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EXPERIMENTAL STUDY OF BAMBOO REINFORCED CONCRETE BEAM

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ABSTRACT

Traditionally, steel has been the primary material used for reinforcing concrete. However, due to issues related to cost and availability, there has been growing interest in exploring alternative materials for this purpose. One such alternative is bamboo, which, despite its widespread use as a construction material in developing countries, has seen limited application as a concrete reinforcement material due to various uncertainties. Bamboo, being a natural, low-cost, and abundantly available resource, presents a promising potential to replace steel in concrete reinforcement. This study aims to evaluate the viability of bamboo as a reinforcement material in concrete. To achieve this, tensile strength tests are conducted on bamboo sticks with three and five nodes, with varying cross-sectional shapes. Additionally, flexural strength tests are performed on bamboo-reinforced concrete beams to assess the material's performance in concrete applications. In these tests, singly and doubly reinforced bamboo beams (750 mm in length, 150 mm in width, and depth) are compared to plain concrete beams to evaluate their relative strength and behavior under stress.

Keywords: Bamboo Reinforcement, Tensile Strength, Flexural Strength, Deflection, Bamboo Reinforced Concrete, Bamboo, Corrosion, Pull-Out Test.

I. INTRODUCTION

In recent years, steel prices have risen significantly, making it difficult for developing countries to obtain due to its high cost. This has led to a heavy restriction on the use of steel in the construction industry. Additionally, the production of steel is highly energy-intensive and relies heavily on fossil fuels. Research institutes have pointed out that the environmental impact of steel use in construction could be drastically reduced. For developing nations, the focus is on building infrastructure in a cost-effective manner, with simple technologies and reliable construction methods.

The rapid development and production of materials such as steel, cement, glass, and aluminum—often sourced from limited mineral resources—has contributed to environmental issues like air and water pollution. In contrast, plants and fibers, such as bamboo, are renewable, environmentally friendly resources. Bamboo, a type of giant grass that originates from underground rhizomes, grows naturally in many parts of the world and is also cultivated in some regions. Found in tropical and subtropical areas between latitudes of about 40° south, bamboo thrives in climates with average annual temperatures ranging from 20°C to 30°C. Some species of bamboo can even grow at altitudes ranging from 20 to 3,000 meters, and the plant reaches full maturity within three to four years.

In recent times, global research efforts have been focused on finding low-cost and energy-efficient alternatives to traditional construction materials. Among these alternatives, bamboo has emerged as a promising candidate. Bamboo has a long history of use in construction, particularly in bridges and homes throughout Asia. It is also energy-efficient to harvest and transport, making it a more affordable option than steel. As such, bamboo holds great potential as a construction material, even in regions that lack advanced manufacturing technologies and construction techniques.

A research study was carried out in our laboratory to evaluate the potential of using bamboo and non-steel materials as reinforcement in concrete structures. This paper discusses the impact of bamboo corrosion, the bond characteristics of bamboo reinforcement influenced by its surface condition, and the flexural performance of bamboo-reinforced concrete slabs under different curing conditions.

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BAMBOO-REINFORCED CONCRETE

Concrete is susceptible to cracking under external influences like heat, dryness, and seismic activity, primarily due to its low tensile strength. To mitigate this issue, concrete is typically reinforced with materials such as steel, which helps prevent cracks (as seen in reinforced concrete and fiber-reinforced concrete structures). The combination of steel and concrete in reinforced concrete structures creates an ideal composite material, leveraging the strengths of both components while offsetting their individual weaknesses.

However, in recent years, the cost of steel has risen significantly.

The cost of steel has increased significantly, making it difficult for developing countries to access steel, thereby limiting its widespread use. As a result, many regions around the world struggle with reinforcing concrete structures adequately. Additionally, steel production is highly energy-intensive, relying on large amounts of fossil fuels. Given the growing concerns about environmental issues and the need to reduce carbon emissions, it is likely that steel production will face restrictions in the future. In light of these challenges, developing steel-free construction methods is becoming increasingly important for sustainable development.

Bamboo-reinforced concrete (BRC) is a type of concrete that uses bamboo as reinforcement. Research into BRC structures began in the early 1900s, aiming to apply traditional construction techniques to address various technical challenges. While the tensile strength of most bamboo is roughly half that of steel, certain bamboo species exhibit comparable strength. Furthermore, bamboo is fast-growing, lightweight, and easy to process, making BRC a viable option in regions where steel is hard to obtain, particularly in tropical and subtropical areas where bamboo is abundant. However, there are several technical challenges to overcome before BRC can be widely adopted. As steel and reinforced concrete structures became dominant with economic development, the use of BRC declined for a period. While research on BRC has persisted at various institutions, including universities, significant academic advancements have only recently begun to emerge.

1.1 CORROSION OF BAMBOO

The volume of bamboo expands as it absorbs water from the concrete, and it contracts as it loses moisture during the drying process. Since the shrinkage of bamboo is significantly greater and occurs more rapidly than that of concrete, the bamboo embedded in the concrete experiences repeated cycles of expansion and contraction. This behavior is thought to be one of the key factors contributing to the loss of bond stress between the bamboo and the concrete. The variation in the tensile strength of bamboo when immersed in alkali water is known, as illustrated in Figure 1. However, the specific experimental details are unclear due to the data being from older studies.

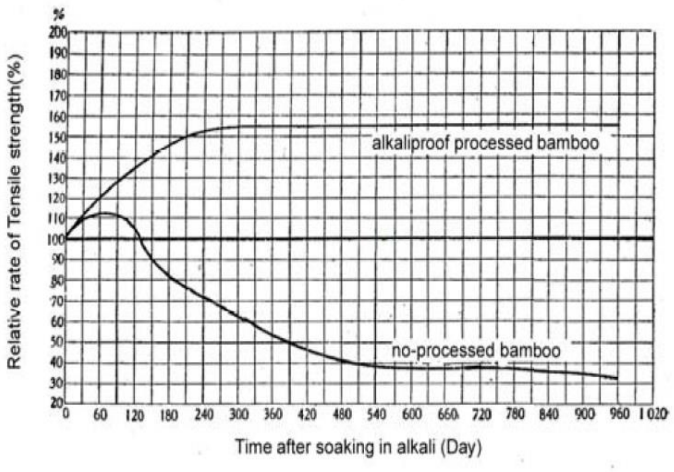

Figure 1. Influence of time on corrosion

II. LITERATURE REVIEW

1. Daiane Romanzini (2012) investigated the impact of fiber hybridization and frequency on the dynamic and mechanical characteristics of hybrid fiber composites. Their findings revealed that incorporating glass fibers enhanced the modulus of elasticity, and the addition of reinforcement improved the stiffness of the composites.

2. **Kasiviswanathan (2015)** examined the effects of hybridizing glass fibers with randomly oriented natural fibers. The fibers were arranged in layers, and various mechanical properties such as impact strength, flexural strength, and tensile strength were evaluated and compared.

3. **Meenambika Bai (2014)** focused on the flexural properties of hybrid fiber composites, finding that the flexural strength improved with an increase in the glass fiber content. Additionally, the composites demonstrated better chemical resistance. They also explored the effects of alkali treatment on bamboo fibers, noting improvements in both flexural and chemical resistance.

4. **Sule U (2014)** studied the mechanical and water absorption properties of hybrid fiber composites. They found that the fiber length and hybridization ratios significantly influenced the composite properties. The optimal tensile strength, modulus of elasticity, and water absorption were notably affected by the fiber length.

5. **Venkata Subba Reddy (2010)** researched the tensile properties of hybrid fibers, observing that the tensile strength of the composites increased with higher fiber content. They also noted that the use of alkali-treated bamboo fibers further enhanced the tensile properties. Additionally, the hybrid fibers exhibited excellent chemical resistance.

6. **Gupta, D.K., and Singh, R.C. (2018),** concluded that incorporating bamboo fiber into concrete enhances its flexural strength by approximately 10% compared to traditional concrete. Regarding compressive strength, they observed that small amounts of bamboo fiber (0.5%) initially improved strength, but further increases in fiber content led to a decrease in strength. Since tensile strength is related to flexural strength, their findings indicate that the increase in flexural strength positively impacts the tensile strength of concrete.

7. **Bhowmik, R.N., Pal, J., and Sarkar, P.P. (2017),** explored the feasibility of using Bambusa Balcooa as a reinforcement in brick aggregate concrete structures. Their study involved several tests to assess the mechanical properties of bamboo-reinforced concrete beams. The results showed that Bambusa Balcooa demonstrated strong tensile strength and ductility. Epoxy treatment significantly reduced the bamboo's water absorption, enhancing the bond strength between the bamboo and concrete by 2.24 times compared to uncoated bamboo. Furthermore, the load-carrying capacity of bamboo-reinforced brick aggregate concrete beams was 4.88 times greater than that of plain concrete beams with 2% bamboo reinforcement. The study concluded that increasing the percentage of bamboo reinforcement (up to 2%) improved the strength of the bamboo-reinforced beams.

8. **Gill, S., and Kumar, R. (2016),** found that bamboo has commendable tensile strength and can be used as a reinforcement in reinforced concrete construction (R.C.C.). Their experiments showed that the behavior of bamboo-reinforced concrete was similar to that of steel reinforcement, although bamboo demonstrated a superior bond strength compared to plain steel bars. They noted that the bond strength increased significantly (between 1.2 to 1.35 MPa) when bamboo underwent full treatment. This research suggests that bamboo sticks could be used as a retrofitting material to improve the structural behavior of reinforced concrete beams.

9. **Lewangamage, C.S., and Perera, P.M.D.J.S. (2015),** concluded that alternating bamboo reinforcement with steel reinforcement increased both the load at first crack and the maximum load-carrying capacity compared to control samples. However, they observed a decrease in ductility ratio relative to the control sample.

III. METHODOLOGY

Following materials were used in ongoing research.

3.1. Cement

For the concrete mix in this study, Ordinary Portland Cement (OPC) was utilized.

3.2. Fine Aggregate

For the fine aggregate in this study, locally sourced sand was employed. The fineness modulus (FM) of the fine aggregate was determined following ASTM C136 [4]. The sand was in a surface saturated dry (SSD) condition, with the FM value measured at 2.69.

3.3. Coarse Aggregate

Crushed stone was used as the coarse aggregate for preparing the sample beams. The maximum size of the coarse aggregate was 20 mm. The gradation of the coarse aggregate was determined in accordance with ASTM

C136. The coarse aggregate was also in a surface saturated dry (SSD) condition. The gradation curve for the coarse aggregate is presented in Figure 2.

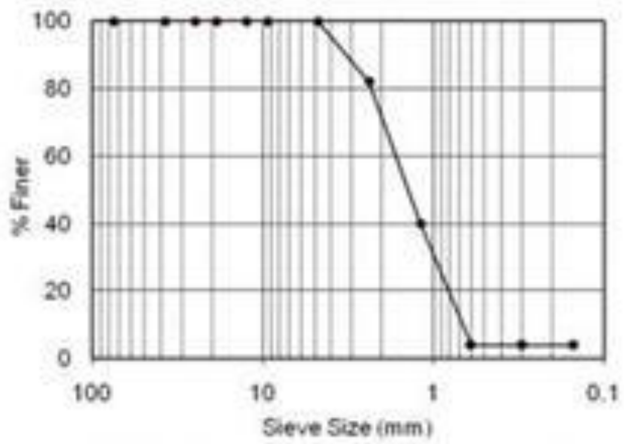

Figure 2: Gradation Curve showing the gradation of coarse aggregate used.

3.4. Bamboo

Bamboo culms are cylindrical in shape, as depicted in Figure 3, and are segmented by nodes, which act as solid transverse diaphragms. The strength of the bamboo is more evenly distributed at the lower portion of the culm compared to the upper or middle sections. This is because the bottom of the bamboo experiences less bending stress, while the top portion is subjected to higher bending forces, particularly due to wind pressure.

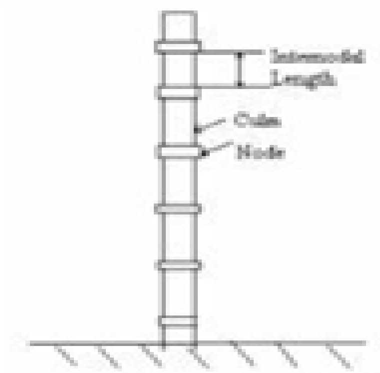

Figure 3: Whole Bamboo Culm

The following criteria should be taken into account when selecting bamboo culms (whole plants) for use as reinforcement in concrete structures:

1. Only bamboo plants that are at least three years old and exhibit a distinct brown color should be used.

2. The longest and thickest culms available should be selected.

3. Fresh, green, or unseasoned bamboo culms should be avoided.

4. Bamboo harvested in spring or early summer should be excluded, as they tend to be weaker due to higher moisture content in the fibers.

For this study, bamboo plants that were three years old and had a pronounced brown color were chosen. Samples of varying lengths, each measuring one meter, were taken from the bottom of the plants, specifically from culms with three and five nodes.

IV. SAMPLE PREPARATION

4.1. Bamboo Sticks

Bamboo sticks are commonly preferred over whole culms in construction applications. Once the bamboo plant is harvested, it is recommended to allow it to dry and season for a period of three to four weeks before it is used in construction.

To carry out the tensile strength test, preparation of the bamboo sample was required. Bamboo sticks, each measuring 1 meter in length and approximately 20 mm in width, were cut and then left to dry and season for 30 days, as illustrated in Figure 4.

Figure 4: Bamboo Specimen

The thickness of the bamboo sample varied along its length, as it is a natural material with properties that cannot be precisely controlled. To account for this variability, the dimensions were measured at five different points along the length of each sample to determine the average dimension. During the seasoning period, all bamboo sticks were supported at regular intervals to prevent any warping.

4.2. Concrete Mix Design

The concrete used for the beams was prepared using Ordinary Portland Cement, sand as the fine aggregate, and stone chips as the coarse aggregate, with a maximum size of 20 mm. The mix ratio was 1:1.5:2.8 by volume, with a water-cement ratio of 0.52. This mix was designed to achieve a compressive strength of 25 MPa at 28 days. The slump value of the mix was found to be between 50 and 70 mm.

4.3. Cylindrical Specimen

The prepared concrete was poured into cylindrical molds with a diameter of 150 mm and a height of 300 mm. After casting, the concrete specimens were kept in a moist environment and demolded after 24 hours. The samples were then placed in an open water tank for curing, as required, for a period of 28 days.

4.4. Beam Specimen

Concrete was poured into molds with dimensions of 150 mm in width, 150 mm in depth, and 750 mm in length. Three types of beams were used in this study: plain concrete beams, singly reinforced beams, and doubly reinforced beams, all with identical dimensions. In the plain concrete beams, no bamboo sticks were used. For the singly reinforced beams, two bamboo sticks were placed at the bottom with a 1-inch clear cover. In the doubly reinforced beams, two bamboo sticks were placed at both the top and bottom, with a 0.254-meter clear cover. Figures 4 and 5 illustrate the dimensions and cross-section of the sample beams.

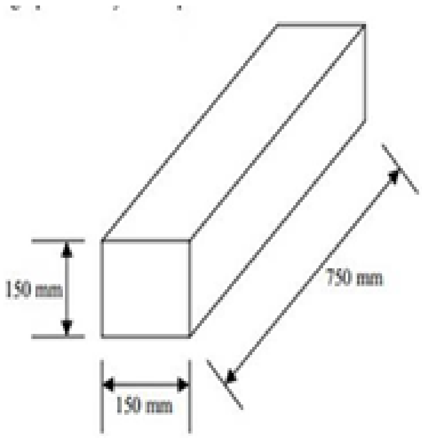

Figure 5: Dimensions of Sample Beam

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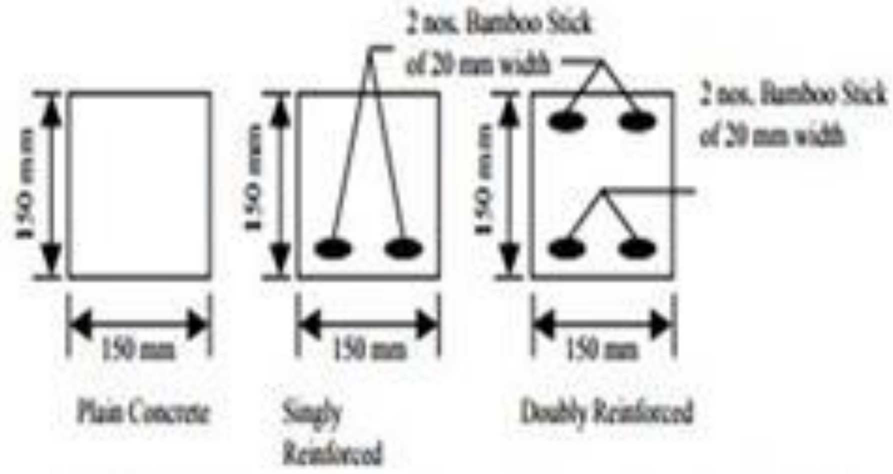

Figure 6: Cross Section of Sample Concrete Beam with and without Bamboo Reinforcement.

After 24 hours, samples were demoulded and submerged in open water tank for curing for 28 days as required for the test. Curing for cylindrical and beam specimen was not performed at a constant temperature. The averages of three days temperatures are shown in table 1.

Table 1: Curing temperature

Days	**Temperature (^{0}C)**	
	8 AM	5PM
1-3	28.0	29.2
4-6	28.7	30.1
7-9	30.2	30.6
10-12	28.5	31.1
13-15	29.4	32.3
16-18	27.9	30.5
19-21	30.3	32.4
22-24	29.2	31.8
25-27	28.6	30.2

V. EXPERIMENTAL PROGRAM

This section outlines the experimental procedures conducted to assess the properties of the materials used in this study. In addition to performing strength tests on cylindrical concrete specimens, sieve analysis was carried out for each material. The tensile strength of bamboo sticks and the flexural strength of the concrete beams were also evaluated. The details of the testing methods are summarized below.

5.1. Concrete Compressive Strength Test

The compressive strength test was conducted on cylindrical concrete specimens with a diameter of 150 mm and a height of 300 mm, in accordance with ASTM C 39. The specimens were tested at 28 days using a Universal Testing Machine (UTM) with a constant loading rate. To ensure uniform stress distribution during the test, each specimen was capped with sulfur. The maximum load at failure was recorded, and the average of three specimens was taken as the compressive strength of the concrete at the specific testing age.

5.2. Splitting Tensile Strength Test

The splitting tensile strength test was performed on cylindrical concrete specimens (150 mm diameter and 300 mm height) following the guidelines of ASTM C 496. The specimen was positioned on its side, and the test was conducted at 28 days using the UTM at a constant loading rate. Three bearing rods were used to apply the load uniformly along the cylinder's length. The maximum load sustained by the specimen was divided by appropriate geometric factors to calculate the splitting tensile strength. The average of three specimens was considered as the splitting tensile strength for the specific test day.

5.3. Tensile Strength Test of Bamboo Stick

The tensile strength of bamboo sticks was measured using the Universal Testing Machine (UTM), as shown in Figure 6. Each bamboo specimen was placed in the UTM, and a tensile load was gradually applied until failure occurred. The elongation of the bamboo was measured at regular intervals of the applied tensile load to monitor its behavior under stress.

5.4. Flexural Test of Beam

For the flexural test, the beam was positioned accurately on the testing machine with supports placed 125 mm from each end, as per the specified dimensions. Dial gauges were installed at the midspan of the beam to measure deflection during the test. A point load was then applied gradually at the midspan using a controlled pumping unit. The deflection at the midspan was recorded at regular intervals as the load was incrementally applied to the beam.

Figure 7: Tensile Strength Test of Bamboo stick

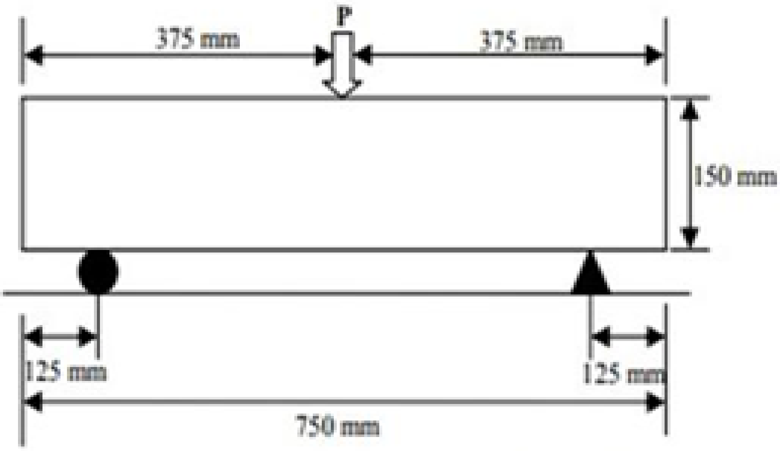

Figure 8: Test Setup for Flexural Test of Beam

VI. RESULT AND DISCUSSION

6.1 Compressive and Tensile Strength of Concrete

Table II presents the results of the compressive and tensile strength tests conducted on cylindrical concrete specimens with a diameter of 150 mm and a height of 300 mm, after a curing period of 28 days.

Table 2: Compressive and tensile strength of cylindrical sample

S.No.	Compressive Strength N/mm²	Average Compressive Strength N/ mm²	Tensile Strength N/ mm²	Average Tensile Strength N/ mm²
1	24.68	24.82	2.56	2.61
2	25.40		2.61	
3	24.38		2.67	

6.2. Tensile Strength of Bamboo Sticks

The tensile strength tests were initially performed on bamboo samples with 3 nodes, followed by tests on bamboo sticks with 5 nodes. In both sets of tests, all specimens failed at the node points. Table 3 summarizes the tensile test results for the various bamboo specimens tested.

Table 3: Tensile stress of bamboo specimen

S. No.	Area (mm²)	Weight (gm)	Ultimate Load (KN)	Stress (N/ mm²)	Avg. Stress (N/ mm²)
Number of nodes= 3					
1	202.5	161.1	24.85	119.85	**111.95**
2	257.3	218.5	26.12	112.5	
3	228.9	172.6	22.89	103.5	
Number of nodes= 5					
1	252.65	180.5	24.50	96.50	**102.25**
2	275.5	223.90	28.85	106.77	
3	265.5	205	25.50	103.50	

From above conclusion, it is evident that the specimens vary in properties such as cross-sectional area and weight, as bamboo is a natural material. Additionally, the number of nodes in the bamboo specimens does not appear to cause a noticeable difference in the stress. Therefore, the average stress can be approximated as 105 MPa, with the influence of the nodes considered negligible.

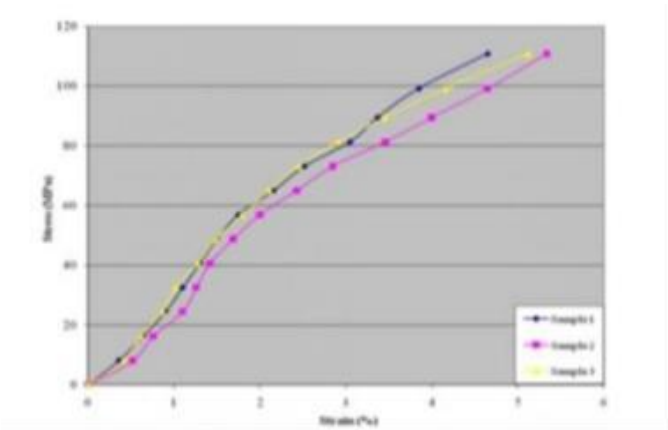

Figure 9: Stress Strain diagram for Bamboo Sticks with 3 Nodes

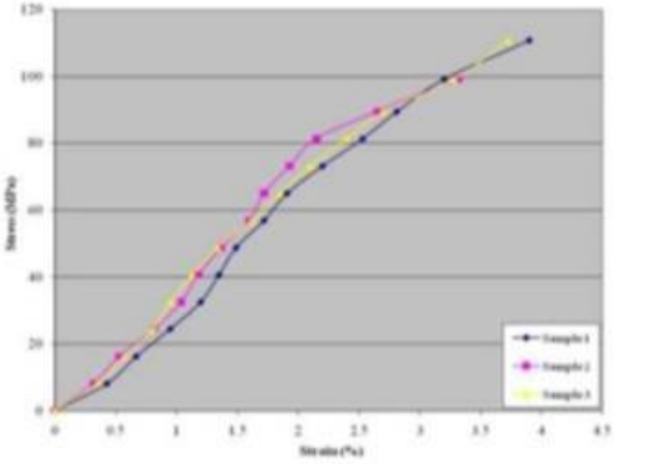

Figure 10: Stress Strain diagram for Bamboo Sticks with 5 Nodes

6.3. Flexural Strength of beam

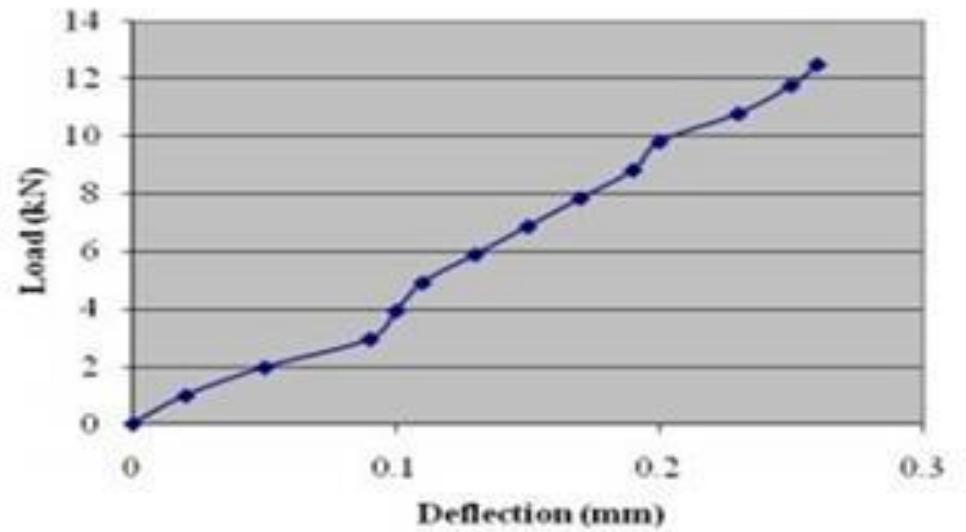

Figure 11: Load-Deflection curve for Plain Concrete Beam

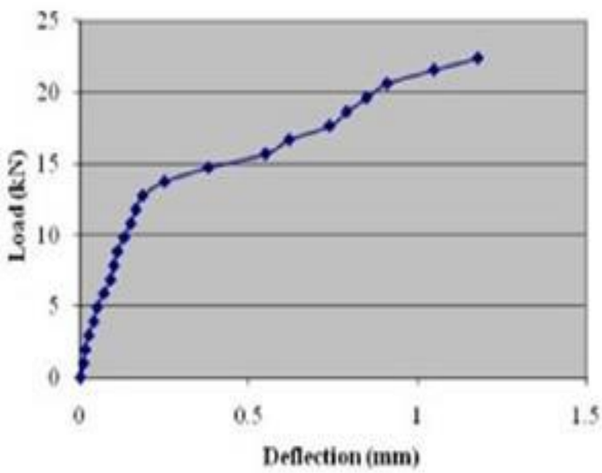

Figure 12: Load-Deflection Curve for Single Bamboo Reinforced Concrete Beam

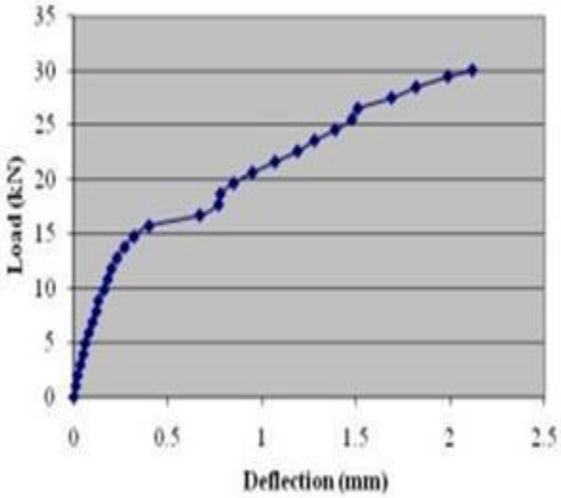

Figure 13: Load-Deflection Curve for Doubly Bamboo Reinforced Concrete Beam

Table 4 presents the ultimate load-carrying capacity and maximum deflection for the plain concrete beam (PC), singly reinforced beam (SR), and doubly reinforced beam (DR) at 28 days, based on the average values from three samples.

Table 4: Ultimate load carrying capacity and maximum deflection of beam specimens

Sample ID	Ultimate Load (KN)	Maximum Deflection (mm)
Plain Cement Concrete	13.5	0.31
Singly Reinforced Beam	23.45	1.25
Doubly Reinforced Beam	31.58	2.25

VII. CONCLUSION

This study explores the use of bamboo as a viable reinforcement material in concrete. The stress-strain curves of bamboo indicate that its modulus of elasticity is significantly lower than that of steel, meaning it cannot effectively prevent cracking in concrete under ultimate load conditions. However, the results from the flexural tests on bamboo-reinforced beams show that bamboo can enhance the structural performance of concrete. For beams with singly bamboo reinforcement, the load-bearing capacity was approximately twice that of plain concrete beams with identical dimensions. In the case of doubly bamboo-reinforced concrete beams, the load-carrying capacity increased by about 2.5 times compared to the plain concrete beams. Additionally, the maximum deflection observed in the singly reinforced beams was about 4.5 times greater, while the doubly reinforced beams exhibited a deflection approximately 8 times greater than that of the plain concrete beams.

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