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OPTIMIZATION OF MECHANICAL PROPERTIES IN BANANA-GLASS FIBER HYBRID COMPOSITES THROUGH SURFACE TREATMENT

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ABSTRACT

In this study, banana/glass hybrid fiber-reinforced polyester composites were developed using the hand layup technique, with various process parameters to optimize the joint strength of the composite laminates. The parameters considered include fiber condition (treated and untreated), fiber sequence (banana and glass), NaOH concentration, boiling time, fiber length proportions, fiber content, and microwave curing time.

Randomly oriented chopped banana fibers and chopped strand mat E-glass fibers were reinforced into a polyester resin matrix to fabricate composites in three different weight percentage (wt%) ratios of banana fiber, with three varying fiber lengths. The banana fibers were treated (boiled) with three different concentrations of NaOH to assess the effect of alkaline treatment. After fabrication, the hybrid composite laminates underwent post-curing in a microwave oven. Mechanical testing was performed to evaluate their strength characteristics. Additionally, the morphological analysis of the microwave-cured banana/glass hybrid composite systems was conducted using Scanning Electron Microscopy (SEM) to study the fiber-matrix interface and microstructural features.

Keyword: *NaOH treatment, laminates, hybrid composites, boiling time and SEM.*

INTRODUCTION

Natural fibers are increasingly gaining attention as renewable, environmentally friendly, and biodegradable materials for various industrial applications, including technical textiles, composites, pulp and paper production, civil engineering, and construction. Natural fiber-reinforced composites offer an advantageous combination of acceptable mechanical properties and low density. These composites provide numerous benefits, such as low cost, renewable resource availability, biodegradability, and eco-friendliness 1,2.

Compared to inorganic fibers, natural fibers offer advantages like lower density, lower cost, and reduced abrasiveness to processing equipment. Additionally, they are harmless, biodegradable, renewable, and can exhibit mechanical properties comparable to inorganic fibers 3−6. Various natural fibers, including flax, jute, banana, hemp, and coir, have been studied as potential reinforcements in composites 7−9. However, when natural fibers are used as reinforcements, interfacial incompatibility remains a significant challenge.

Surface modification of natural fibers through chemical treatments has become a major research focus to enhance compatibility and improve interfacial bonding. It is essential to note that chemical treatments can either enhance or degrade fiber strength, making it crucial to understand the structural changes that occur during treatment 10.

In recent years, the demand for composite materials has grown, primarily due to their superior properties compared to monolithic metal alloys. Composites are engineered materials consisting of two or more distinct phases, typically a discontinuous reinforcement phase and a continuous matrix phase. This combination enhances the strength, stiffness, and other mechanical properties of the material.

Banana fiber has emerged as a promising reinforcement material for composites, owing to its high physical strength, low processing cost, and aesthetic appeal. However, its susceptibility to environmental variations leads

to rapid deterioration, limiting its practical applications 11. To mitigate this issue, hybrid composites combining banana fiber with glass fiber are gaining interest.

The fracture surfaces of banana fiber composites subjected to tensile, flexural, and impact tests indicate poor interfacial bonding, resulting in inferior mechanical properties 3. Combining banana fiber with glass fiber can significantly enhance mechanical strength and address these limitations. Natural fibers like cotton, coir, sisal, and jute have also gained attention for applications in consumer products, low-cost housing, and civil structures.

These natural fiber composites demonstrate better electrical resistance, superior thermal and acoustic insulation properties, and higher fracture resistance. Among natural fibers, banana fiber stands out as a cost-effective and commercially available material with relatively high strength and modulus compared to plastics 12. This makes it a viable alternative to conventional fibers in various applications. However, due to its multicellular structure with highly non-uniform cross-sections, the complete characterization of the mechanical properties of banana and glass fiber-reinforced polyester composites remains an area requiring further exploration. Future studies should focus on evaluating their tensile strength and modulus, compressive strength and modulus, flexural strength and modulus, impact strength, and hardness.

EXPERIMENTAL METHODS

Materials

Banana fibers were collected from local industries in Karaikudi. Orthophthalic polyester (GP Resin) was used as the matrix material, supplied by GVR Traders, Madurai, Tamil Nadu. The catalyst, Methyl Ethyl Ketone Peroxide (MEKP), and the accelerator, Cobalt Naphthenate, were also obtained from GVR Traders. The glass fibers used in the composites were supplied by GVR Traders' glass service center in Madurai, Tamil Nadu.

Composite Processing

The composites were fabricated using a simple hand lay-up technique. To ensure easy removal of the molds, the working surfaces were treated with wax. The matrix material was prepared by mixing commercially available general-purpose polyester resin with the accelerator and catalyst in a weight ratio of 1:0.02:0.026.

Each layer of fabric was pre-impregnated with the matrix material and carefully stacked in the mold, ensuring proper alignment within practical tolerances. To prevent leakage during curing, the mold's two opposite ends were left open to allow the escape of hot air. After molding, the composite was cured under light pressure for 30 minutes before demolding.

A fiber volume fraction of 45 ± 1% was maintained using the hand lay-up technique. Each specimen was fabricated individually to minimize edge effects and defects during the machining process.

NaOH Boiling Treatment

The banana fiber underwent a NaOH boiling treatment to remove impurities and enhance its mechanical properties. In this process, the fibers were immersed in a liquid solution containing 5%, 10%, or 18% NaOH at a temperature of 100ºC. The treatment affected the fiber’s structure, resulting in increased hardness and improved bonding characteristics.

Following the treatment, both NaOH-treated and untreated fibers were used for composite fabrication. The mechanical properties of the resulting composites were then compared to evaluate the effect of the NaOH treatment.

MECHANICAL PROPERTIES

Hardness Test

Hardness is a measure of a material's resistance to abrasion, scratching, and cutting. It provides a clear indication of the material's strength. In hardness testing, a defined force is mechanically applied to the test specimen for approximately 15 seconds. The load is transmitted through an indenter, which may vary in size and shape

depending on the type of test. Common indenters are typically made of hardened steel or diamond. In the Brinell hardness test, a steel ball is used as the indenter. The choice of the indenter's diameter (D) and the applied force (P) depends on the thickness of the test specimen. For accurate results, the depth of the indentation (d) should not exceed 1/8th of the specimen thickness. As the thickness of the test specimen increases, the diameter of the indenter and the applied force are adjusted accordingly. The hardness value is calculated by measuring the indentation and applying the appropriate formula.

$$BHN = \frac{P}{\frac{\Pi}{2} D(D - \sqrt{D^2 - D^2_I})}$$

Where

P=applied load in kg, D=ball diameter, Di=indentation of ball

Shear Property Test

The shear properties of the wood dust and woven jute fiber matrix hybrid composite were evaluated using a shear load testing machine. The shear capacity of the composite was determined through this test.

Ex. No.	Banana fiber length (MM)	Glass fibre (%)	Glass type	NAOH boiling treatment (min)
1	10	8	C1	15
2	20	16	C1	15
3	30	24	C1	15
4	10	16	C2	20
5	20	24	C2	20
6	30	8	C2	20
7	10	24	C3	30
8	20	8	C3	30
9	30	16	C3	30

$$\text{Shear strength} = \frac{P}{L.T} \text{ MPa}$$

Where,

P=Applied load in N

L=Length of the specimen (mm)

T=Thickness of the specimen (mm)

Control factor	Levels			Unit
	I	II	III	
Banana CSM length	10	20	30	MM
Glass	8	16	24	%
Banana weight	6	12	18	%
NAOH treatment	15	20	30	Min

Table 1-Parameter table

EXPERIMENTAL DESIGN

The design of experiments (DOE) is a powerful analytical tool used for modeling and analyzing the effects of control factors on performance outcomes. A critical aspect of the experimental design process is the careful selection of appropriate control factors, as they significantly influence the results.

RESULTS AND DISCUSSION

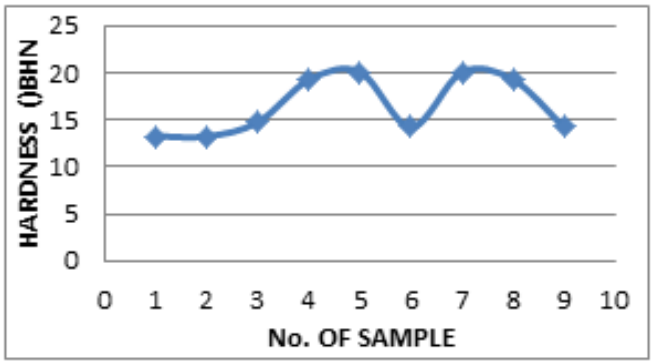

Fig 1 Variation of hardness with no. of samples

This graph shows the hardness values (in Brinell Hardness Number, BHN) for 9 different samples. The x-axis represents the sample number, while the y-axis indicates the hardness values.

Observations:

Trend: The hardness values show a fluctuating trend across the samples.

Initial Values: Samples 1 to 3 exhibit relatively stable and low hardness values, around 12 to 14 BHN.

Peak Values: Samples 4 and 7 show a noticeable increase in hardness, reaching values close to 20 BHN.

Drop and Recovery: After sample 5, the hardness drops significantly, followed by another increase for samples 6 and 7.

Final Decline: Samples 8 and 9 display a gradual reduction in hardness, with sample 9 returning to a level similar to the initial values.

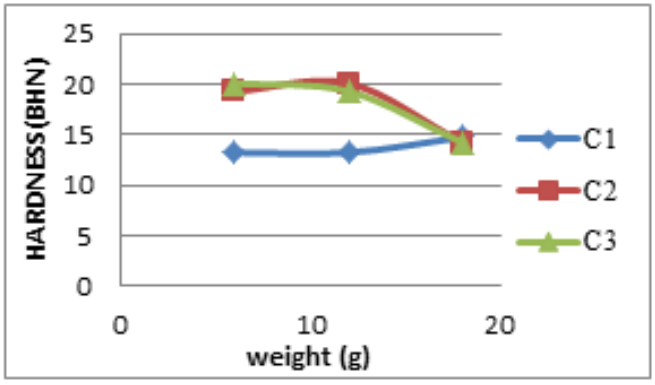

Fig 2 variation of hardness with weight

This graph shows the relationship between weight (g) and hardness (BHN) for three different samples labelled C1, C2, and C3. The x-axis represents the weight in grams, while the y-axis shows the hardness values in Brinell Hardness Number (BHN).

Observations:

C1 (Blue Line):
The hardness remains relatively constant, with minor fluctuations around 12 to 14 BHN as the weight increases. This suggests that the hardness of sample C1 is less sensitive to changes in weight.

C2 (Red Line):
The hardness increases initially, peaking around 20 BHN at approximately 10 beyond this point, the hardness decreases as the weight increases further, indicating that the material may experience reduced structural integrity with higher weight.

C3 (Green Line):
Similar to C2, C3 shows a rise in hardness, reaching its peak around 10 g at about 20 BHN. After the peak, the hardness drops, demonstrating a similar trend of weakening at higher weights.

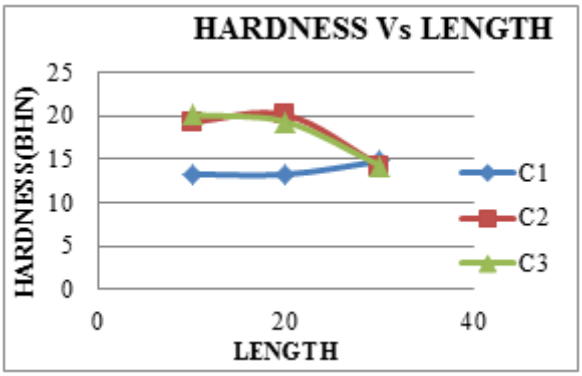

Fig 3: Variation of hardness with varying length

This graph represents the relationship between Length and Hardness (BHN) for three different samples labelled C1, C2, and C3. The x-axis shows the Length (in an unspecified unit), while the y-axis indicates the Hardness in Brinell Hardness Number (BHN).

Observations:

C1 (Blue Line):
The hardness remains relatively stable across increasing lengths, ranging between 12 to 14 BHN.This suggests that the hardness of C1 is not significantly affected by changes in length.

C2 (Red Line) and C3 (Green Line):
Both samples show an increase in hardness initially, peaking at around 20 BHN for lengths of approximately 20 units. After reaching this peak, the hardness starts to decline as the length increases further. This indicates that longer lengths may reduce the structural integrity of these materials, possibly due to increased susceptibility to deformation or reduced bonding strength.

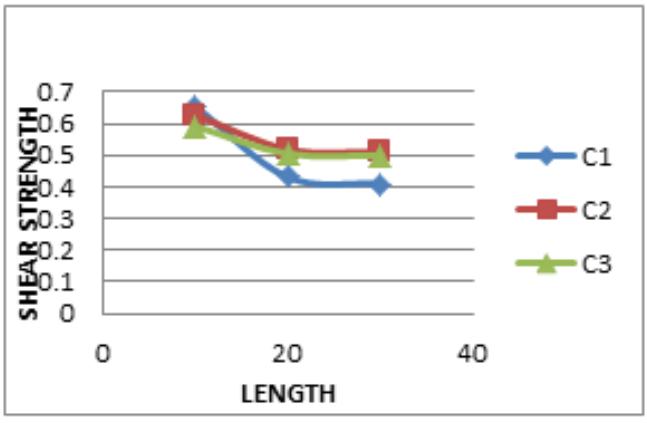

Fig 4 Variation of shear strength with varying length

This graph illustrates the relationship between Length and Shear Strength for three different samples labelled C1, C2, and C3. The x-axis represents the Length (in an unspecified unit), while the y-axis shows the Shear Strength.

Observations:

C1 (Blue Line):
The shear strength starts at a moderate level and declines as the length increases. This indicates that the longer the material, the more likely it is to experience structural weakening under shear forces.

C2 (Red Line) and C3 (Green Line):
Both samples initially exhibit higher shear strength compared to C1, peaking at around 0.65.

As the length increases, the shear strength gradually decreases, though C2 and C3 maintain better shear resistance than C1 at all lengths.C2 retains slightly higher strength compared to C3 for longer lengths, suggesting better structural performance.

SCANNING ELECTRON MICROSCOPY (SEM)
This image appears to be a Scanning Electron Microscope (SEM) image of a composite material, likely showing the microstructure of a fiber-reinforced composite. The magnification is 200x with a scale of 200 µm, indicating a detailed view of the fiber-matrix interface.

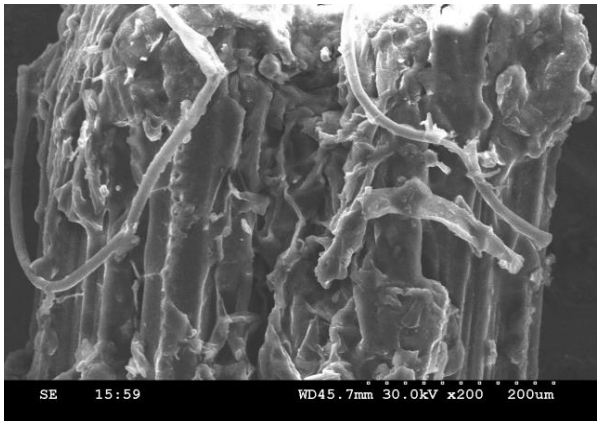

Fig 5: Untreated surface speciman

Observations:

Fiber Structure:
The fibers are visible as cylindrical, elongated structures, indicating a typical natural or synthetic fiber arrangement within the matrix. Some fibers appear to be pulled out, suggesting fiber debonding or weak fiber-matrix adhesion.

Surface Morphology:
The rough, uneven texture of the fibers and matrix suggests damage or failure, possibly due to shear or tensile loading. Cracks and voids can be seen, which may have formed during mechanical testing or material failure.

Fiber Pullout and Matrix Cracks:
Fiber pullout is evident, which is a common failure mode in composite materials. This typically occurs when the interfacial bonding strength between the fiber and the matrix is insufficient.

Matrix cracks are also present, indicating brittle fracture behavior, especially if the matrix material is a thermosetting resin.

Possible Treatment Effects:
If the fibers underwent NaOH treatment, the surface roughness and fiber-matrix bonding can be further analyzed to determine if the treatment improved interfacial adhesion. Poor bonding may suggest inadequate treatment or insufficient resin penetration.

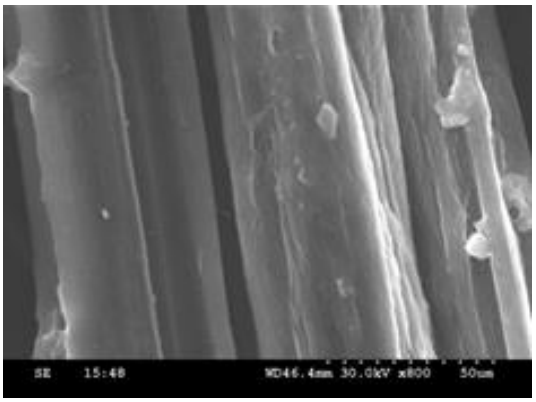

Fig 6: NaOH treated (boiled) speciman

This is another Scanning Electron Microscope (SEM) image, captured at 800x magnification with a scale of 50 µm. It shows a closer view of the fibers within a composite material, likely highlighting the fiber surface characteristics and fiber-matrix interactions.

Observations:

Fiber Surface Morphology:
The fibers appear smooth with some visible impurities or particles on the surface.

The smooth surface may suggest that the fibers have undergone some form of chemical treatment, possibly NaOH treatment, which could remove surface impurities and improve bonding with the matrix.

Matrix Adhesion:
No significant signs of resin residue on the fibers are visible, suggesting possible weak bonding between the fiber and matrix. This can lead to poor load transfer and fiber pullout during mechanical stress.

Surface imperfections and cracks on the fibers might indicate fiber damage, potentially reducing mechanical strength.

Impurities or Debris:
The small particles attached to the fibers could be remnants of the matrix material, unreacted chemicals, or surface impurities. These may affect the overall composite strength.

Fiber Alignment:

The fibers are relatively well aligned, which generally results in better load distribution in the composite. Proper alignment is critical for maximizing tensile strength and stiffness.

CONCLUSION

This experimental investigation into the mechanical behavior of banana fiber polyester composites has led to the following conclusions:

Successful Fabrication:
Banana fiber-based polyester composites with varying layers of glass, different fiber lengths, and weights were successfully fabricated using a simple hand lay-up technique.

Influence of Parameters:
The mechanical properties, including hardness and shear strength, are significantly influenced by factors such as the banana and glass fiber layers, the number of glass layers, and the duration of NaOH treatment.

Surface Analysis:
The surface characteristics of the glass-filled, boiled banana fiber polyester composite were analyzed using shear and hardness tests. The results highlight the effects of fiber treatment and composition.

Effect of NaOH Treatment:
An increase in NaOH treatment duration improves the composite's strength. Lower glass density and reduced GSM (grams per square meter) values of the banana layer contribute to enhanced mechanical properties in a linear manner.

Improved Strength with Reinforcement:
The introduction of additional banana fiber reinforcement enhances the strength of glass-filled, boiled banana fiber-based polyester composites.

Optimal Combinations for Shear Strength:
A combination of 10 mm banana fiber with 8% glass yielded the highest shear strength, making it a suitable choice for applications requiring high shear resistance.

Optimal Combinations for Hardness:
The best hardness results were observed in composites with the following fiber-glass combinations:

20 mm banana fiber with 16% glass

10 mm banana fiber with 8% glass

Overall Best Performance:
The composite with 20 mm banana fiber and 16% glass, as well as the one with 10 mm banana fiber and 8% glass, exhibited excellent shear strength, suggesting these combinations as optimal for both hardness and shear applications.

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