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Characterization of mechanical properties of bamboo fiber-reinforced epoxy composites

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ABSTRACT

This research investigates the mechanical properties of bamboo fiber-reinforced unidirectional epoxy composites, focusing on two bamboo species, *Bambusa Vulgaris* (Baijja bamboo) and *Melocanna Baccifera* (Mulli bamboo). The study examines the tensile, flexural, and impact properties of composites fabricated from bamboo fibers extracted from different sections (top, middle, bottom) of the bamboo culm. The composites were prepared using a hand layup method and subjected to mechanical testing according to ASTM standards. Results show that the middle portion of both bamboo species exhibits superior mechanical performance compared to the top and bottom portions. Specifically, the middle section demonstrates higher tensile strength, tensile modulus, flexural strength, flexural modulus, and impact strength. The enhanced properties of the middle section are attributed to factors such as fiber alignment, density, and composition. The findings suggest that utilizing bamboo fibers from the middle portion can lead to the development of high-quality composite materials suitable for various engineering applications, particularly in automotive part manufacturing. This research underscores the importance of understanding the mechanical behavior of bamboo composites for optimizing their use in sustainable and eco-friendly industrial products.

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1. INTRODUCTION

In recent time, there's been a growing emphasis on promoting sustainable and eco-friendly materials across a range of industries. Composite materials, known for their exceptional mechanical properties and versatility, have surfaced as an alternative to conventional materials in numerous sector [1]. Natural plant fiber composites have been engineered for manufacturing a diverse array of industrial goods, offering advantages such as biodegradability and environmental preservation [2]. Composite materials made from natural fibers have gained popularity due to their durability and eco-friendliness [3]. Bamboo has various applications in composite materials, ranging from short bamboo fibers to long strips composed entirely of bamboo. Researchers have become more interested in developing these materials using stronger bamboo fibers to produce high-quality sustainable industrial products [4]. Among the many accessible natural fibers, bamboo fibers are suggested as bamboo fibers offer low density, excellent toughness, low abrasion, and sufficient specific strength, along with enhanced energy recovery [5]. The bamboo subfamily is called "Bambusa." This study incorporates two bamboo species: *Bambusa Vulgaris*, commonly referred to as "Baijja," and *Melocanna Baccifera*, known as "Mulli." Each bamboo plant is divided into three distinct sections: the top, middle, and bottom. Bamboo fiber reinforced has a good strength-to-weight ratio when compared to steel, concrete, and timber [6]. The mechanical properties of the composites, such as tensile strength, flexural strength, and impact strength, had been highly influenced by the NaOH treated fibers used[7]. The primary aim of this study is to assess the performance of Bamboo Reinforced Unidirectional Epoxy composites through mechanical testing, including Tensile, Impact, and Flexural tests. Understanding the mechanical properties of these composites is crucial for identifying the most suitable bamboo fiber and analyzing their behavior under varying loading conditions, thus determining their potential for specific engineering applications.

2. RESEARCH METHOD

Two species of bamboo, (i) *Bambusa Vulgaris* (ii) *Melocanna Baccifera*. (known locally as Baijja and Mulli), were used in the process of preparing laminates [8]. The bamboo was chopped into three parts (top, bottom, and middle) and then cut into strips of 1.5mm thickness and 350mm length. These strips were treated with 5% Sodium Hydroxide (NaOH) for 12 hours, washed with distilled water, and left to dry for 24 hours at ambient temperature. The Long fibers were extracted using a hammering and cutting approach.

Figure 2(a): Bamboo Strips

Figure 2(b): Chemical Treatment

Figure 2(c): Extracted fibers

2.1 Fabrication of Composite

The hand layup method was used to create composites. A mold measuring (23 cm x 23 cm) was used, with fibers measuring 9 inch x 9 inch. The epoxy resin to hardener ratio was 10:1, and the matrix's weight fraction was 25%. This accurate mix ratio assures strong, strength and durability [9].

A total pressure of 2650 Pa was applied to each mold, which was held at this pressure for 24 hours. Applying pressure helps to improve the fiber-to-matrix bonding, which is crucial to achieving the desired mechanical properties in the final product. The pressure helps to drive the fibers closer together, increasing the overall contact area, which results in a more durable and long-lasting composite material [10].

Figure 2.1(a): Composite fabrication

Figure 2.1(b): Applying Pressure

Figure 2.1(c): Final Composite

Cutting composite materials entails breaking down or shaping composite structures into desired shapes and sizes. Many ASTM standards applied to the cutting of composite materials, depending on the circumstances and the cutting technique utilized.

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Figure 2.1(d): Laser cutting of the Composite

2.2 Mechanical Testing

Tensile Test

The tensile test was carried out in the Universal Testing Machine (UTM) utilizing a 10 kN load cell with a total length of 64 mm. The UTM's crosshead speed was set to a constant 10 mm/minute. The tensile test sample measured 65 mm × 8 mm × 4.2 mm, with a gauge length of 20mm as per ASTM D 638 (Type-V) standards. To preserve dimensional precision and remove differences in dimensions across samples, samples were laser cut from made laminate plates in accordance with the ASTM standards.

Figure 2.2(a): Tensile Specimen

Flexural Test

The flexural test followed ASTM D790 using TECQUIPMENT UNIVERSAL TESTING MACHINE. The sample dimensions were 130 mm × 14 mm × 3.5 mm, laser cut as before. The testing rate ranges from 0.05 to 0.1 inches per minute, and the span length is kept at 55 mm.

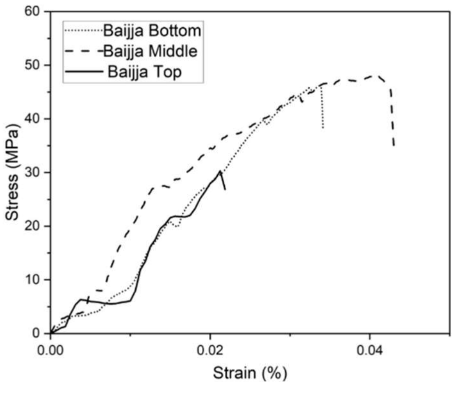
Figure 2.2(b): Flexural Specimen

Impact Test
The impact test was also done in accordance with ASTM D256 using a Universal Charpy Analog Impact Tester. The sample dimensions for this test were (55 mm × 12 mm × 4 mm), laser cut as before.

Figure 2.2(c): Impact Specimen

3. RESULTS AND DISCUSSIONS

Tensile Test
Figure 3 and figure 4 demonstrates the comparison of stress vs strain curve for both treated bamboo fibers. In terms of tensile stress and strain, the middle part of Baijja bamboo shows a higher stress of 23.83 N, while Mulli bamboo shows a stress of 14.42 N for the middle part. It has been noticed that stress is higher for Mulli bamboo, and the portion is middle. In bamboo, fibers of the middle region, known as the culm, has higher tensile stress vs. strain values than the top and bottom sections. The culm's length is where the longitudinal orientation of the bamboo fibers is found. Fibers in the middle are more tightly packed and aligned, leading in increased load-bearing capacity and tensile stress resistance. The middle portion of the bamboo culm includes a larger concentration of cellulose, the primary load-bearing component in plant fibers. The increased cellulose content improves the tensile strength and stiffness of the fibers. Bamboo's mechanical qualities are influenced by its hierarchical structure, which is made up of microfibrils embedded in a hemicellulose and lignin matrix. The arrangement of these components varies along the length of the culm, with the central section frequently having an optimal structure for tensile strength.



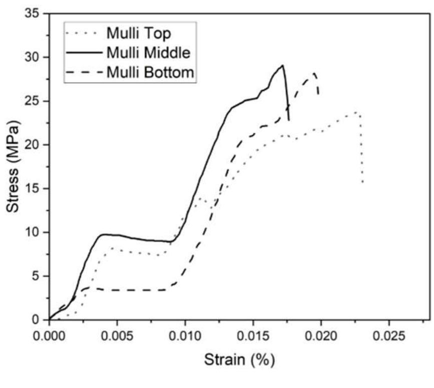


Figure 3: Stress vs strain curve of Baijja Bamboo **Figure 4:** Stress vs strain curve of Mulli Bamboo

The purpose of this research was to determine the tensile modulus, tensile strength, and stress vs. strains of Mulli and Baijja bamboo treated with 5% NaOH at a 25% weight fraction. Figures 5, 6, 7 and 8 provides a comparison of the tensile modulus and tensile strength of Mulli and Baijja bamboo at a 25% weight fraction, respectively. The middle section of the bamboo fiber exhibits greater tensile modulus and strength. Baijja bamboo has the highest tensile modulus of 1409 MPa, while Mulli bamboo has the highest value of 928 MPa, both values obtained from the center of the bamboo. It is notable that Baijja bamboo has a higher tensile modulus than Mulli bamboo. The highest tensile strength recorded is 187.82 MPa for Baijja bamboo and 131.47 MPa for Mulli bamboo. Both bamboo and Baijja bamboo have higher tensile strength in the middle part, which is greater than Mulli bamboo. The middle portion of the Baijja bamboo fiber composite exhibits higher tensile strength and modulus values compared to the Baijja top and bottom. This could be due to various factors, such as the quality and alignment of the bamboo fibers within the composite. The middle portion of the bamboo stalk may contain fibers that are more uniform in size, better aligned, and exhibit fewer defects compared to those found in the top and bottom sections. Differences in the processing or treatment of the bamboo fibers at different heights of the plant could also contribute to differences in mechanical properties. Further analysis of the fiber morphology, processing techniques, and composite structure may provide deeper insights into the observed differences in tensile performance.

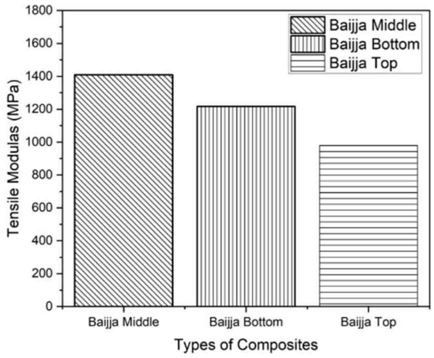


Figure 5: Tensile Modulus of Baijja Bamboo

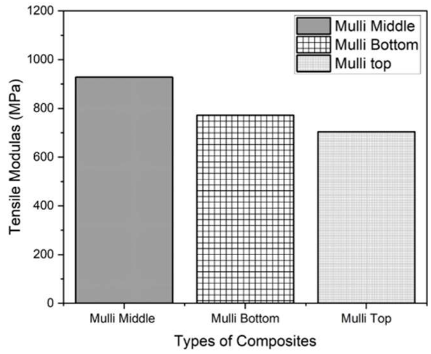


Figure 6: Tensile Modulus of Mulli Bamboo

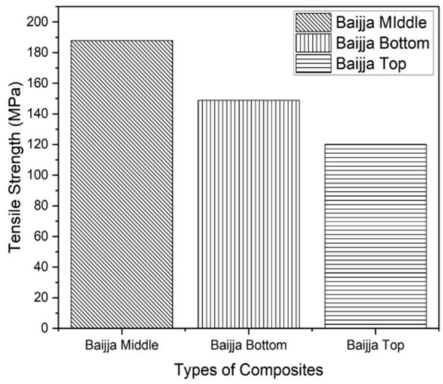


Figure 7: Tensile Strength of Baijja Bamboo

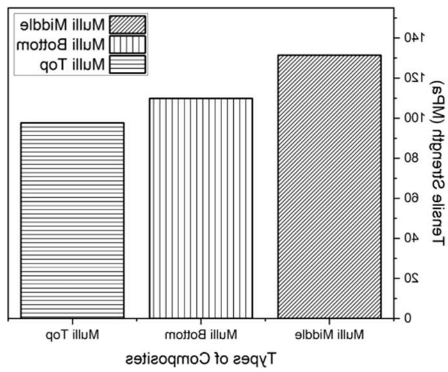


Figure 8: Tensile Strengt of Mulli Bamboo

Flexural Test

Flexural strength refers to the ability of a composite material to withstand bending forces. Figures 9, 10, 11, and 12 compare the flexural modulus and strength of bamboo composite laminates. It was observed that both the flexural modulus and strength were higher for Baijja Middle and Mulli Middle bamboo composites. Specifically, the Baijja Middle bamboo exhibited the highest flexural modulus of 3102.31 MPa, and the Mulli Middle bamboo showed a similarly high value of 2899.6 MPa. Furthermore, the highest flexural strength was recorded for both Baijja Middle and Mulli Middle composites, with values of 349.7 MPa and 388.5 MPa, respectively. The objective of this research was to investigate the mechanical properties of Baijja and Mulli bamboo composites at different positions within the bamboo culm. The study finds that Baijja Middle and Mulli Middle bamboo composites demonstrate superior flexural modulus and flexural strength compared to their Baijja Top, Bottom, and Mulli Top, Bottom counterparts. This distinction can be attributed to the composite construction with a balanced weight fraction of 25%, ensuring a homogeneous distribution of fibers within the epoxy resin matrix. Additionally, the precise mixing ratio of epoxy resin at 10:1 facilitates optimal bonding between bamboo fibers and the resin matrix, enhancing overall composite performance. Pre-molding treatment of bamboo fibers with sodium hydroxide (NaOH) further enhances interfacial bonding by removing impurities and increasing fiber surface roughness. This promotes better adhesion to the epoxy resin matrix, thus improving the overall composite performance. Collectively, these factors contribute to the observed improvements in flexural modulus and flexural strength in Baijja Middle and Mulli Middle bamboo composites. This highlights the significance of balanced weight fraction, precise resin ratio, and fiber surface treatment in enhancing composite mechanical properties.

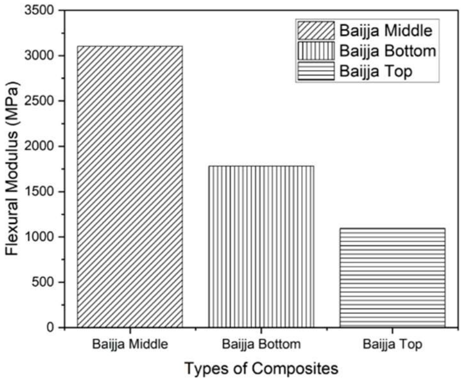


Figure 9: Flexural Modulus of Baijja Bamboo

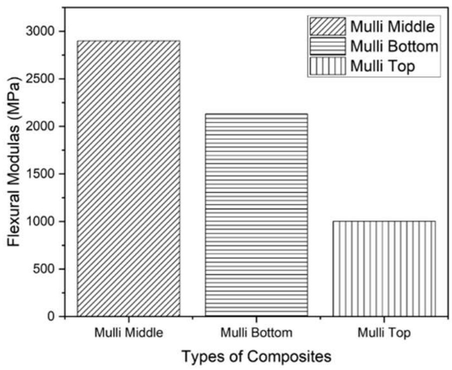


Figure 10: Flexural Modulus of Mulli Bamboo

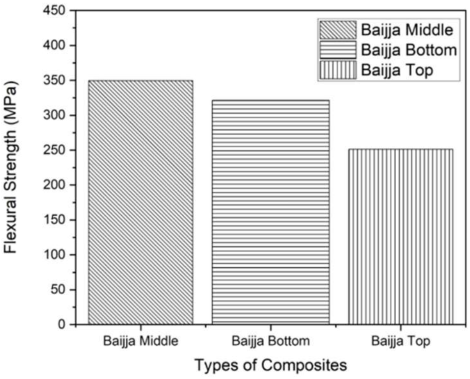


Figure 11: Flexural strength of Baijja Bamboo

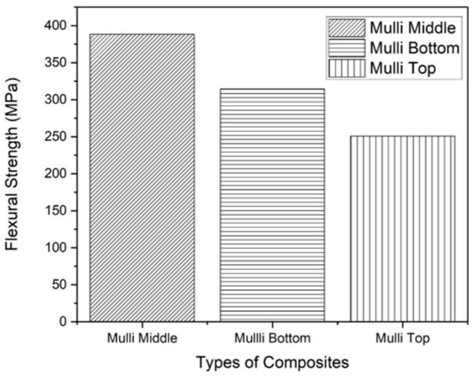


Figure 12: Flexural strength of Mulli Bamboo

Impact Test

Impact strength refers to a shock absorbing capacity of material. This is entirely related to toughness [10]. The effect of both bamboo fibers loading and fiber length on impact strength of composites is shown in Figure 13 and Figure 14. The higher impact strength of Baijja Middle is 59.7 kJ/m^2, while that of Mulli Middle is 46.10 kJ/m^2. The impact strength of bamboo fibers varies along the length of the fiber due to differences in structure, composition and mechanical properties. The middle part of the bamboo culm generally has a higher fiber density and is often more aligned and tightly packed, making it more efficient in load-bearing and able to withstand impact forces. Environmental factors during bamboo growth, such as moisture levels, temperature variations, and mechanical stresses, can influence the development of fiber properties. The middle part of the culm may experience more favorable conditions for the formation of robust fibers with higher impact resistance. Factors such as fiber density, orientation, cellulose content, lignin distribution, structural integrity, and growth conditions collectively contribute to the ability of bamboo fibers to withstand impact forces and resist fracture or failure.

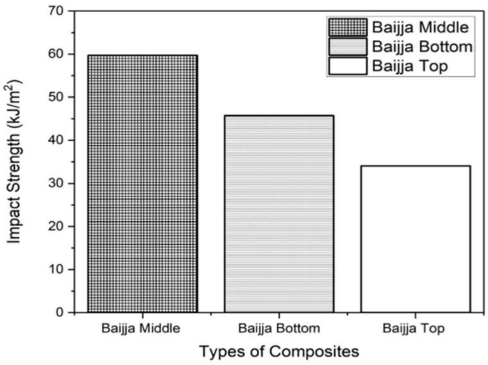


Figure 13: Impact Strength of Baijja Bamboo

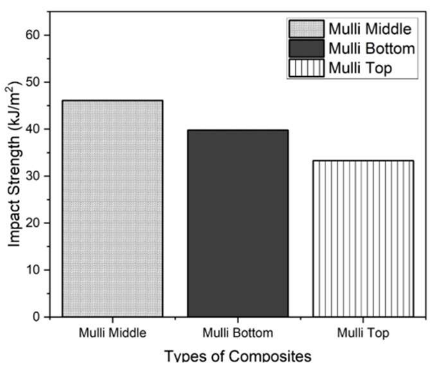


Figure 14: Impact Strength of Mulli Bamboo

4. CONCLUSION

Composite materials are now preferred choice for tailor made structures since they can be manufactured as per the required strength in the field of engineering. In this study, two species of bamboo fibers were investigated: *Bambusa Vulgaris* (Baijja bamboo) and *Melocanna Baccifera* (Mulli bamboo). Fibers were extracted from the top, bottom, and middle parts of these bamboos and flexural, tensile, and impact tests were conducted.

The study found that the middle portion of both types of bamboo fibers exhibited higher values for tensile strength, tensile modulus, flexural strength, flexural modulus and impact strength compared to the top and bottom portions. The lowest values were observed in the top part. Specifically, the tensile strength of the middle portion of mulli bamboo was 34.52% higher than the top portion, and that of baijja bamboo was 56.42% higher than the top portion. Similarly, the tensile modulus of the middle portion of mulli bamboo was 31.82% higher than the top portion whereas the tensile modulus of baijja bamboo was 43.77% higher than the top portion. For flexural strength, the middle part of mulli bamboo was 54.84% higher than the top portion, and the middle part of baijja bamboo was 39.18% higher than the top part. Finally, for the impact test, the impact strength of the middle part of Mulli bamboo was 38.52 percent higher than the top part, and that of the middle part of the Baijja bamboo was 75.33% higher than the top part.

The study suggests that the middle portion of both types of bamboo fibers is ideal for use in manufacturing automotive parts such as interior trim panels, door panels, headliners, seat backs, and bumpers. By properly utilizing the middle part of the bamboo fiber, manufacturers can take advantage of its superior properties and create high-quality products.

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