ICEST_ME_015

STRUCTURAL ANALYSIS OF BAMBOO REINFORCED COMPOSITE MATERIAL

Bhavish S. Ail[1], Muhammed Afsal C. [1], Sheikh Mohammed Rahil [1]Suheb Alam Khan[1], Praveen Suvarna[2]*, Chethan K. M.[1], Maruthi Prashanth[1].

[1]Department of Mechanical Engineering, P.A. College of Engineering, Mangaluru, Karnataka, India.

[2]Department of Civil Engineering, P.A. College of Engineering, Mangaluru, Karnataka, India.

*Corresponding Author: Praveen Suvarna Email: Praveen_civil@pace.edu.in

Abstract:

For centuries, wood has been a primary material in global construction. In tropical and sub-tropical regions, bamboo has also played a significant role due to its versatility. In our current climate-conscious era, bamboo has emerged as a vital resource. Its exceptional ability to sequester carbon makes it invaluable in mitigating greenhouse gas emissions and reducing our carbon footprint. Bamboo is a promising building material due to its outstanding tensile strength and impressive weight-to-strength ratio. Natural bamboo can have a tensile strength ranging from 80 to 120 N/mm2, making it an excellent choice for sustainable construction. The objective of this research is to enhance the tensile strength of bamboo through mechanical methods. The composite material is created by bundling bamboo fibers using geofabric thread, along with an appropriate epoxy resin (LY 556) and hardener (HY 951). The study also investigates the impact of various threading patterns on the formation of bamboo fiber composites. The results indicate that closely spaced threading patterns yield superior results compared to other threading patterns. This process effectively increases the tensile strength of bamboo composite materials by 57% to 100%.

Key Words: Bamboo fiber, Epoxy Resin, Hardener, Tensile Strength.

1. Introduction

The most widely used fibers for composite manufacturing are generally manufactured with non-renewable resources, including carbon, steel, glass, and polymer materials. The manufacturing of these traditional fibers can lead to concerns about unsustainable development and environmental

ISBN-978-81-19905-39-3

pollution. To resolve these issues, the researchers are considering replacing traditional fibers with renewable plant fibers for composite reinforcement. Apart from its sustainability, low weight, wide availability, and biodegradability, plant fibers have comparable or superior mechanical performance compared to that of the commonly used fibers, including high vibration absorption capability , high fracture toughness , high specific strength, and high flexibility. All these properties indicate that plant fibers can be utilized as a potential alternative to traditional fibers. Bamboo fiber, in particular, has relatively greater mechanical strength among all plant fibers.The tensile strength and modulus of the bamboo fibers can reach 600 MPa and 46 GPa, respectively. In contrast, the elongation, the tensile strength, and Young's modulus of single bamboo fiber are superior to some other plant fibers such as bagasse, flax, and coir So embedding bamboo fiber into cement and resin as reinforcement has various application prospects. Bamboo fiber can be used as a viable substitute for glass and polymer fiber as well as a green and sustainable fiber reinforcement. Furthermore, the use of bamboo fiber in building materials reduces the carbon footprint.

Studies on short bamboo fibers and their composites have widely been conducted and showed that the short bamboo fiber as a reinforcing material could significantly enhance the tensile and impact strengths of composites. Bamboo species, fiber content, extraction methods, modification treatments, matrix type, and fiber–matrix interface affect the reinforcing performance. However, the related investigation on long plant fibers is relatively limited. Previously, it was found that unidirectional long fiber reinforcement is essential to fully utilize its strength capacity. More research into high-performance long bamboo fiber-reinforced composites is required. Therefore, this review paper focuses on evaluating the characteristics of long bamboo fibers and their composites. These characteristics are essential for the effective design and use of fiber-reinforced composites. This study begins with a multi-scale structure of the bamboo fiber prior to reviewing its cell wall structure.

A summary of the mechanical properties of long bamboo fiber composites is then provided. In addition, water absorption and fire retardancy of bamboo fiber composites are reviewed, followed by bamboo fiber-based cement and concrete composites. Lastly, the mechanical and interfacial bonding compatibility of bamboo fiber-reinforced composites is comprehensively reviewed. The review finishes with some concluding remarks and suggestions for future works.

ISBN-978-81-19905-39-3

The studies by Khan, Yousif, Chandra Mohan, and Yanglun and Huang all investigate the properties of bamboo and natural fiber-reinforced composites, focusing on enhancing mechanical performance through different treatments and material combinations. Khan and Yousif's research on bamboo fiber-reinforced epoxy composites determined that treating fibers with 6% NaOH significantly improved tensile strength and interfacial adhesion, confirmed through experimental and Finite Element Analysis (FEA) using ABAQUS. Chandra Mohan's study tested natural fiber particle-reinforced polymer composites under ASTM standards and found that hybrid composites outperformed single fiber glass-reinforced composites in terms of tensile, flexural, shear, and impact strength in both moist and dry conditions. Yu and Huang's research on bamboo fiber bundle-reinforced composites (BFCs) highlighted a significant enhancement in strength and modulus due to high densification achieved by filling intercellular spaces and cell cavities with phenol-formaldehyde resin, resulting in mechanical properties that were more than double those of raw bamboo. Overall, these studies underscore the importance of fiber treatment and composite structure in optimizing the mechanical properties of bamboo and natural fiber-reinforced composites.

The articles by Bahrum Prang Rocky, Kai Zhang, Fuli Wang, and Jyun-Kai Huang and Wen-Bin Young explore various aspects of bamboo fiber production and the enhancement of bamboo fiber-reinforced composites. Rocky's research emphasizes the complexity of producing high-quality spinnable bamboo fibers, highlighting the necessity of combining mechanical, chemical, and enzymatic processes, including delignification treatments, to achieve fibers suitable for spinning. Zhang's study confirms the effectiveness of treating bamboo fibers with 6 wt.% NaOH, significantly improving the flexural, fracture, and thermal properties of bamboo fiber-reinforced epoxy composites. Wang investigates bamboo's tensile properties and radial organizational structure, demonstrating how its multi-layered composite structure at different scales—microscopic, miso, and macroscopic—contributes to its superior mechanical properties and functionally graded material characteristics. Huang and Young examine the mechanical and interfacial strength of continuous bamboo fiber-reinforced epoxy composites, showing that alkali treatment, despite reducing fiber strength, improves tensile strength due to enhanced interfacial bonding between the fibers and epoxy resin. Collectively, these studies underscore the importance

ISBN-978-81-19905-39-3

of treatment methods and structural analysis in optimizing bamboo fiber properties for composite applications.

The studies by P. Lokesh, Kong Fah Tee, Nabanita Banik, Kefei Liu, and Assima Dauletbek collectively highlight the diverse applications and properties of bamboo fiber composites. Lokesh's research focuses on the mechanical properties of bamboo fiber-reinforced polymer composites, noting that while NaOH-treated fibers enhance tensile, flexural, and impact strength, too many fibers can reduce mechanical properties due to poor bonding with the matrix. Tee's study emphasizes the improved physical-mechanical properties of bamboo fibers treated with a 10% NaOH solution, which significantly enhances tensile strength, making them suitable for various applications traditionally dominated by synthetic fibers. Banik explores the industrial potential of bamboo composites as eco-friendly alternatives to hardwood, suggesting that bamboo's strength and stiffness make it a viable substitute in structural applications, reducing reliance on timber resources. Liu investigates bamboo fiber's performance as reinforcement in asphalt mixtures, highlighting its crack resistance and reinforcing capabilities. Lastly, Dauletbek reviews laminated bamboo lumber (LBL), noting that while LBL's environmental performance is lower than conventional materials like wood and plywood, it remains a valuable material for structural applications due to its mechanical properties. Collectively, these studies underscore bamboo's versatility and potential as a sustainable, high-performance material in various engineering and industrial applications.

2. Material used

2.1 Natural Bamboo Fiber

Bamboo fiber is a natural material derived from bamboo plants as shown in Figure 1.

Figure 1: Natural bamboo fiber

ISBN-978-81-19905-39-3

Bamboo is a fast-growing and renewable resource, holds significant cultural, economic, and environmental importance in India. This report explores the diverse range of bamboo species native to India, their characteristics, and their various applications.

2.2 Epoxy Resin (Ly 556) And Hardener (Hy 951).

For the study LY556 (HERENBA BRAND) epoxy, cobalt polyester and HY951 Hardener was used in this research as shown in Figure 2.

Figure 2: Epoxy resin and hardener

Epoxy resin LY 556 is a versatile, high-performance material widely used in industrial and commercial applications. It's known for its strong adhesive properties, excellent chemical resistance, and durability. LY 556 is commonly used for bonding, coating, encapsulating electronic components, and creating composite materials.

Hardener HY 951 is typically used in conjunction with epoxy resin LY 556 to initiate the curing process. It's designed to react with the epoxy resin to form a strong, durable bond. HY 951 hardener can influence the curing time, viscosity, and final properties of the epoxy resin system, making it crucial to achieve the desired performance characteristics for specific applications.

2.3 Geofabric Thread

Designed to withstand heavy loads, environmental stress, and mechanical strain, making it suitable for applications like geotextiles, landscaping, and construction. Geofabric thread is a specialized type of thread used in geotextiles for various civil engineering and environmental applications. It's

ISBN-978-81-19905-39-3

typically made from synthetic materials like polyester or polypropylene, which offer durability and resistance to environmental factors like moisture, chemicals, and UV radiation. This thread is designed to provide strength and stability to geotextile fabrics used in construction projects such as roadways, retaining walls, erosion control, and landscaping. It enhances the overall performance and longevity of geotextile products by ensuring they can withstand the stresses and pressures of the environment they're placed in.

2.4 Preparation of Bamboo Fibre Rod

The process begins by crafting bamboo rods with varying diameters of 6mm, 8mm, and 10mm. These rods are meticulously prepared to ensure uniformity and structural integrity. Once fabricated, the rods undergo a tensile test, a critical procedure that evaluates their mechanical properties under tension. To prepare bamboo sticks for construction, begin by selecting straight and uniform sticks of the desired length and thickness. Clean them thoroughly to remove any dirt or debris, and allow them to dry completely to prevent moisture retention. This drying process is crucial in preparing the bamboo sticks for use. Once dried, apply a layer of resin evenly over the surface of the bamboo sticks using a brush or roller, ensuring complete coverage to enhance the strength and durability of the sticks. Next, wrap geofabric thread around the resin-coated bamboo sticks in a spiral pattern, ensuring that the wrapping is tight and uniform to provide additional reinforcement. Finally, allow the resin to cure fully to ensure the bamboo sticks are ready for use in construction. The process involved is depicted in Figure 3 to Figure 5.

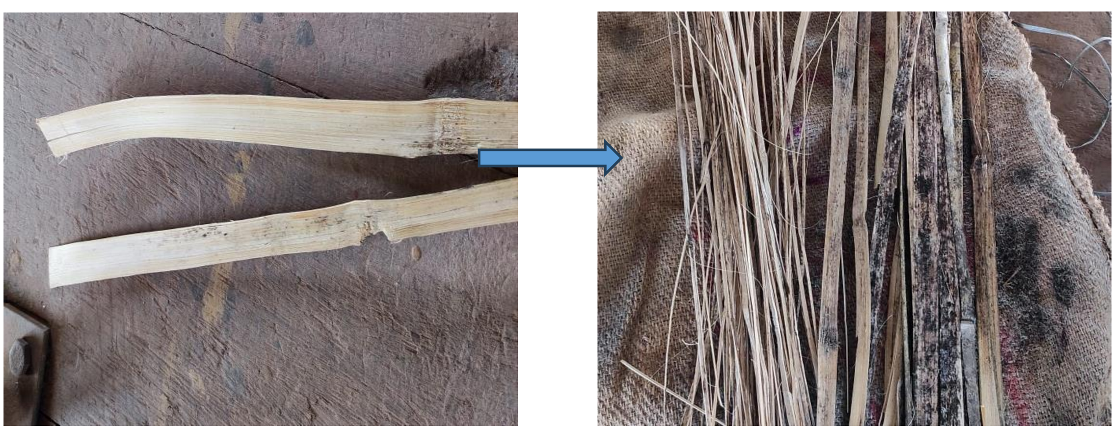

Figure 3: Preparation of Bamboo into thin Sticks

ISBN-978-81-19905-39-3

(a) (b)

Figure 4: Resin and Hardener mixing

(a) (b)

Figure 5: Preparing Threads

3. Results and Discussions

3.1 Tensile Strength Test

The tests on both composite and regular bamboo using a Universal Testing Machine (UTM) following IS: 1786 standards.

CASE-1

The tensile stress of normal bamboo rods with varying diameters was investigated, as detailed in Figure 6. The rods tested had diameters of 6 mm, 8 mm, and 10 mm. The results showed

ISBN-978-81-19905-39-3

that the tensile stress experienced by these bamboo rods was relatively consistent across different diameters, with a slight variation.

Figure 6: Normal Bamboo Rod

Table 1: Normal bamboo rod Tensile stress result

Thread Pattern	Diameter in mm	Tensile stress in N/mm^2
Normal Bamboo	6mm	98 N/mm^2
Normal Bamboo	8mm	97 N/mm^2
Normal Bamboo	10mm	101.3 N/mm^2

The tensile stress values in Table 8.1 indicate that normal bamboo rods, regardless of diameter, have a tensile stress close to 100 N/mm^2. This suggests that bamboo's inherent material properties offer consistent strength across different sizes.

CASE -2

The tensile stress of close thread bamboo rods with diameters of 6 mm, 8 mm, and 10 mm was analyzed. The results demonstrated a variation in tensile stress values depending on the rod diameter.

ISBN-978-81-19905-39-3

Figure 7: close thread Bamboo Rod

The tensile stress of normal bamboo fiber rods with varying diameters was investigated, as detailed in (Fig. 8.4).

Table 2: Close Thread bamboo fiber Tensile stress result

Thread Pattern	Diameter in mm	Tensile stress in N/mm^2
Close Thread	6mm	162 N/mm^2
Close Thread	8mm	159 N/mm^2
Close Thread	10mm	102 N/mm^2

The tensile stress values in Table 2. Indicate that close-thread bamboo rods exhibit higher tensile stress at smaller diameters (6 mm and 8 mm), with a noticeable decrease at a diameter of 10 mm. This variation suggests that the threading pattern influences the mechanical properties of bamboo rods, with smaller diameters providing higher tensile strength

CASE -3

The tensile stress of helical pitch thread bamboo fiber rods with diameters of 6 mm, 8 mm, and 10 mm was examined. The results indicated a significant variation in tensile stress depending on the diameter of the rod (Figure 8).

Figure 8: helical pitch thread Bamboo Rod

ISBN-978-81-19905-39-3

Table 3: Helical Pitch Thread bamboo fiber Tensile stress result

Thread Pattern	Diameter in mm	Tensile stress in N/mm^2
Helical Pitch Thread	6mm	207 N/mm^2
Helical Pitch Thread	8mm	132 N/mm^2
Helical Pitch Thread	10mm	98.4 N/mm^2

The tensile stress values in Table 3. show that helical pitch thread bamboo rods have the highest tensile stress at a diameter of 6 mm, which decreases significantly as the diameter increases to 8 mm and 10 mm. This suggests that the helical pitch threading pattern enhances the tensile strength more effectively in smaller-diameter rods.

CASE -4

The tensile stress of reverse helical pitch thread bamboo rods with diameters of 6 mm, 8 mm, and 10 mm was investigated. The results revealed varying tensile stress values depending on the diameter of the rod.

Figure 9: Reverse helical pitch thread bamboo rod

Figure 9 provides a visual representation of the reverse helical pitch thread bamboo rods used in the study

ISBN-978-81-19905-39-3

Table 4: Reverse Helical Pitch Thread bamboo fiber Tensile stress result

Thread Pattern	**Diameter in mm**	**Tensile stress in N/mm^2**
Reverse Helical Pitch Thread	6mm	173 N/mm^2
Reverse Helical Pitch Thread	8mm	133 N/mm^2
Reverse Helical Pitch Thread	10mm	108 N/mm^2

The results (Table 4) showed that the tensile stress values varied across different diameters of the rods. Specifically, the tensile stress decreased as the diameter of the rod increased, with the highest stress observed in the 6 mm diameter rod (173 N/mm^2), followed by the 8 mm diameter rod (133 N/mm^2), and the lowest stress in the 10 mm diameter rod (108 N/mm^2).

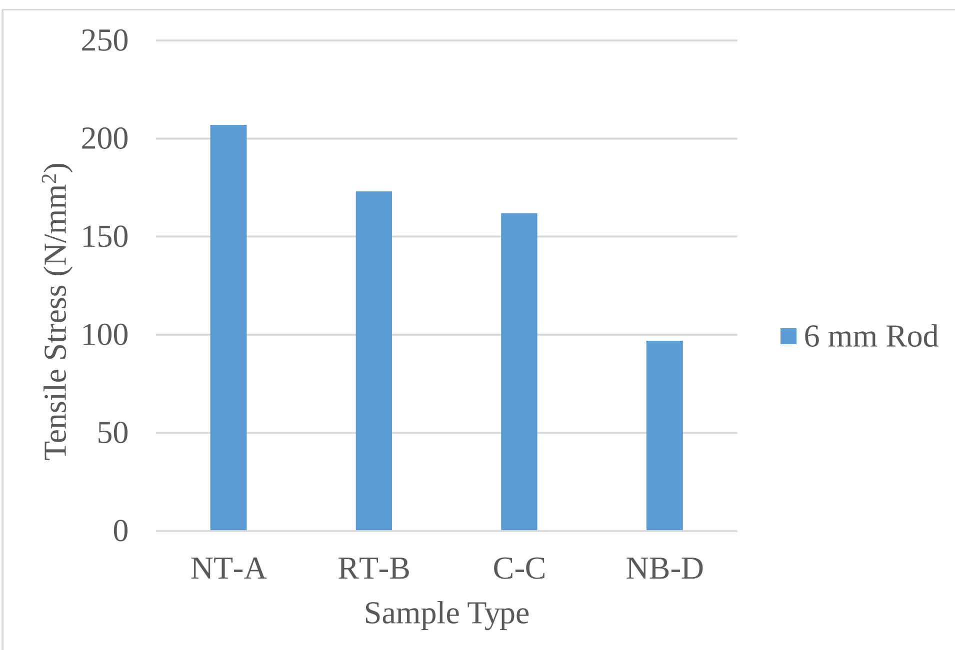

Figure 10: Tensile stress characteristics of 6mm diameter rods

The above Figure 10 tensile stress characteristics of 6mm diameter rods which consists of tensile stress versus different patterned bamboo rods. Horizontal axis of the chart lists the various types of rods being compared, while the vertical axis shows the tensile strength values.

ISBN-978-81-19905-39-3

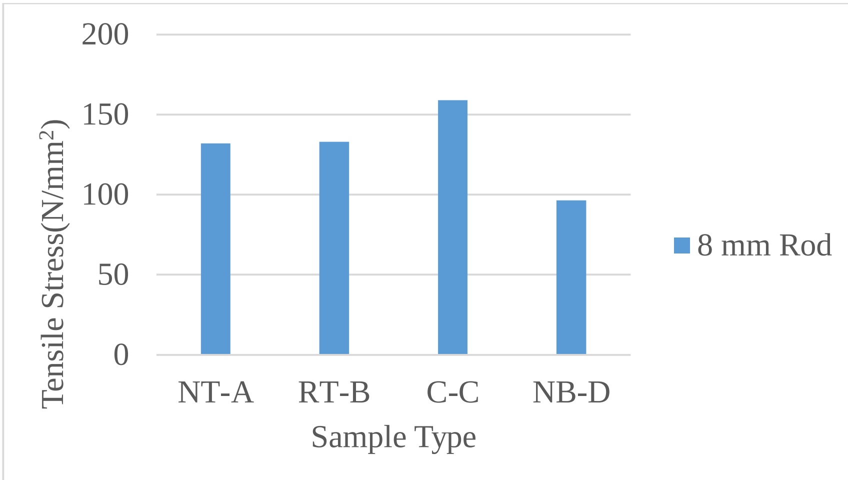

Figure 11: Tensile stress characteristics of 8mm diameter rods

The above Figure 11 tensile stress characteristics of 8mm diameter rods which consists of tensile stress versus different patterned bamboo rods. Horizontal axis of the chart lists the various types of rods being compared, while the vertical axis shows the tensile strength values.

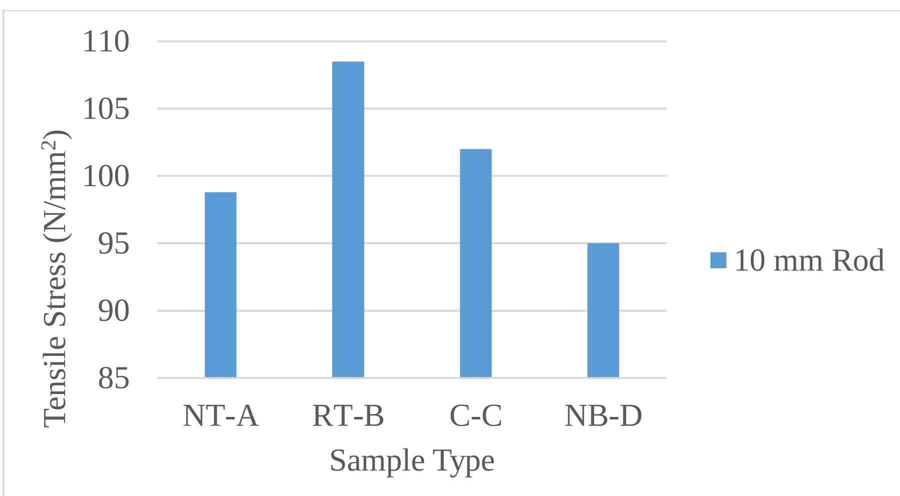

Figure 12: tensile stress characteristics of 10mm diameter rods

The above Figure 12 tensile stress characteristics of 8mm diameter rods which consists of tensile stress versus different patterned bamboo rods. Horizontal axis of the chart lists the various types of rods being compared, while the vertical axis shows the tensile strength values

ISBN-978-81-19905-39-3

3.2 Comparison of Normal Bamboo and Composite Bamboo Fiber Rods

The study illustrated in Figure 13 demonstrates that composite bamboo fiber rods have significantly higher tensile strength compared to regular bamboo samples. Regular bamboo showed an average tensile strength of 60-100 MPa, whereas composite bamboo fiber rods exhibited a tensile strength of 120-180 MPa. This indicates that composite bamboo is stronger and more suitable for load-bearing and durable applications in construction and manufacturing.

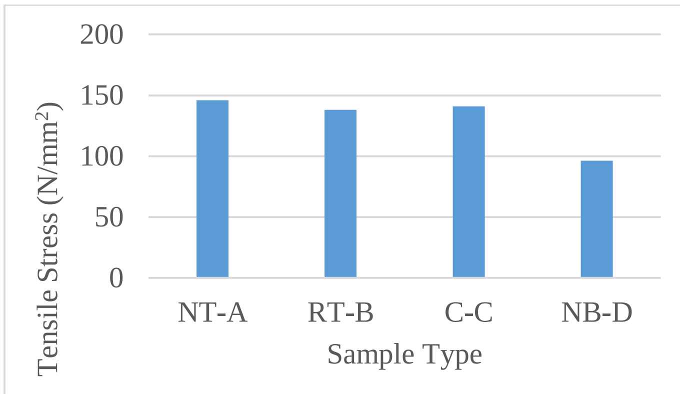

Figure 13: Normal bamboo and Composite bamboo fiber rods

3.3 Flexural Strength Test-Concrete Beam

The below figure 14 shows the flexural strength of the sample tested. The results indicate the effectiveness of Composite Bamboo Reinforcement (CBR) in enhancing the flexural strength of concrete beams. The beam with normal bamboo reinforcement (BRB) exhibited an 8% increase in flexural strength compared to the plain concrete beam (NB). In contrast, the beam with composite bamboo reinforcement (CBRB) showed approximately a 20% increase in flexural strength.

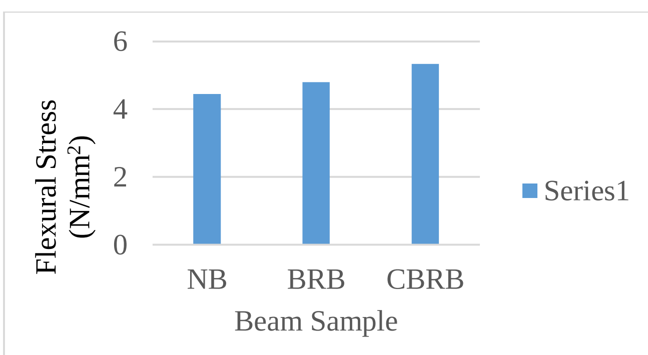

Figure 14: Flexural strength test-concrete beam

ISBN-978-81-19905-39-3

4.0 CONCLUSION

The present study demonstrates the superior performance of Composite Bamboo Reinforcement (CBR) over regular bamboo reinforcement in both tensile and flexural strength applications.

Tensile Strength Comparison:

- Regular Bamboo: Exhibited an average tensile strength of 60-100 MPa.
- Composite Bamboo Fiber Rod: Showed a significantly higher tensile strength of 120-180 MPa.
- Implication: Composite bamboo is considerably stronger than regular bamboo, making it more suitable for load-bearing and durable applications in construction and manufacturing.

Flexural Strength Enhancement:

- Normal Beam (NB): Baseline flexural strength.
- Beam with Regular Bamboo Reinforcement (BRB): Displayed an 8% increase in flexural strength compared to the normal beam.
- Beam with Composite Bamboo Reinforcement (CBRB): Achieved approximately a 20% increase in flexural strength over the normal beam.

These findings confirm that Composite Bamboo Reinforcement (CBR) not only significantly enhances the tensile strength of the material but also improves the flexural strength of concrete beams more effectively than regular bamboo reinforcement. Therefore, CBR is a promising material for use in construction and other structural applications, offering improved performance, durability, and load-bearing capacity.

ISBN-978-81-19905-39-3

Reference:

[1] Z. Khan, B.F. Yousif, Md Mainul Islam, Fracture behavior of bamboo fiber reinforced epoxy composites (2017),.2017.02.015

[2] D. Chandra Mohan, Experimental data on the properties of natural fiber particle reinforced polymer composite material published on 5 August 2017

[3] Yanglun Yu, Yuxiang Huang, Fandan Meng, Wenji yu, Key Laboratory of Wood Science and Technology of State Forestry Administration Date of publication: 18 March 2018.

[4] Bahrum Prang Rocky's The effect of mercerization on thermal and mechanical properties of bamboo fibers as a bio composite material on 5 February 2021.

[5] Kai Zhang, Fangxin, Wenyan Liang, Thermal and Mechanical Properties of Bamboo Fiber Reinforced Epoxy Composites, Published on 3 June 2018.

[6] Fuli Wang, Study on the variation law of bamboo fibers' tensile properties and the organization structure on the radial direction of bamboo Published on 26 October 2018.

[7] Jyun-Kai Huang, Wen-Bin Young, The mechanical, hygral, and interfacial strength of continuous bamboo fiber, 15 November 2018.

[8] P. Lokesh, T.S.A. Surya Kumari, R. Gopi, A study on mechanical properties of bamboo fiber reinforced polymer composite Published on 3 August 2019.

[9] Kong Fah Tee, Thermal and mechanical properties of bamboo fiber reinforced composites Received 30 May 2019; Received in revised form 14 September 2019; Accepted 23 December 2019.

[10] Nabanita Banik, Manufacturing of bamboo composite in the industrial aspect, 23 January 2020 Accepted 14 February 2020

[11] Kefei Liu, Chaofan Wu, Kang jiang, Xianming shi, Bamboo fiber has engineering properties and performance suitable as reinforcement, Article Received 14 July 2020 revised form 2 April 2021 Accepted 2 April 2021.

[12] Assima Dauletbek, A review of mechanical behavior of structural laminated bamboo lumber on 5 May 2021.

ISBN-978-81-19905-39-3