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Comparative Study on Locally Available Bamboo Species as Reinforcement in Concrete Beam

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Abstract - *This study looks at bamboo's potential as a cost-effective and environmentally friendly replacement for steel reinforcement in concrete structures. Three locally available bamboo species were evaluated for their mechanical properties and suitability for structural applications using tensile testing. To improve bonding performance and durability, each bamboo sample was sand-coated and treated with a water-based epoxy resin prior to being embedded in concrete. Concrete beams reinforced with each species of bamboo were cast and tested under centre-point loading for seven, fourteen, and twenty-eight days. Steel-reinforced beams and regular concrete were tested for comparison. To evaluate the effect of bamboo reinforcement on the overall behaviour of concrete, workability and compressive strength tests were performed on all mixes. Comparing the flexural strength, load-bearing capacity, and general performance of beams reinforced with various bamboo species was the main goal of the experimental program. The findings showed that the three species' structural behaviour varied significantly. Among these, Solid Chewali/Chivari (Dendro calamus stocksii) outperformed the others in terms of strength and load resistance. This suggests that it has a great deal of potential as a useful reinforcing material. The results show that solid chewali/chivari (Dendroca lamus stocksii) bamboo is an efficient, sustainable, and cost-effective reinforcement option that is appropriate for rural housing applications where accessibility, affordability, and environmental advantages are crucial. Overall, the study supports the creation of substitute reinforcement techniques for environmentally friendly building and offers insightful information about the structural behaviour of bamboo-reinforced concrete.*

Keywords: Tensile strength, compression strength, flexural strength, steel reinforced concrete, experimental investigation, bamboo reinforced concrete, UTM

1. INTRODUCTION

The growing environmental and financial issues facing the construction sector have raised demand for affordable and environmentally friendly substitutes for steel reinforcement. Due to its high tensile strength, quick renewability, and widespread availability, bamboo has drawn interest as a possible reinforcing material. However, more research is needed to understand its structural performance in concrete, particularly how it behaves under various curing conditions. This study compares the performance of several locally accessible bamboo species to ascertain which is best suited for construction applications. It also looks at the flexural behavior of bamboo-reinforced concrete beams under different curing regimes. The study intends to offer useful information on how to choose effective bamboo species for reinforcement and assess their feasibility as environmentally friendly steel substitutes.

1.2 Species of Bamboo Used for Testing

[1] Melocanna baccifera (Bamboo murali/muli from assam)
[2] Dendrocalmus stocksii (bamboo solid chewali/chivari from konkan)
[3] Dendrocalmus stocksii (bamboo hollow chewali/chivari from konkan**)**

1. Dendrocalamus Stocksii (Solid and Hollow Chewali/Chivari – Konkan)

The Western Ghats of Maharashtra, Goa, Karnataka, and Kerala are home to this robust, clump-forming species of bamboo. It is found naturally in both solid and hollow varieties, with a height of 6–9 m and a culm diameter of 2.5–4 cm. It is widely used in construction, agricultural supports, and handicrafts because of its excellent tensile strength, high durability, and quick growth. The species grows well in a variety of soil types and tropical climates, but it rarely produces seeds and needs careful clump management.

Fig-1: Dendrocalmus Stocksii

2. Melocanna Baccifera (Murali/Muli – Assam)

This tall species of bamboo is common in Northeast India and Assam. It has long internodes and thin-walled culms with a diameter of 3–7 cm, reaching a height of 10–20 m. Well-drained soils and humid tropical climates are ideal for the species' growth. Every 40 to 50 years, it experiences gregarious flowering, which results in massive fruit clusters linked to the "Mau tam" phenomenon. M. baccifera is appropriate for light construction, scaffolding, handicrafts, and the paper industry because of its flexible and lightweight culms. Its thin culm walls and ecological problems associated with mass flowering make it less suitable for heavy structural use, despite its quick growth and strong soil-binding ability.

Fig-2: Melocanna Baccifera

1.3 Selection of Bamboo

To increase durability and structural performance, a number of preparation steps must be completed before using bamboo as reinforcement. To lessen moisture-related shrinkage and decay, mature culms between the ages of three and five are chosen and thoroughly dried. To improve resistance against insects and fungi, the bamboo is subsequently treated with preservatives like smoke curing or boric acid-borax. The culms are split or shaped, and their surfaces are smoothed for consistent placement in concrete, depending on the reinforcement design. To improve bonding and lessen water absorption, a protective coating—typically bitumen or epoxy—is applied. The treated bamboo is then cut to the proper length, secured with wire or clamps as needed, and placed in the mold with a suitable concrete cover.

1.4 Problem Statement

To determine whether bamboo is a suitable substitute for steel reinforcement, a systematic experimental methodology is required. There is insufficient data on the tensile strength of bamboo species, their behaviour in reinforced concrete beams, and their comparison with conventional steel reinforcement. Therefore, this study adopts a structured methodology involving material testing, specimen preparation, bamboo treatment, casting, and load testing to obtain reliable and comparable results. Specifically, three locally available bamboo species will be compared by measuring physical properties (density, moisture content), mechanical properties (tensile strength, bending strength), bond behavior with concrete (flexural tests), and durability characteristics. Identical beam specimens will be cast using each bamboo species as tension reinforcement and tested under flexure; results will be benchmarked against steel-reinforced beams to provide a performance baseline. Statistical analysis of repeated tests will determine which local species offers the best combination of strength, bond, ductility, durability, and practicality (availability and ease of treatment) for structural use, leading to clear recommendations for bamboo-reinforced construction.

1.5 Objective of the Study

The purpose of this paper is to assess whether bamboo reinforcement for concrete beams is feasible. On the other hand, steel-reinforced concrete's mechanical characteristics and behavior have been extensively researched and documented. Thus, the purpose of this study is to make a preliminary contribution to the collection of the mechanical characteristics and behavior of bamboo reinforced beams with regard to particular bamboo species in accordance with their availability.

2. LITERATURE REVIEW

Amit Singh et al. [2016] evaluated bamboo's suitability for use as concrete reinforcement. The IS code 10262-2009's design requirements have been met by the concrete mix for M-25 grade concrete. Two beam sizes—150 x 150 mm and 150 x 200 x 700 mm, were chosen for this project. For every size of beam, beams made of steel reinforced concrete (SRC), bamboo reinforced concrete (BRC), treated bamboo reinforced concrete (TBRC), and plain cement concrete (PCC) were cast and put through a flexural testing machine. For every type of beam, there were six samples. For both sizes of beams, the area of reinforcement in steel reinforced concrete beams (SRC), bamboo reinforced concrete beams (BRC), and treated bamboo reinforced concrete beams (TBRC) remained constant. BRC, TBRC, and SRC beams were reinforced with Fe 415 grade steel and treated bamboo sticks, respectively. After being seasoned for two to three weeks, the bamboo sticks were utilised as reinforcement. According to the results of the flexural test, the steel-reinforced concrete beam outperformed the others in terms of flexural strength. In contrast to plain cement concrete beams, the flexural strength of bamboo reinforced concrete beams—both treated and untreated—showed a notable improvement. For light load-bearing structures like beams and slabs for small panels, it is therefore advised to use bamboo-reinforced concrete beams. It can also be applied to temporary structures.

Sri murnidewi et al. [2017] studied the effect of adding pegs along the bamboo reinforcement to boost the tog capacity of bamboo reinforced concrete beams was the subject of his research. The beams' capacity and strain energy are increased by inserting pegs. The average tensile stress of the reinforcement also increased. The collapse began with cracks on the tensile area of the beam, and as the number of cracks increased, they eventually continued at the compression area. There are some loose and torn pegs, but none of the 24 test objects drop the beam reinforcement.

Syed Faraz Siddique et al. [2017] examined the behavior of a composite material made of bamboo as a substitute for concrete reinforcement. Bamboo's mechanical characteristics are examined, and fundamental tests such as water absorption tests with two different coatings and bamboo compression tests are performed. To lessen the amount of steel reinforcement in a beam element, bamboo culms are positioned beneath the reinforcement. The analytical results from the ANSYS software's analysis of bamboo-reinforced beams are compared. to the outcomes of the experiment. 8.09% of the water was absorbed by the polyester resin-coated bamboo. Bamboo without knots has a higher ultimate compressive strength than bamboo with knots, according to a comparison of the ultimate compressive strength (N/mm) of the two types of bamboo. It was discovered that bamboo reinforced concrete with an 8 mm diameter bar had a flexural strength of 38 MPa. In ANSYS software, the bamboo reinforced beam element's final cracking load is 26KN.

Ayesha Siddika et al. [2017] examined the mechanical and physical characteristics of bamboo reinforcements. Specimens of bamboo-reinforced concrete beams were tested with various ratios of reinforcement, and the load capacity, deflection, and failure patterns were noted. The flexural strength of bamboo-reinforced columns was found to be comparable to steel-reinforced concrete beams and sufficiently higher than that of plain cement concrete. Additionally, the ultimate compressive strength and failure pattern were tested and observed in bamboo reinforced concrete columns with varying reinforcement ratios. It was discovered that the concrete crushing caused all the columns to fail in a similar manner. Among plain cement concrete and steel reinforced concrete, bamboo reinforced beams and columns with a moderate reinforcement ratio demonstrated the best strength-cost ratio, according to cost analysis.

Abhijeet Deya et al. [2018] conducted tests for the use of bamboo reinforced concrete beams, which are straightforward, effective, and affordable for rural buildings. This study compares the frictional characteristics of bamboo-reinforced concrete beams. By rolling the bamboo reinforcements with sand, G.I. wire, and coir, the frictional qualities of bamboo reinforced concrete beams have been attained. Steel stirrups make up the majority of the web material, which aids in preventing bamboo reinforced concrete beams from shearing. The four-post bend test was used to test eighteen of these beams until they failed. For comparison, flexural strengths at 28, 45, and 60 days have been taken into account. Beams with longer curing times and larger reinforcement sizes have been found to perform better at failure than beams with shorter curing times and smaller reinforcement sizes. Furthermore, beams with G have been found to have higher bond stress. I rolled reinforcements made of bamboo. Therefore, it can be suggested that bamboo can serve as a good potential reinforcement for inexpensive housing and can easily replace steel, saving a significant amount of natural resources.

Mr. Mahesh Sadashiv Sarode et al. [2019] did investigation to determine design parameters and the possibility of using bamboo as reinforcement in concrete slabs to make up for the concrete's low tensile strength. Considering the cost, steel reinforcement is a very suitable material to complement the low tensile strength of concrete. In certain regions of the world, people construct their homes entirely of mudbrick or concrete, which is extremely vulnerable. Bamboo could be used to replace the reinforcing bar in concrete for less significant structures in order to solve these issues tension test was performed on a bamboo specimen to assess these characteristics. This test yielded satisfactory results regarding the tensile strength and stress-strain characteristics of bamboo for use as reinforcement in concrete. The tensile strength, proof strength, and modulus of elasticity were calculated from the stress-strain curve for bamboo reinforcement.

Durga G et al, [2019] examined the use of bamboo reinforcement in M20 grade concrete beams and cylinders. Tests have been carried out to examine the impact of substituting bamboo for steel reinforcement. split tensile strength and flexural strength. We can cut construction costs by twenty-five percent by using bamboo. Composite structural members made of bamboo concrete can offer more affordable, customized solutions for eco-housing projects.

R. Shivkumar et al. [2023] examined the impact of using bamboo instead of steel reinforcement in concrete. To demonstrate bamboo as a building material, a 200 x 500 mm concrete beam is constructed, and 1 to 4% of the reinforcement area is made up of bamboo bars with a diameter of 20 mm. After 28 days of curing, a number of tests were conducted to determine whether bamboo could be used as building materials; the results showed promise. There are numerous tests in the study, such as flexural strength, tensile test, pull-out test, axial compression test, and rate comparison. The ultimate tensile strength of mild steel and bamboo ranges from 140N/mm2 to 280N/mm2, according to experimental research. Only 25% of wear and tear was found in the impact test. Additionally, compared to steel reinforced concrete (SRC), bamboo reinforced concrete (BRC) offered 50% axial compressive strength without altering cross sections. Nevertheless, BRC performed better

than SRC in the tensile test, offering 50% greater resistance against tensile load. Rate analysis between SRC and BRC revealed that, on a small scale, it nearly cut costs by

3 EXPERIMENTAL PROGRAMS

3.1 TENSILE STRENGTH TEST

Laboratory experiment was carried on the specimen of Chivari (Dendrocalamus Stocksii) and Muli (Melocanna baccifera) Bamboo under the UTM (Universal Testing Machine).

3.1.1 Selection of bamboo

Initially, one-meter-long bamboo samples were gathered. Using a chisel, each sample was then divided into four sections, each of which was then further divided in half to produce a total of eight pieces. At least two or three knots were present in each sample. A chisel and other carpentry tools were used to carefully remove any surface undulations.

3.2 FLEXURAL STRENGTH TEST

3.2.1 Preparation of Bamboo

Cutting was the first step in the bamboo preparation process. Mature, three to four-year-old bamboo culms were chosen, cut into strips of the necessary length, and the nodes were trimmed to guarantee a uniform cross-section. The strips were then seasoned by air-drying them in the shade for two to three weeks to minimize moisture content, shrinkage, and dimensional changes. Following seasoning, the strips were coated with a water-based epoxy and covered with fine sand to improve bonding, waterproofing, and mechanical interlock with concrete, all of which increased durability. To enhance anchorage and lower the chance of pullout, grooves were added at the ends of the coated strips after they had been allowed too fully dry.

Fig-3: Surface Treatment of bamboo using water-based epoxy resin and sprinkling sand

3.2.2 PREPARATION OF BEAM SAMPLE

1. Beam Reinforcement Details

Two of the 48-cm-long bamboo reinforcement strips were positioned in each beam's tension zone. To concentrate only on the flexural behavior of the beams, stirrups were not used and a clear cover of 20 mm was kept on all sides. To improve anchorage, the ends of the strips were roughened and given nails or grooves. Three beams were made for each of the three bamboo species that were tested, for a total of nine beams.

2. Placement of Bamboo

Before casting, the treated bamboo strips were precisely positioned inside the mold. In order to stop any movement during the casting process, stiff concrete was then positioned and compacted around the strips.

Fig-4: Placement of bamboo in mould

3. Beam Casting

The molds used to cast the 500 × 100 × 100 mm beams were thoroughly cleaned and oiled to make demolding them easier. For casting, M20 grade concrete with a water–cement ratio of 0.50 and a mix proportion of 1:1.5:3 was utilized. To ensure adequate consolidation, a table vibrator was used to compact each of the two layers of concrete that were poured. Finally, a trowel was used to smooth out the top surface.

Fig-5: Casting of Beams

4. Curing

The beams were cured for seven, fourteen, and twenty-eight days in water that was kept between twenty-seven and thirty degrees Celsius. The beams were taken out of the water and tested right away while still wet after each curing period.

Fig-6: Curing of Beam

3.2.3 Preparation of Cube Samples

To guarantee that all ingredients—such as cement, sand, and aggregates—were thoroughly blended, concrete for the cubes was combined using a machine mixer. A consistent mix was made possible by the mixer's revolving drum and blades. While continuous mixers provided concrete for larger needs, batch mixers were used to prepare smaller quantities.

1. Cube Casting

To ensure easy demolding, clean molds coated with oil were used to prepare cubes measuring 150 × 150 × 150 mm. To eliminate air spaces and guarantee adequate consolidation, freshly mixed concrete was put into the molds and compacted using a tamping rod, using at least 35 strokes per layer. As soon as the concrete was mixed, the cubes were cast.

Fig-7: Casting of Cube

2. Cube Curing

Following casting, the cubes were kept at a temperature of 27° ± 2°C and a relative humidity of at least 90% for a full day. After that, they were placed in either clean water or a lime-saturated solution to cure; the water was changed every seven days to ensure ideal conditions. Tests of compressive strength were performed after seven and twenty-eight days.

Fig-8: Curing of Cubes

4 RESULTS AND DISCUSSION

4.1 Tensile Test on Bamboo Species

Bamboo was subjected to a tension test to ascertain its tensile strength and axial loading behaviour. The bamboo culms were cut into uniform strips for this test, and the ends were securely clamped to stop them from slipping when being loaded. Tensile load was applied gradually until failure occurred while the specimens were mounted in a Universal Testing Machine. To examine the stress-strain behaviour, the corresponding load and elongation were noted. The test helped in understanding the potential strength of bamboo.

BMH – Bamboo muli hollow

BHC- Bamboo hollow chivari

BSC- Bamboo solid chivari

Table-1: Tensile test on bamboo species

Species	Avg dia (mm)	Elongation (%)	Max force (KN)	Tensile strength N/mm^2	Avg.Tensile strength N/mm^2
BMH1	10.12	16.6	11.94	148.4	
BMH2	10.09	15.5	10.40	130.8	
BMH3	10.10	17.0	12.32	153.7	144.33
BHC1	10.11	14.0	22.04	274.3	
BHC2	10.08	15.2	23.00	288.7	
BHC3	10.15	14.1	22.05	272.67	278.55
BSC1	10.05	17.9	31.04	391.32	
BSC2	10.08	17.8	32.40	406.72	
BSC3	10.06	18.3	29.21	367.74	388.56

4.2 Flexural Test on beam [BRC and SRC)

The capacity of a material to tolerate bending forces applied perpendicular to its longitudinal axis is known as flexural

strength. Concrete's flexural strength is calculated using the formula.

$f=PL/(bd^2)$,

Where,

f is the concrete's flexural strength (in MPa),

P is the failure load (in N), and L is the beam's effective span

4.1.1 A 7-day flexural strength test on a bamboo-reinforced beam

Table-2: Flexural strength test for seven days on a beam reinforced with bamboo

Species	Sample	Failure Load (KN)	Flexural Strength N/mm^2	Avg Flexural Strength N/mm^2
BMH1	18.02	10.81	10.86	
BMH2	19.20	11.52		
BMH3	17.10	10.26		
BHC1	15.00	9.00	9.22	
BHC2	21.01	12.60		
BHC3	10.10	6.06		
BSC1	12.10	7.26	11.28	
BSC2	20.20	12.12		**17.55**
BSC3	24.10	14.46		

4.1.1 A 14-day flexural strength test on a bamboo-reinforced beam

Table-3: Flexural strength test for seven days on a beam reinforced with bamboo

Species	Sample	Failure Load (KN)	Flexural Strength N/mm^2	Avg Flexural Strength N/mm^2
BMH1	25.10	15.06	13.47	
BMH2	20.14	12.08		
BMH3	22.12	13.27		
BHC1	17.76	10.65	10.68	
BHC2	17.68	10.60		
BHC3	18.00	10.80		
BSC1	34.11	20.46	15.86	
BSC2	25.10	15.06		**27.12**
BSC3	20.14	12.08		

4.1.1 A 28-day flexural strength test on a bamboo-reinforced beam

Table-4: Flexural strength test for seven days on a beam reinforced with bamboo

Species	Sample	Failure Load (KN)	Flexural Strength N/mm^2	Avg Flexural Strength N/mm^2
BMH1	30.26	18.15	15.50	
BMH2	19.18	11.50		
BMH3	28.12	16.87		
BHC1	28.12	16.87	14.44	
BHC2	21.68	13.00		
BHC3	22.46	13.47		
BSC1	31.80	19.08	16.24	
BSC2	30.26	18.15		31.93
BSC3	19.18	11.50		

4.3 Compression Test on Cubes

A cube compression test is performed on standard cubes of size 150 x 150 x 150 mm after 7,14 and 28 days of immersion in water for curing .The following formula is used to determine the specimen's compressive strength.

$F = P/A$

Where

A is the estimated cross-sectional area in mm, P is the maximum applied load by N, and F is the specimen's compressive strength in MPa.

Table-4: Compression test on cubes

Days	Sample No.	Weight	Failure Load (KN)	Compressive Strength (MPa)	Avg Compressive Strength (MPa)
7	1	9.08	450.2	20.01	17.33
	2	9.18	319.3	14.19	
	3	9.09	400.4	17.80	
14	1	8.79	600.7	26.70	25.78
	2	8.90	592.2	26.32	
	3	8.80	522.2	24.33	
28	1	8.28	659.7	29.32	30.05
	2	8.23	749.6	33.31	
	3	8.64	619.5	27.53	

5. CONCLUSION

Solid Chewali bamboo outperformed the other two species by roughly 35% out of the three locally available bamboo species that were tested. It contributed to beam specimens that carried greater loads and demonstrated enhanced flexural strength, as well as superior tensile strength. Additionally, the solid chewali-reinforced beams showed more stable failure modes and more controlled crack patterns. Furthermore, following treatment, this species exhibited improved bonding behavior with concrete. Among the tested species, Solid Chewali was found to be the most dependable reinforcement material due to its improved mechanical strength and favorable structural behavior. Its characteristics imply that it might be particularly appropriate for low-cost and rural housing applications where accessibility and affordability are crucial. Solid Chewali bamboo is a viable and efficient substitute for light reinforcement in non-critical concrete elements, even though it cannot completely replace steel in heavy structural applications.

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