnered considerable attention because of their eco-friendliness, low density, and cost-effectiveness. Researchers have extensively investigated the integration of natural fibers such as flax, hemp, jute, and bamboo into polymer matrices to boost mechanical properties while maintaining sustainability. Findings indicate that these fibers can enhance tensile strength, stiffness, and thermal characteristics when effectively combined with polymers (Faruk et al., 2012). Polylactic acid (PLA) is among the most commonly used biodegradable polymers in additive manufacturing, especially in Fused Deposition Modeling (FDM). However, its natural brittleness and low impact resistance restrict its use in structural applications. To overcome these limitations, various studies have aimed at reinforcing PLA with natural fibers. Pickering et al. (2016) found

that natural fiber reinforcement significantly enhances the mechanical properties of PLA composites, although the effectiveness relies on fiber treatment, dispersion, and interfacial bonding. Fiber pre-treatment is essential for improving composite performance. Alkali (NaOH) treatment is frequently employed to eliminate lignin, hemicellulose, and surface contaminants, thus enhancing fiber-matrix adhesion. Mohanty et al. (2005) showed that treated fibers display better compatibility with polymer matrices, leading to increased strength and reduced moisture uptake. Within the realm of additive manufacturing, the use of natural fiber-reinforced filaments introduces specific challenges. Problems such as nozzle clogging, uneven filament consistency, and irregular extrusion have been documented due to inadequate fiber size and distribution. Le Duigou et al. (2016) emphasized that control over particle size and uniform dispersion are vital for successful FDM printing of composite materials. Although there is substantial research on commonly used fibers, limited attention has been given to *Luffa cylindrica*. Its porous and fibrous structure provides potential benefits such as lightweight reinforcement and enhanced energy absorption. Nonetheless, its application in PLA-based FDM composites remains largely unexplored. Consequently, this study seeks to fill this research gap by examining the viability of using *Luffa cylindrica* as a reinforcement in PLA composite filaments. The study centers on processing techniques, filament fabrication, and mechanical performance assessment to advance the development of sustainable materials for additive manufacturing. should be described in detail. Cite previously published procedures in References. Tables and Figures are presented center, as shown below and cited in the manuscript.

### 3. Method

The methodology employed in this study centers on the development of natural fiber-reinforced composite filaments using *Luffa cylindrica* and polylactic acid (PLA), followed by the preparation of test specimens and mechanical evaluation. The entire process encompasses material selection, fiber processing, filament extrusion, specimen fabrication,

and mechanical testing.

#### 3.1. Material Selection

Polylactic acid (PLA) was selected as the matrix material due to its biodegradability, ease of processing, and compatibility with fused deposition modeling (FDM) 3D printing. *Luffa cylindrica* fibers were chosen as the reinforcement material owing to their lightweight, porous lignocellulosic structure, availability, and sustainability. The integration of PLA with natural fibers aims to enhance mechanical properties while preserving environmental benefits.

#### 3.2. Fiber Selection

##### 3.2.1. Raw Fiber Selection

Dried *Luffa cylindrica* fibers were collected and manually cleaned to remove dust, impurities, and foreign particles. Proper selection ensures consistent material properties.

##### 3.2.2. Cleaning and Drying

The fibers were thoroughly washed with water to eliminate surface contaminants. Subsequently, they were dried under controlled conditions to remove moisture, which is essential to prevent defects during extrusion and printing.



**Figure 1 Treated Luffa Cylindrica with NaOH**

##### 3.2.3. Pre-Treatment (Alkali Treatment)

The fibers underwent alkali treatment using a sodium hydroxide (NaOH) solution. This process removes lignin, hemicellulose, waxes, and other impurities from the fiber surface, thereby improving fiber-

matrix adhesion and enhancing mechanical performance.

### 3.2.4. Grinding and Pulverizing

The treated fibers were cut into smaller pieces and subjected to grinding to produce coarse particles. Further reduction in size was achieved using a high-speed pulverizer operating at approximately 7000 RPM, converting the fibers into fine powder suitable for composite processing.



**Figure 2 Powdered Luffa Cylindrica**

### 3.2.5. Sieving

The pulverized fibers were sieved to obtain a uniform particle size distribution. Uniform particle size is crucial for consistent mixing, smooth extrusion, and preventing nozzle clogging during FDM printing.

### 3.3.Extrusion

The processed Luffa fiber powder was mixed with PLA pellets in two different weight fractions: 2% fiber reinforcement 3% fiber reinforcement The mixture was fed into a filament extrusion system to create composite filaments. During the initial extrusion, filament breakage and inconsistent diameter were observed due to poor bonding and dispersion. To resolve this issue, the material was re-extruded, leading to improved filament quality and uniformity.

### 3.4.Test Specimen Creation

Preparation Standard test specimens were fabricated using FDM 3D printing technology. The printed samples were prepared according to standard dimensions suitable for mechanical testing. Consistent printing parameters were maintained to

ensure uniformity across all samples.



**Figure 2 Dog-Bone Test Specimen**

### 3.5.Testing

The fabricated specimens underwent various mechanical tests to assess the performance of the composite material. The tests conducted include:

- Tensile Test – to determine strength and elongation behavior
- Compression Test – to evaluate load-bearing capacity
- Flexural Test – to analyze bending strength
- Shear Test – to assess resistance to shear forces

The mechanical behavior was analyzed using:

- Load vs. Displacement curves
- Stress vs. Strain curves

These analyses provide insight into material stiffness, strength, and deformation characteristics for different

## 4. Results and Discussion

### 4.1.Results

The mechanical properties of Luffa cylindrica reinforced PLA composites were tested and compared with pure PLA. The findings show that adding fiber improves tensile and compressive strength. Tensile strength went up from 20.4 N/mm<sup>2</sup> for pure PLA to 22.7 N/mm<sup>2</sup> at 2% fiber and further to 27.06 N/mm<sup>2</sup> at 3%, showing better ability to handle loads. Compression strength also improved, from 43.43 N/mm<sup>2</sup> for PLA to 46.9 N/mm<sup>2</sup> at 2% and 48.73 N/mm<sup>2</sup> at 3%, meaning the material can better handle squeezing forces. These results suggest that

adding Luffa fibers helps transfer stress more effectively and makes the composite stronger overall. On the other hand, flexural and shear properties moved in a different direction. The 2% fiber composite had the highest flexural strength at 3.34 N/mm<sup>2</sup>, which is better than pure PLA (2.16 N/mm<sup>2</sup>) and the 3% composite (2.93 N/mm<sup>2</sup>), showing better flexibility when less fiber is used. Shear strength also went up a lot with 2% fiber (41.73 N/mm<sup>2</sup>) compared to PLA (33.66 N/mm<sup>2</sup>), but dropped slightly at 3% (38.26 N/mm<sup>2</sup>), possibly due to weaker bonding between fibers and the matrix. Overall, the results show that higher fiber content makes the material stronger in tension and compression, but lower fiber content gives better flexibility and shear resistance. This means finding the right amount of fiber is important to get the best balance of mechanical properties.

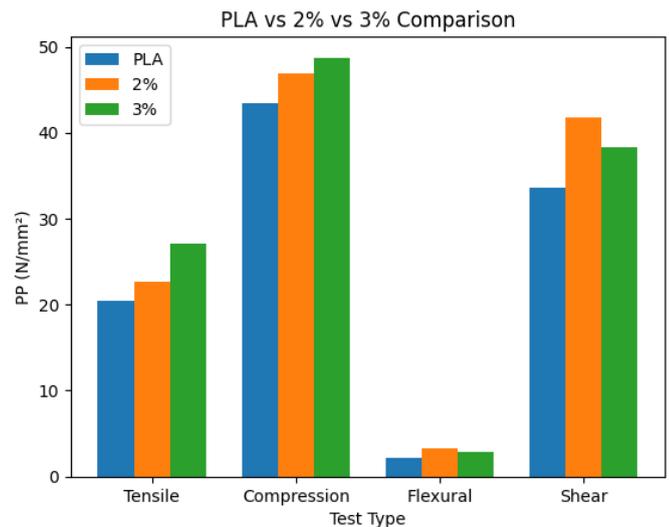
**Table 1 PLA vs 2% vs 3%**

Test	Sample	PLA	2% (N/mm <sup>2</sup> )	3% (N/mm <sup>2</sup> )
Tensile	T1	21.4	19.1	27.8
	T2	19.1	27.2	27.8
	T3	20.7	21.8	25.6
	<b>Mean</b>	<b>20.4</b>	<b>22.7</b>	<b>27.06</b>
Compression	C1	43.6	46.9	47.5
	C2	43.2	46.9	51.6
	C3	43.5	46.9	47.1
	<b>Mean</b>	<b>43.43</b>	<b>46.9</b>	<b>48.73</b>
Flexural	F1	1.8	2.5	3.5
	F2	2.5	4	2.5
	F3	2.2	3.5	2.8
	<b>Mean</b>	<b>2.16</b>	<b>3.34</b>	<b>2.93</b>
Shear	S1	34.1	50	36.2
	S2	33.3	37.1	34.9
	S3	33.6	38.1	43.7
	<b>Mean</b>	<b>33.66</b>	<b>41.73</b>	<b>38.26</b>

### 4.2. Discussion

The increase in tensile and compressive strength as more Luffa cylindrica fibers are added is because the fibers work well with the PLA material to transfer stress effectively. The natural structure of Luffa, made up of lignocellulosic components, helps spread the load better throughout the composite. When fiber content goes from 2% to 3%, there are more points where the fibers can support the material, which

makes it stronger against pulling and pushing forces. This shows the fibers are helping to strengthen the material, not just filling up space. However, when fiber content gets too high, like at 3%, the flexural and shear strength drops. This is because the fibers might not be spread out evenly, they could clump together, and the connection between the fibers and the matrix might be weak. These problems make the material less flexible and less efficient at handling bending and shear forces. On the other hand, the 2% fiber composite performs better because the fibers are more evenly spread and the connection between fibers and the matrix is stronger. These findings show that there is an ideal amount of fiber needed to balance strength and flexibility. Adding too many fibers beyond that point actually hurt the overall performance the material.



**Figure 1 Test Results**

### Conclusion

This study effectively showcased the development and assessment of Luffa cylindrica reinforced PLA composite filaments for FDM-based additive manufacturing. The findings indicated that the inclusion of natural fibers significantly affects the mechanical properties of PLA. As the fiber content increased from 2% to 3%, there was an improvement in tensile and compressive strength, suggesting better load-bearing ability due to enhanced stress transfer between the fiber and matrix. Nevertheless, the study also found that higher fiber content can adversely



affect flexural and shear properties, attributed to issues such as poor dispersion, fiber agglomeration, and weak interfacial bonding. The 2% composite displayed better flexibility and shear performance, whereas the 3% composite exhibited greater tensile and compressive strength. These results emphasize the need for an optimal fiber content to attain a balanced set of mechanical properties. In conclusion, *Luffa cylindrica* demonstrates as a viable and sustainable reinforcement material for PLA composites. The research contributes to the creation of eco-friendly materials for additive manufacturing and underscores the significance of process optimization in enhancing composite performance.

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