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Investigation of Mechanical Properties of Bamboo and Banana Hybrid Natural Fiber Reinforced Polyester Composites.

Jay Patel

Department of Mechanical Engineering,

Sardar Patel College of Engineering, Bakrol, Gujarat, India

Abstract

The increasing need for eco-friendly and sustainable materials has driven significant research into natural fiber composites. Aerospace and automobile industries have a very vast use of the fiber composite because of the ratio of weight to strength. The composite material also having more engineering usage than ever before. This study investigates the mechanical aspect of hybrid composites with bamboo and banana yarns in a polyester matrix. The hybridization of these fibers in an attempt to combine their individual benefits to achieve superior mechanical performance. The material sheets were manufactured using a hand lay-up technique followed by compression molding. Mechanical characterization, including modules like flexural and tensile strength, were performed to identify and evaluate the performance of the composites. This study targeted to investigate the effect of the hybridization of bamboo and banana natural fiber composite on mechanical properties. In the preparation of laminate; yarn form of bamboo and banana were used with different weight fractions of each laminate with 70% bamboo 30% banana, 30% bamboo 70% banana, and 50% bamboo 50% banana with polyester as matrix material. The results demonstrate that the hybridization in composites exhibit enhanced mechanical attributes compared to single fiber composites. All modules of tensile strength showed significant improvement respecting the synergistic effect of bamboo and banana fibers. Flexural strength also indicated notable enhancements, attributed to the better stress distribution and transfer amidst the fibers and the polyester matrix. The variance in mechanical

properties is examined and assessed. The flexural and tensile strengths were tested using a universal testing machine.

Keywords: Bamboo fibers, Banana fibers, Composite, Hybrid composite, Natural fiber, Mechanical properties, Sustainable materials

I. INTRODUCTION

Composite materials are systems that integrate two or more distinct components, either on a microscopic or macroscopic scale, which vary in structure and chemical composition and do not dissolve into each other.

In today's world, the demand for more efficient materials is essential for the development of modern products. Composite materials are highly valued in this context because they combine strong load-bearing capabilities with weaker materials. The reinforcement in these composites provides the necessary strength and rigidity to support structural loads. Polymer matrix composites are commonly used for these purposes; however, polymers alone often lack the mechanical strength and stiffness required for structural applications, particularly when compared to ceramics or metals. Reinforcing polymers with other materials addresses these limitations. Various studies are actively exploring the use of natural fibers as reinforcement in polymer composites. The quest for sustainable and environmentally friendly materials has gained considerable momentum in recent years, driven by growing environmental concerns and the need to reduce reliance on synthetic and non-renewable resources. Natural fiber-reinforced composites have emerged as promising candidates in this context due to their biodegradability, renewability, and favorable mechanical properties. Bamboo and banana fibers, in particular, are notable for their wide availability, affordability, and superior mechanical properties, making them highly researched natural fibers. Extracted from the bamboo plant, bamboo fibers are highly regarded for their excellent strength-to-weight ratio, flexibility, and durability. Their outstanding tensile strength and stiffness make them an ideal choice for reinforcing polymer matrices. Furthermore, their lightweight nature and biodegradability contribute to their growing popularity in eco-friendly composite applications. Additionally, bamboo fibers have a relatively low density, which contributes to the overall lightweight nature of the composites. Bamboo fibers have been investigated for their use in a range of composite applications, such as automotive parts, construction materials, and sports equipment, where strength and weight considerations are crucial [1]. Their lightweight and high-strength properties make them particularly suitable for industries requiring durable yet eco-friendly materials.

Conversely, banana fibers, sourced from the pseudo-stem of the banana plant, are highly regarded for their excellent tensile properties and good thermal stability. These fibers are also biodegradable and exhibit significant resistance to moisture and microbial degradation. Banana fibers, when incorporated into polymer matrices, have been found to improve both the mechanical and thermal performance of the composites. Their application spans across multiple industries, such as packaging, automotive interiors, and construction [2]. In India, banana and bamboo are abundantly cultivated. Banana and bamboo fibers can be effectively acquired from the pseudo stem [3]. Numerous research efforts have shown that reinforcing materials with two or more natural fibers can lead to a substantial improvement in properties like strength and stiffness. The hybridization of bamboo and banana fibers in a single composite material aims to leverage the unique properties of both fibers, thereby achieving superior mechanical performance compared to single-fiber composites. The synergistic effect of combining these fibers is expected to with enhanced tensile, flexural, and impact properties, these hybrid composites become viable for a wider variety of applications. This study focuses on the development and characterization of hybrid natural fiber-reinforced polyester composites, utilizing bamboo and banana fibers as reinforcing agents.

Ramachandran et al. (2016) [4] studied mechanical properties like impact test and Rockwell hardness examination using bamboo with epoxy, bamboo-banana with epoxy, bamboo-linen with epoxy.Patel et al. (2018) [5] investigated the influence of different nano clay addition on mechanical properties of bamboo / polyester composite with different nano clay proportions as 0%, 1%, 2%, 3% and 4% of weight fraction of the composite. Murali Manohar Rao et al. (2010) [6] fabricated and tested mechanical characteristics of different natural fiber composite asvakka, sisal, bamboo, and banana with a polyester matrix and the output result showed the maximum flexural and tensile strength withbamboo fiber reinforced composite followed by other fiber composites. Prasad and Rao (2011) [7] have examined the mechanical aspect of natural fiber reinforced polyester composite with bamboo, jawar and sisal fiber. Theyobserved that the bamboo fiber composite has the highest tensile strength followed by jawar fiber composite and the flexural strength of jawar fiber composite was found to be significant among all followed by the bamboo fiber composite. Shankar et al. (2013) [8] studied the effect of variety of weight fractions of banana fiber in the composite on mechanical properties. 15% fiber loading indicates the highest tensile strength whereas the flexural strength improving with the fiber loading starting from 10% and maximum at 20% loading. Also, the impact value is maximum at 15% loading of banana fiber in the composite. Venkateshwaran et al. (2011) [9] manufactured the natural fiber hybrid composite with banana and sisal reinforcement. The study presented that thesignificance of both fibers at 50% each has better mechanicalproperties and water absorption capabilities. In conclusion, the investigation of bamboo and banana hybrid natural fiber-reinforced polyester composites represents a significant step towards the development of sustainable and high-performance materials. By understanding the mechanical properties and optimizing the fabrication process, this research seeks to pave the way for the vast adoption of natural fiber composites in various industrial usages, thereby contributing to a more sustainable future.

In this work, composite sheets were fabricated with different weight ratios of banana and bamboo fibers (30%, 50%, and 70%) in combination with each other and polyesteras a matrix component to form the hybrid composite. To avoid the mis orientation of fibers, the yarn extracted form of Banana and Bamboo have been used. Hybridization of bamboo and banana fibers yields positive improvement in mechanical properties.

II. MATERIALS AND METHODS

The investigation of the mechanical behavior of hybrid composites with bamboo and banana fibers involves a detailed assessment of their tensile and flexural strengths. These properties are critical for understanding the possible applications and performance of these composites in various structural and load-bearing scenarios.

Tensile Strength:

Tensile strength is a crucial mechanical property that measures the resistance of a substance to breaking under tension. It provides insights into how a material behaves when subjected to forces that attempt to stretch or elongate it. For fiber-reinforced composites, tensile strength is largely influenced by the type of fibers used, their orientation, the quality of fiber-matrix adhesion, and the volume fraction of the fibers within the matrix.

Bamboo fibers, recognized for their excellent tensile strength and modulus, play a crucial role in enhancing the composite's resistance to tensile forces. These fibers possess excellent load-bearing capabilities due to their increased cellulose concentration and long fiber length, which enhance the overall strength of the composite. Similarly, banana fibers are valued for their good tensile properties and biodegradability, making them a suitable reinforcement material. When used in combination, the bamboo and banana fibers are expected to provide a synergistic effect, resulting in a hybrid composite with superior tensile strength compared to composites reinforced with individual fibers alone.

Flexural Strength:

Flexural strength, or bending strength, is another fundamental mechanical characteristic that characterizes a material's resistance to deformation under load. It is particularly important for applications where the material will be subjected to bending or flexural stresses. Flexural tests evaluate the composite's stiffness and its ability to withstand bending forces without cracking or breaking.

Numerous factors, including as fiber type, fiber orientation, fiber volume fraction, and the quality of the fiber-matrix interface, affect a composite's flexural strength. Bamboo fibers, with their high modulus and toughness, enhance the flexural performance of the composite by providing resistance to bending forces. Banana fibers, which are also strong and flexible, contribute to the composite's ability to bend without failing. The incorporation of these two fibers in a hybrid composite is anticipated to result in improved flexural properties, offering better performance in bending applications.

Fabrication Process:

Fabrication of composite laminates was carried out with hand lay-up method. Banana and Bamboo yarn were arranged in unidirectional alignment for the manufacturing of the hybrid composite.

Fig. 1. Unidirectional form of Bamboo yarn

The hybrid composite sheets were fabricated using a hand lay-up method followed by compression molding. This process involves placing the fibers in a mold and impregnating them with a polyester resin. The hand lay-up technique allows for precise control over the fiber placement and orientation, ensuring uniform distribution and optimal alignment of the fibers. After laying up the fibers and applying the resin, the composite is subjected to compression molding, where pressure and heat are applied to cure the resin and consolidate the composite structure. In order to achieve the appropriate mechanical qualities, robust attachment between the fibers and the matrix is ensured using this approach.

Composite specimen sheets were manufactured with different weight ratios of the fibers i.e. 1) 70% bamboo, 30% banana. 2) 30% bamboo, 70% banana. and 3) 50% bamboo, 50% banana. The loading of fiber into the matrix material was maintained with 13% fibers for all three specimens.

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Testing Procedures:

To evaluate the mechanical properties, mechanical testing like tensile and flexural tests were conducted using standard testing methods. A universal testing machine (UTM) was used to conduct tensile tests in adoption of ASTM D3039 guidelines. Specimens were prepared with specific dimensions and subjected to tensile loading until failure, recording parameters such as elongation at break, modulus of elasticity and tensile strength.

In compliance with ASTM D790 guidelines, flexural tests were performed utilizing a three-point bending configuration. Samples were loaded at the center while supported at two ends, and the load-deflection behavior was recorded. From this data, the flexural modulus, flexural strength and maximum deflection, were calculated.

By systematically investigating the both flexural and tensile strength of bamboo and banana hybrid fiber-reinforced polyester composites, this study aims to provide comprehensive perspectives into their mechanical strength and potential applications. The results will contribute to the growth of high-performance, sustainable composite materials compatible with a variety of industrial applications.

Tensile and flexural properties were examined in this study using a Universal Testing Machine (UTM). Figures 2 and 3 display the tensile and flexural test samples, respectively, prior and post testing.

Fig. 2. Test specimen prior to testing

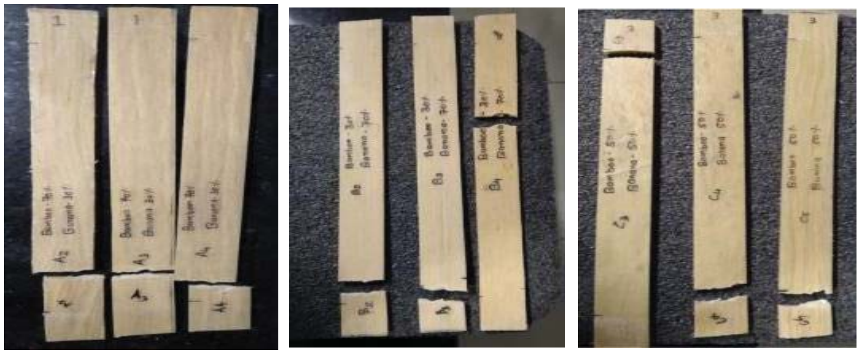

Fig. 3. Test specimen post testing

III. RESULTS AND DISCUSSION

Specific mechanical properties of the composite made with hybridization of two fibers bamboo and banana reinforced polyester composites were examined through tensile and flexural tests. The final material were manufactured with variable weight percentages of bamboo and banana fibers: 70% bamboo and 30% banana, 30% bamboo and 70% banana, and 50% bamboo and 50% banana. The results for the tensile and flexural properties of above prepared materials are listed in Table 1.

TABLE 1. MECHANICAL PROPERTIES OF SPECIMENS WITH VARYING FIBER WEIGHT LOADINGS.

Composite with different weight % of fibers	**Tensile Properties**			**Flexural Properties**		
	Tensile Strength	***% Elongation***	***Modulus of Elasticity***	***Flex. Strength***	***Flex. Strain %***	***Flex. Modulus***
Bamboo 70% Banana 30%	48.23 Mpa	6.17	1460 Mpa	80.3 Mpa	5.6	2613 Mpa
Bamboo 30% Banana 70%	69.63 Mpa	9.02	1792 Mpa	90.66 Mpa	9.94	2073 Mpa
Bamboo 50% Banana 50%	51.67 Mpa	5.22	1668 Mpa	120 Mpa	7.15	3823Mpa

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3.1. Tensile Properties

Tensile Strength:

The tensile strength of the composites displayed noticeable variation depending on the fiber weight ratios. The composite containing 70% banana fibers and 30% bamboo fibers showed the highest tensile strength, measuring 69.63 MPa. The composite with an equal distribution of bamboo and banana fibers (50% each) exhibited a moderate tensile strength of 51.67 MPa. Meanwhile, the composite with 70% bamboo and 30% banana fibers had the lowest tensile strength, recorded at 48.23 MPa. These differences suggest that the tensile strength is strongly affected by the proportion of banana fibers in the composite.

Elongation at Break:

The elongation at break (% elongation) showed a trend where the composite with 70% banana fibers and 30% bamboo fibers exhibited the highest elongation at break (9.02%), followed by the composite with 70% bamboo and 30% banana fibers (6.17%). The composite with equal weight percentages of bamboo and banana fibers demonstrated the lowest elongation at break (5.22%). This suggests that a higher proportion of banana fibers contributes to greater ductility. The Figure 4 and Figure 5 shows the tensile strength and modulus of elasticity of specimens with a combination of different fiber loading respectively.

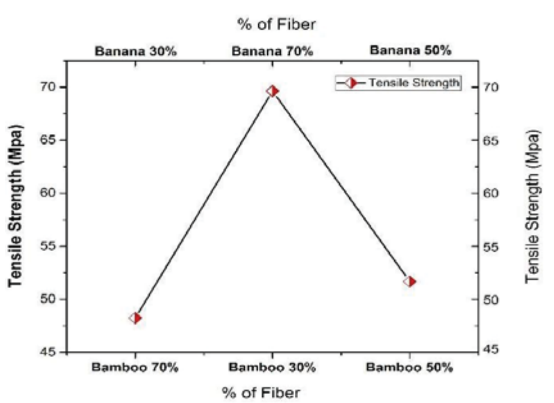

Fig. 4: Tensile strength

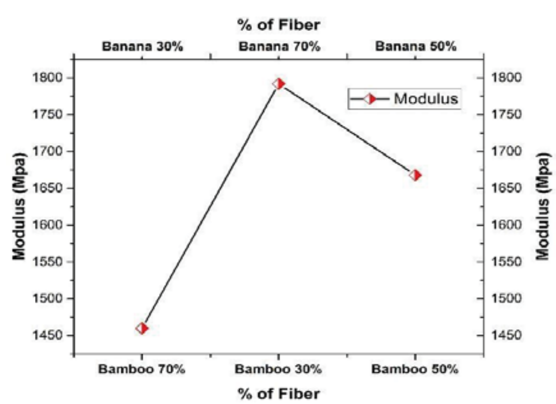

Fig. 5: Modulus of elasticity

Modulus of Elasticity:

The modulus of elasticity was highest for the composite with 70% banana fibers (1792 MPa), indicating that this composite was the stiffest among the tested samples. The composite with equal weight percentages of bamboo and banana fibers had a modulus of elasticity of 1668 MPa, while the composite with 70% bamboo fibers had the lowest modulus of elasticity (1460 MPa). These results suggest that the stiffness of the composite improves with an increasing proportion of banana fibers.

3.2. Flexural Properties

Flexural Strength:

The flexural strength of the composites varied with fiber content. The composite with equal weight percentages of bamboo and banana fibers (50% each) exhibited the highest flexural strength (120 MPa). The composite with 70% banana fibers had a flexural strength of 90.66 MPa, while the composite with 70% bamboo fibers showed the lowest flexural strength (80.3 MPa). These results indicate that an equal proportion of bamboo and banana fibers leads to superior flexural performance.

Flexural Strain:

Flexural strain at break was highest for the composite with 70% banana fibers (9.94%), suggesting greater flexibility. The composite with equal weight percentages of bamboo and banana fibers had a flexural strain of 7.15%, while the composite with 70% bamboo fibers had the lowest flexural strain (5.6%). This trend indicates that banana fibers enhance the composite's flexibility under bending loads.

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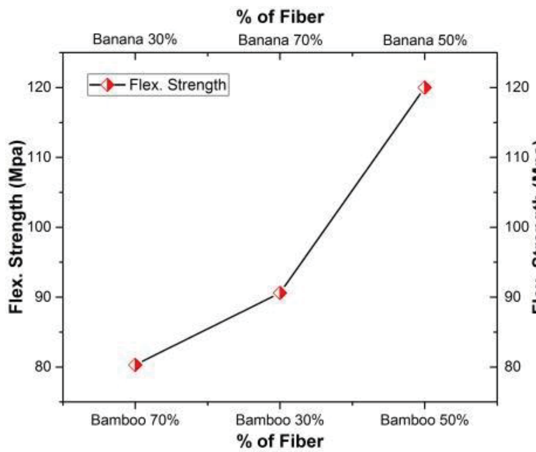

Fig. 6: Flexural strength

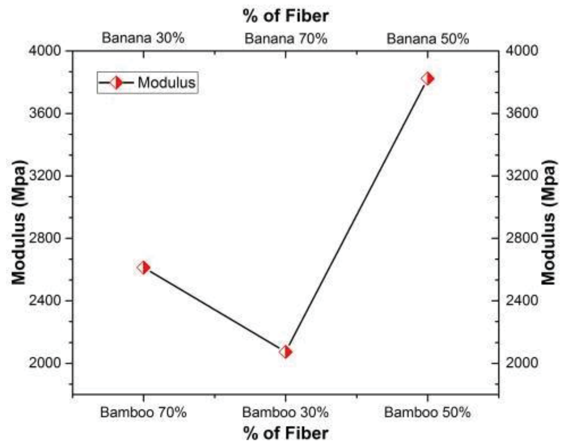

Fig. 7: Modulus of elasticity

Flexural Modulus:

The composite with equal weight percentages of bamboo and banana fibers had the highest flexural modulus (3823 MPa), indicating superior stiffness in bending. The composite with 70% bamboo fibers had a flexural modulus of 2613 MPa, and the composite with 70% banana fibers had the lowest flexural modulus (2073 MPa). This suggests that a balanced hybridization of fibers enhances the stiffness in flexural loading conditions. Figure 6, and figure 7 shows the flexural strength and flexural modulus of specimens with a combination of different fiber loading respectively.

IV. CONCLUSION

1. Tensile Strength:
   - The composite with 70% banana fibers and 30% bamboo fibers showed the highest tensile strength, indicating that banana fibers contribute significantly to the tensile properties.
   - The composite with equal weight percentages of bamboo and banana fibers demonstrated moderate tensile strength, while the composite with 70% bamboo fibers showed the lowest tensile strength.

2. Elongation at Break:
   - The highest elongation at break was recorded in the composite with 70% banana fibers, suggesting that banana fibers enhance ductility.
3. Modulus of Elasticity:
   - The composite with 70% banana fibers had the highest modulus of elasticity, indicating superior stiffness.
   - A balanced fiber composition resulted in a moderate modulus of elasticity.
4. Flexural Strain:
   - The highest flexural strain was seen in the composite with 70% banana fibers, suggesting enhanced flexibility.
   - The composite with 70% bamboo fibers showed the lowest flexural strain.
5. Flexural Modulus:
   - The composite with equal weight percentages of bamboo and banana fibers had the highest flexural modulus, indicating excellent stiffness in bending.
   - The lowest flexural modulus was found in the composite with 70% banana fibers.

These findings indicate that the mechanical attributes of the hybrid composites shall be tailored by adjusting the proportions of bamboo and banana fibers, allowing for optimization based on specific application requirements. Further research should explore the impact of different fiber surface treatments and matrix modifications to enhance the interfacial bonding and overall performance of these composites.

DECLARATION

I declare that this research paper, titled "Investigation of Mechanical Properties of Bamboo and Banana Hybrid Natural Fiber Reinforced Polyester Composites.," is my own work and has not been presented anywhere. All sources and references used in this research have been fully acknowledged.

The research and analysis contained in this research paper have been carried out independently.

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