Effect of Foxtail Millet Biosilica on the Mechanical Behaviour of Pineapple Fiber Reinforced Epoxy Composites

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Abstract
Natural fiber reinforced polymer composites have emerged as promising alternatives to conventional synthetic materials due to their environmental sustainability, low density, and cost-effectiveness. In the present study, a hybrid composite was developed using pineapple fiber as the primary reinforcement, epoxy resin as the matrix material, and biosilica derived from agricultural waste as a filler. The biosilica content was maintained constant while varying the proportions of fiber and resin to investigate its influence on the overall mechanical behavior of the composite. The composite laminates were fabricated using the hand lay-up technique, followed by curing under ambient conditions. Standard test specimens were prepared and subjected to mechanical characterization, including tensile, compressive, flexural, impact, and hardness tests. The experimental results reveal that the incorporation of biosilica significantly enhances interfacial adhesion between the fiber and matrix, resulting in improved load transfer efficiency, increased strength, and enhanced surface hardness. Furthermore, the developed composite exhibits favorable energy absorption characteristics and structural integrity under different loading conditions. The findings of this study highlight the potential of biosilica-filled natural fiber composites as lightweight, eco-friendly, and high-performance materials suitable for applications in automotive, construction, and other engineering sectors.

Keywords: Natural Fiber Reinforced Composite, Biosilica Filler, Pineapple Fiber, Epoxy Resin, Mechanical Characterization, Tensile Strength, Flexural Strength, Impact Strength, Hardness, Eco-friendly Materials

1. Introduction

In recent years, increasing environmental concerns and the need for sustainable development have led to the growing interest in eco-friendly materials. Conventional synthetic fiber composites, although possessing high strength, are non-biodegradable and contribute to environmental pollution. As a result, natural fiber reinforced composites have emerged as a viable alternative due to their renewability, biodegradability, low density, and cost-effectiveness.

Natural fibers such as pineapple fiber have gained significant attention in composite applications because of their good mechanical properties, availability, and lightweight characteristics. These fibers provide a favorable strength-to-weight ratio, making them suitable for various structural and semi-structural applications. Additionally, natural fibers require less energy for processing compared to synthetic fibers, making them more sustainable.

To further enhance the performance of natural fiber composites, filler materials are incorporated into the matrix. Biosilica, derived from agricultural waste such as rice husk or other biomass sources, has proven to be an effective reinforcing filler. It improves the interfacial bonding between the fiber and matrix, reduces void formation, and enhances mechanical properties such as strength, stiffness, and hardness.

The mechanical behavior of composite materials is evaluated through various tests such as tensile, compression, flexural, impact, and hardness testing. Tensile testing determines the ability of the material to withstand pulling forces, while compression testing evaluates its resistance to compressive loads. Flexural testing measures bending strength, and impact testing assesses the material's ability to absorb sudden energy. Hardness testing indicates the resistance of the material surface to indentation and wear.

Several researchers have investigated natural fiber reinforced composites due to their eco-friendly properties and low cost. Studies have shown that natural fibers such as pineapple fiber exhibit good mechanical strength and are suitable for lightweight applications. The incorporation of fillers like silica has been reported to enhance interfacial bonding between the fiber and matrix. Biosilica derived from agricultural waste has gained attention as a sustainable reinforcing material. Previous research indicates that the addition of biosilica improves tensile, flexural, and impact properties of composites. Moreover, hybrid composites with fillers show better durability and hardness compared to conventional composites. However, most studies focus on varying filler content rather than maintaining it constant. Therefore, this study aims to evaluate the mechanical performance of composites with constant biosilica content.

In this study, a natural fiber reinforced composite is developed using pineapple fiber and epoxy resin, with biosilica used as a filler material. The biosilica content is maintained constant while varying the proportions of fiber and matrix. The objective of this work is to investigate the effect of fiber content on the mechanical properties of the composite and to evaluate its suitability for engineering applications.

The developed composite material is expected to find applications in automotive components, building materials, and other lightweight structures where eco-friendly and sustainable materials are required.

2. Materials and Methods

2.1 Materials

The materials used in this study include:

- Pineapple Fiber (Reinforcement)
- Epoxy Resin (Matrix)
- Hardener
- Biosilica (Filler material derived from husk)

2.2 Fabrication Process

The composite was fabricated using the hand lay-up technique. Initially, the mold was prepared and coated with a releasing agent. The pineapple fibers were cut into required sizes and placed uniformly in the mold. Epoxy resin and hardener were mixed in a proper ratio and applied over the fiber layers. Biosilica was added and distributed evenly throughout the matrix. The composite was then compressed and allowed to cure at room temperature. After curing, the specimens were removed and cut according to standard dimensions for mechanical testing.

2.3 Specimen Dimensions

The test specimens were prepared as per standard sizes:

- Tensile Test: 400 mm × 40 mm × 10 mm
- Compression Test: 50 mm × 50 mm × 50 mm
- Flexural Test: 400 mm × 40 mm × 40 mm
- Impact Test: 63.5 mm × 12.7 mm × 3 mm
- Hardness Test: 10 mm × 10 mm

2.4 Specimen Identification

Specimen	(%) of fiber	(%) of epoxy	(%) of filler
D1	60	40	-
D2	60	37	3%
D3	60	35	5%
D4	60	33	7%

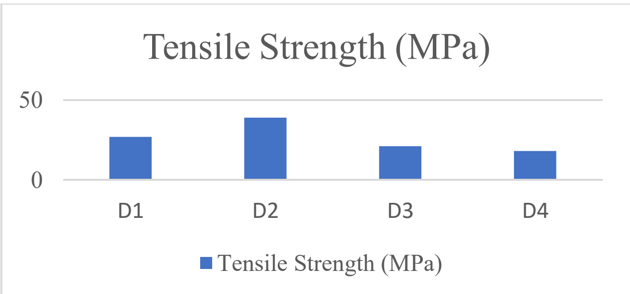
3. Results and Discussion

3.1 Tensile Test

The tensile strength of the composite varies with the addition of biosilica filler, showing improvement at optimal filler content and reduction at higher filler percentages, indicating effective stress transfer between the matrix and reinforcement. The presence of biosilica enhances interfacial bonding, resulting in improved load-bearing capacity. The optimal composition exhibits the highest tensile strength due to uniform distribution of fiber and filler.

Table 3.1 Tensile Test Results

Composition (Fiber/Epoxy/Filler)	Tensile Strength (MPa)
D1	27
D2	39
D3	21
D4	18



Tensile Graph

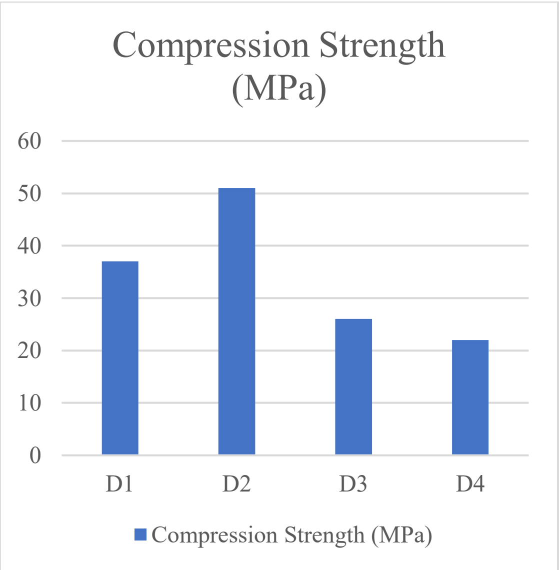
- Tensile strength increases due to enhanced fiber–matrix interfacial adhesion.
- Biosilica contributes to improved stress transfer efficiency within the composite.
- Optimal composition exhibits maximum ultimate tensile strength (UTS).
- Beyond the optimal filler content (3%), excessive biosilica leads to agglomeration and weak interfacial bonding, resulting in reduced tensile strength.

3.2 Compression Test

The compressive strength shows a gradual improvement due to the addition of biosilica, which increases the stiffness of the composite material. The filler restricts deformation under compressive loads, thereby enhancing structural stability. Higher strength values are observed for samples with better matrix–filler interaction.

Table 3.2 Compression Test Results

Composition (Fiber/Epoxy/Filler)	compression Strength (MPa)
D1	37
D2	51
D3	26
D4	22



Compression Graph

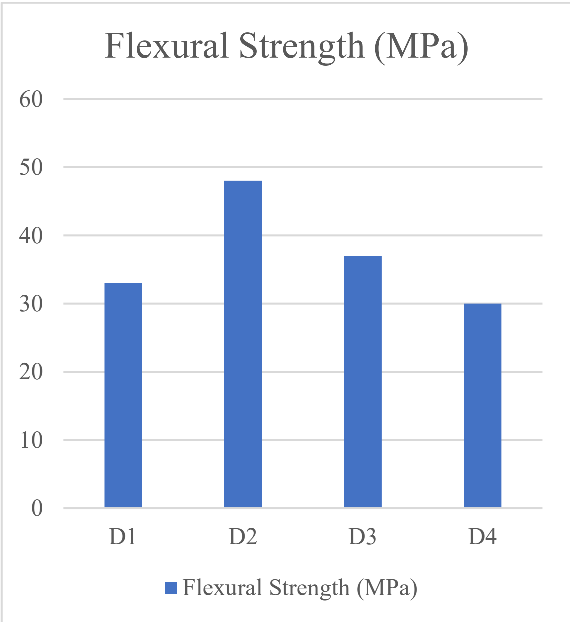
- Compressive strength improves due to increased matrix stiffness and filler reinforcement.
- Biosilica restricts plastic deformation under compressive loading.
- Enhanced load-bearing capacity observed with uniform filler dispersion.

3.3 Flexural Test

Flexural strength results indicate improved resistance to bending loads with increasing fiber reinforcement. The uniform dispersion of biosilica contributes to better stress distribution across the composite. The maximum flexural strength is observed in samples with balanced fiber and resin composition.

Table 3.3 Flexural Test Results

Composition (Fiber/Epoxy/Filler)	Flexural Strength (MPa)
D1	33
D2	48
D3	37
D4	30



Flexural Graph

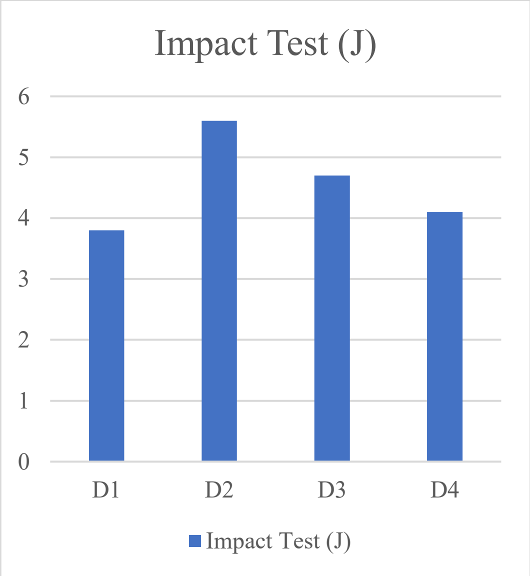
- Flexural strength increases due to improved interfacial bonding and structural integrity.
- Uniform biosilica distribution enhances stress distribution under bending load.
- Higher flexural modulus achieved at optimal fiber–matrix ratio.

3.4 Impact Test

The impact strength of the composite increases due to the energy absorption capability of natural fibers. The presence of biosilica improves the toughness of the material by preventing crack propagation. The composite exhibits better impact resistance at optimized fiber content.

Table 3.4 Impact Test Results

Composition (Fiber/Epoxy/Filler)	Impact Strength (MPa)
D1	3.8
D2	5.2
D3	5.8
D4	4.9



Impact Graph

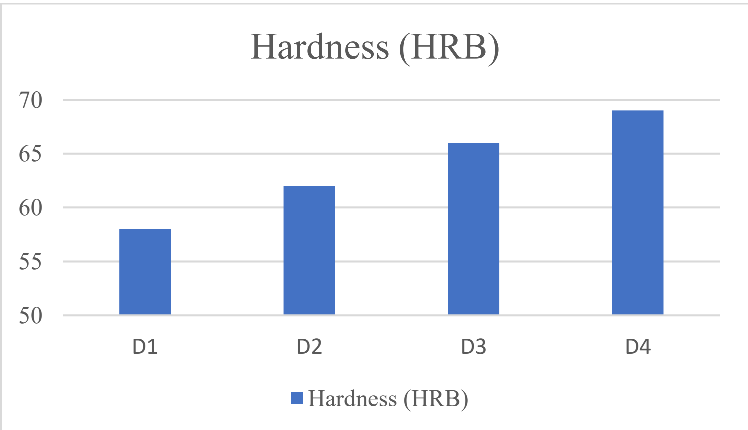
- Impact strength improves due to increased energy absorption capacity of fibers.
- Biosilica reduces crack initiation and propagation.
- Composite exhibits higher impact toughness at optimized composition.

3.5 Hardness Test

Hardness values increase with the addition of biosilica, indicating enhanced surface resistance. The filler material improves the rigidity and reduces surface deformation under applied load. Higher hardness is achieved due to strong bonding between fiber, matrix, and filler.

Table 3.5 Hardness Test Results

Composition (Fiber/Epoxy/Filler)	Hardness Strength (MPa)
D1	58
D2	62
D3	66
D4	69



Hardness Graph

- Hardness increases due to enhanced surface rigidity from biosilica addition.
- Improved resistance to localized plastic deformation is observed.
- Strong interfacial bonding results in higher indentation resistance.

Table 3.6 Overall Mechanical Performance Comparison

Test	Best Sample	Maximum Value
Tensile	D2	39(MPa)
Compression	D2	51(MPa)
Flexural	D2	48(MPa)
Impact	D3	5.8(J)
Hardness	D4	69(HRB)

4. Conclusion

The present study successfully developed a natural fiber reinforced composite using pineapple fiber, epoxy resin, and biosilica as a filler material. The biosilica content was maintained constant while varying the fiber and resin proportions.

The experimental results revealed that the incorporation of biosilica significantly enhanced the mechanical properties of the composite. The tensile, compressive, and flexural strengths showed noticeable improvement due to better interfacial bonding between the fiber and matrix. Additionally, impact strength and hardness values increased, indicating improved energy absorption capacity and surface resistance.The composite with 3% biosilica (D2) exhibited maximum tensile (39 MPa), compressive (51 MPa), and flexural strength (48 MPa), indicating optimal filler content.

Among the tested compositions, the optimized sample exhibited superior overall performance compared to other combinations. The developed composite is lightweight, eco-friendly, and cost-effective, making it suitable for applications in automotive components, construction materials, and other structural applications. The developed composite can be effectively used in lightweight applications such as automotive interior components, panels, and eco-friendly construction materials. The material can be further explored for applications in automotive and structural components. These composites are widely used in automotive and construction industries.

5. Future Scope

Further research can be carried out by varying the percentage of biosilica content to analyze its effect on mechanical properties in detail. Different natural fibers such as banana fiber, jute fiber, and sisal fiber can be explored to compare performance with pineapple fiber composites.

Advanced fabrication techniques like compression molding and vacuum infusion can be adopted to improve uniformity and reduce voids in the composite structure. In addition, thermal analysis and water absorption tests can be performed to evaluate the durability and environmental resistance of the material. The developed composite can be extended for real-time applications such as automotive interior components, lightweight panels, and eco-friendly construction materials.

6. References

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