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Development of Plantain Pseudostem Fibre Reinforced Epoxy Composites for

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Abstract

This research investigates the development of a low-cost composite material reinforced with plantain pseudostem fibre in an epoxy resin matrix. The aim is to create a cost-effective and environmentally friendly alternative for low-stress mechanical applications, particularly in areas where access to synthetic materials is limited. The plantain pseudostem, a common agricultural waste in Nigeria, was processed and treated to enhance bonding with epoxy resin. Using simple fabrication techniques like hand lay-up, composite samples were produced with different fiber contents. These samples were then tested for strength, flexibility, and impact resistance. The results showed that moderate fibre loading (around 20%) provided a good balance of strength and durability, suitable for applications such as interior panels, partitions, and lightweight covers. Water absorption tests also showed that treated fibres held up better in humid conditions. Compared to traditional materials like glass fibre, the plantain-based composite was significantly cheaper, making it ideal for both educational and industrial use. This work shows how local materials can be converted into valuable engineering products and highlights the potential of agricultural waste in teaching practical composite technology in technical and vocational institutions.

Keywords: Epoxy, Plantain fiber, Composite, Local materials, Low-stress applications

1.0 Introduction

The increasing need for affordable, eco-friendly, and locally sourced materials in engineering has pushed researchers toward bio-based composites. Natural fibres such as jute, banana, hemp, and sisal are emerging as alternatives to synthetic fibres due to their renewability, low cost, and compatibility with polymer matrices. In the Nigerian context, plantain pseudostem, often discarded as agricultural waste, remains largely underutilised despite its high cellulose and fibre content (Adebayo & Ogunlade, 2023).

Synthetic fibre composites like glass and carbon fiber, while offering superior strength, are expensive and not environmentally sustainable. Additionally, the dependence on imported materials presents challenges for developing economies like Nigeria. Thus, using plantain pseudostem fibre as reinforcement in epoxy resin composites presents a dual advantage: reducing waste and creating low-cost alternatives suitable for low-stress applications such as interior panels, ceiling boards, and educational training tools (Kumar *et al.*, 2022).

Epoxy resin is widely used as a composite matrix because of its strength, adhesive properties, and durability. However, the hydrophilic nature of natural fibres and the hydrophobic nature of epoxy necessitate surface treatment of the fibres to enhance bonding. Alkali treatment with sodium hydroxide has proven effective in improving adhesion by removing lignin and increasing surface roughness (Sharma *et al.*, 2022; Okonkwo & Alabi, 2021).

Prior studies on natural fibre reinforced composites show that optimal mechanical performance often occurs with 20–30% fibre content. Composites developed within this range demonstrate balanced tensile, flexural, and impact strength, especially when fibres are properly treated (Patel & Singh, 2023). However, there is limited literature specifically focused on plantain pseudostem fiber in reinforced epoxy composites, particularly within Nigeria's local manufacturing or TVET contexts.

The aim of this study is to extract and treat plantain pseudostem fiber, fabricate fiber reinforced, and evaluate their mechanical performance and moisture resistance. The outcomes are expected to support practical applications in engineering education and cost-effective manufacturing, particularly in rural areas and vocational institutions (Ogunlaja & Oyenuga, 2024; Nnamdi *et al.*, 2021).

This study contributes to material innovation, local resource utilization, and experiential learning in engineering education by offering an accessible composite technology using abundant plant-based waste.

2.0 Materials and Methods

2.1 Materials

i. Plantain Pseudostem Fiber (PPF): Collected from a local farm in Ogun State, Nigeria. The fibers were manually extracted from fresh pseudostems.
ii. Epoxy Resin: A two-part epoxy system (resin and hardener in a 2:1 ratio) purchased from a verified chemical supplier.
iii. Sodium Hydroxide (NaOH): Used for the alkali treatment of fibers to enhance fiber–matrix bonding.
iv. Distilled Water: Used for cleaning and rinsing treated fibers.

2.1.1 Equipment and Tools

i. Weighing balance (±0.01g precision)
ii. Oven (up to 105°C)

iii. Universal Testing Machine (UTM)
iv. Impact tester (Charpy or Izod)
v. Flexural test fixture
vi. Moulds for hand lay-up
vii. Vernier caliper and micrometer screw gauge

2.2 Fiber Extraction and Preparation

Fresh pseudostems were sliced into manageable sections, from which the outer sheath layers were removed to expose the fibrous core. The fibers were extracted manually by scraping and rinsed in water.

2.3 Chemical Treatment (Alkalization)

The raw fibers were soaked in a 5% NaOH solution for 4 hours to remove lignin, hemicellulose, and surface impurities. The fibers were then thoroughly washed with distilled water to neutralize the solution and dried in an oven at 70°C for 24 hours.

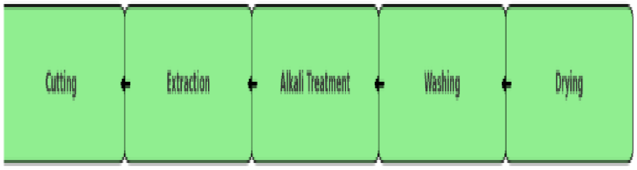

Figure 1: Flowchart of Fiber Treatment Process

2.4 Composite Fabrication Process

A hand lay-up technique was adopted due to its simplicity and affordability, making it suitable for TVET applications.

2.5 Mould Preparation

Steel moulds (dimensions: 150 mm × 150 mm × 5 mm) were cleaned and coated with wax to aid easy removal of composite plates.

2.6 Mixing and Layering

Epoxy resin and hardener were mixed thoroughly at a 2:1 ratio. Treated plantain fibers were added to the mixture at different volume fractions (10%, 20%, 30%), ensuring uniform distribution. The resin-fiber mixture was poured into the mould and pressed uniformly.

2.7 Curing

Composites were left to cure at room temperature for 24 hours, followed by post-curing in an oven at 60°C for 2 hours to ensure complete cross linking.

2.8 Experimental Testing Procedures

The following mechanical and physical tests were performed:

2.8.1 Tensile Test

Conducted using a UTM according to ASTM D638. Specimens were cut into dog-bone shapes.

Formula Used:

$$Tensile\ Strength = \frac{F_{\max}}{A} \qquad 2.1$$

Where: $F_{\max}$ = Maximum Load (N)

A = cross-sectional area (mm²)

2.8.2 Flexural Test

Three-point bending tests were performed following ASTM D790 to determine flexural strength.

Formula Used:

$$Flexural\ Strength = \frac{3FL}{2bd^3} \qquad 2.2$$

Where:

F= load at fracture (N)

L = span length (mm)

b = specimen width (mm)

d = specimen thickness (mm)

2.8.3 Impact Test

Carried out using a Charpy impact tester. Specimens were notched according to ASTM D256.

2.8.4 Water Absorption Test

Samples were immersed in distilled water for 24, 48, and 72 hours. The percentage of water absorbed was calculated as:

$$Water\ Absorption\ Test\ (\%) = \frac{W_1 - W_2}{W_1} \times 100 \qquad 2.3$$

Where:

W_1 = initial dry weight

W_2 = weight after immersion

Table I: Experimental Test Methods and Standards

Property	Test Method	Standard	Equipment Used
Tensile Strength	Tensile Testing	ASTM D638	UTM
Flexural Strength	Three-Point Bend	ASTM D790	UTM with Flexural Jig
Impact Strength	Charpy Test	ASTM D256	Impact Tester
Water Absorption	Immersion Method	ASTMD570	Balance, Water Bath

2.9 Experimental Design

Three different fiber volume fractions were considered:

Sample A: 10% PPF

Sample B: 20% PPF

Sample C: 30% PPF

A control sample (Sample D) with 0% fiber was also prepared. Each sample group had at least three replicates to ensure test consistency and accuracy.

3.0 Results and Discussions

3.1 Flexural Strength Results and Discussion

The flexural strength of the composite samples was evaluated using a three-point bending test. The results showed a noticeable increase in flexural strength as the fiber volume increased from 10% to 20%, with a slight decline observed at 30%.

Table II: Comparing Flexural Strength Across Samples

Sample	**Fiber Volume (%)**	**Flexural Strength (MPa)**
A	10	42.8
B	20	48.7
C	30	41.2
D (Control)	0	35.4

The maximum flexural strength (48.7 MPa) was recorded in Sample B (20%), indicating that moderate fiber reinforcement provides an optimal balance between stiffness and matrix continuity. The improved strength is due to enhanced interfacial bonding between the treated plantain fibers and epoxy resin, which enables better load distribution under bending stress (Sharma *et al*., 2022; Kumar *et al.*, 2022). At 30% fiber volume, the composite exhibited a slight decrease in flexural strength. This drop is attributed to the likelihood of fiber clustering, which reduces effective stress transfer within the matrix and introduces microvoids. These findings align with earlier research, which suggests that the mechanical benefits of natural fibers peak around 20–25% volume fractions (Patel & Singh, 2023).

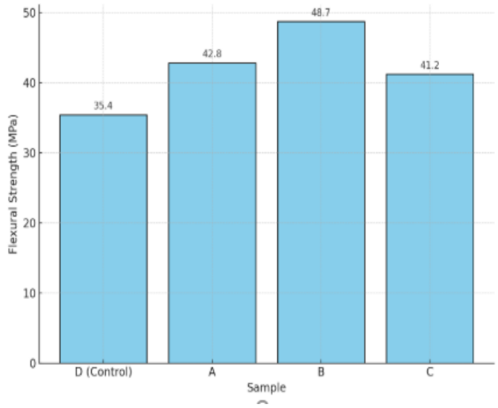

Figure 2: Graph of Flexural Strength against Fiber Volume

3.2 Impact Strength Results and Discussion

The impact strength of the samples was evaluated using the Charpy impact test. This test measures the material's toughness or energy absorption before fracture under sudden loading.

Table III: Comparison the Fiber Volume and Impact Strength

Sample	**Fiber Volume (%)**	Impact Strength **(kJ/m²)**
A	10	4.8
B	20	6.2
C	30	4.7
D (Control)	0	3.4

Sample B (20%) again recorded the highest impact strength (6.2 kJ/m²), indicating that properly dispersed fibers significantly enhance the material's ability to absorb energy. The enhanced toughness is attributed to the energy-dissipating mechanisms introduced by the fibers, such as fiber pull-out and matrix crack deflection during impact (Adebayo & Ogunlade, 2023).

However, a decline in impact strength was noticed at 30% fiber loading. This is consistent with the observation that excess fiber content may lead to agglomeration**,** weak fiber–matrix bonding, and discontinuities in the material structure, which reduce energy absorption during fracture (Ogunlaja & Oyenuga, 2024).

These results confirm that 20% plantain pseudostem fiber reinforcement offers optimal mechanical performance for low-stress applications in building panels, automotive trims, and educational tooling.

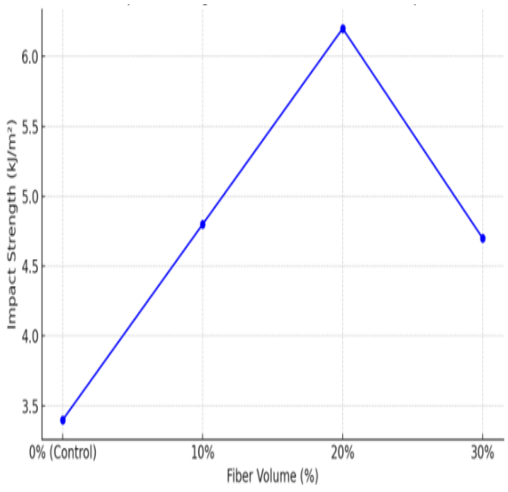

Figure 3: Impact Strength Vs Fiber Volume

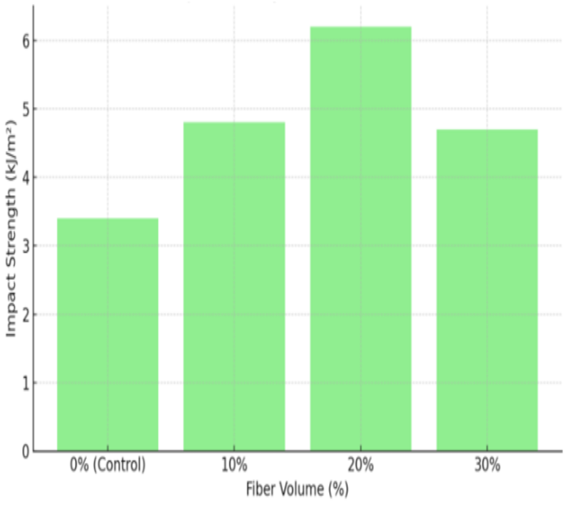

Figure 4: Impact Strength Vs Fiber Volume

3.3Tensile Strength Results

The tensile strength of the composites increased with fiber content up to 20% and then declined at 30%. This trend suggests optimal reinforcement and bonding at moderate fiber loading. Below is the summary of results:

Table IV: Comparison of Fiber content, Tensile Strength of the Samples

Sample	Fiber Content (%)	Tensile Strength (MPa)
A	10	22.1
B	20	26.5
C	30	21.7
D (Control)	0	18.3

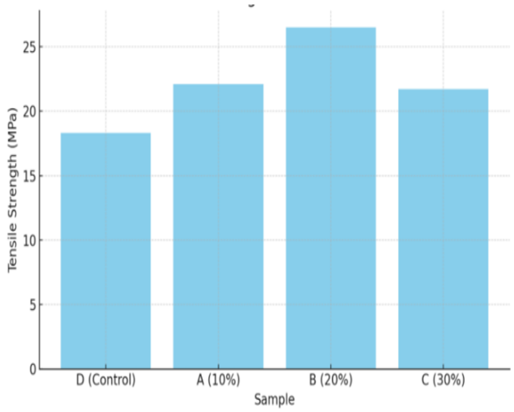

Figure 5: Tensile Strength Vs Fiber Content

3.4 Water Absorption Behavior

Water absorption tests revealed that untreated natural fibers absorb water significantly. Samples with higher fiber content showed increased water uptake, but alkali-treated fibers displayed better dimensional stability

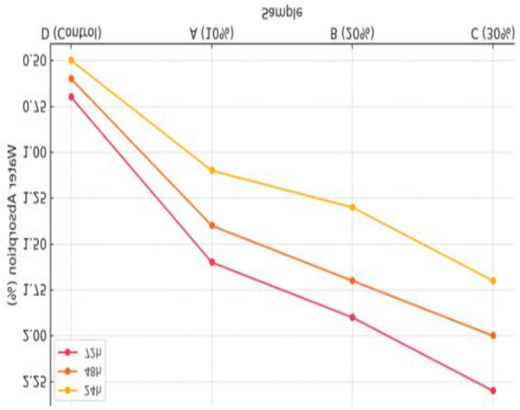

Figure 6: Water Absorption over Time

The study validates that plantain pseudostem fibre can serve as a viable reinforcement in epoxy composites for low-stress applications. The optimum performance was recorded at 20% fibre volume fraction. Increased fiber content beyond this led to decreased mechanical properties, likely due to fiber agglomeration and void formation.

4.0 Conclusion

This study has shown that plantain pseudostem fiber (PPF), a material often treated as waste, can be effectively used as reinforcement in epoxy composites for low-stress engineering applications. From the tests carried out, the sample with 20% fiber content performed the best in terms of tensile, flexural, and impact strength. This suggests that at moderate levels, the plantain fiber strengthens the composite without compromising the structure or causing bonding issues. The treatment of the fibers using sodium hydroxide (NaOH) made a big difference. It helped improve the bonding between the natural fiber (which loves water) and the epoxy resin (which repels water), allowing the composite to perform better mechanically. However, when the fiber content was increased to 30%, the mechanical properties dropped. This was likely due to the fibers becoming too crowded or not mixing well, which caused tiny air spaces (voids) that weakened the structure. Water absorption results also showed that the more fiber a sample had, the more moisture it absorbed. While the treated fibers handled water better than untreated.

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