Study Of Strength and Durability of Bamboo Reinforced Concrete (BRC) Beams Under Flexural Load

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Abstract—This research investigates the flexural strength and durability of bamboo-reinforced concrete (BRC) beams using locally available, 25-30 mm diameter treated bamboo as a sustainable alternative to steel reinforcement. A total of six concrete beams were cast, i.e., three with bamboo reinforcement and three with conventional steel reinforcement, and tested under two-point flexural loading. The bamboo strips were chemically treated with a boric acid–borax solution and coated with engine oil and cement slurry to enhance durability and improve bonding with the concrete.

The experimental results showed that BRC beams achieved approximately 70% of the ultimate load capacity of steel-reinforced beams. Although the BRC beams exhibited greater deflection and earlier crack formation, they demonstrated ductile failure behavior, which is favorable in structural applications. No signs of decay or deterioration were observed in the treated bamboo after 28 days of curing and testing.

This study confirms that treated bamboo can serve as an eco-friendly, low-cost reinforcement for light-duty concrete structures, particularly in rural and resource-constrained regions. Further long-term studies are recommended to evaluate its performance under environmental exposure and dynamic loading.

Index Terms—Bamboo-Reinforced Concrete (BRC), Flexural Load, Treated Bamboo, Sustainable Construction, Eco-Friendly Material, Alternative Reinforcement, BRC Beam, Flexural Strength.

I. INTRODUCTION

Concrete is one of the most widely used construction materials due to its high compressive strength. However, it has low tensile strength, which is typically addressed by adding steel reinforcement. While effective, steel is expensive, energy-intensive to produce, and contributes to environmental pollution. In many rural and developing areas, its availability is also limited.

Bamboo offers a sustainable alternative. It is a fast-growing, flexible, and locally available natural material with good tensile strength. Commonly used in traditional construction across Asia, bamboo is cost-effective and has a lower environmental impact compared to steel.

Despite its advantages, bamboo has not yet been widely adopted in modern reinforced concrete structures due to concerns about its durability and bonding with concrete, especially under long-term exposure to moisture and air.

This study aims to evaluate the flexural strength and durability of bamboo-reinforced concrete (BRC) beams and compare their performance with conventional steel-reinforced concrete (RC) beams. The goal is to determine whether bamboo can serve as a practical reinforcement material in sustainable and cost-sensitive construction.

II. LITERATURE REVIEW

2.1 Concrete Reinforcement Overview

Concrete is widely used for its compressive strength but lacks tensile strength. Steel bars are commonly added to provide the necessary tensile resistance and improve crack control. However, steel is expensive, heavy, and has a high carbon footprint, prompting researchers to explore sustainable alternatives.

2.2 Bamboo in Construction

Bamboo has a long history in traditional construction across Asia, Africa, and South America. It is lightweight, fast-growing, strong in tension, and often referred to as "green steel." Its environmental advantages include renewability, low energy consumption, and carbon sequestration. It has been used in scaffolding, housing, and roofing, and its potential as reinforcement in concrete is gaining increased attention in modern research.

2.3 Indian Research Contributions

In India, the use of bamboo as a replacement for steel in reinforced concrete has received growing attention due to its eco-friendliness, low cost, and easy availability. Recent Indian studies have provided helpful insights into how bamboo can be used in concrete structures.

Dr. Vijaya Kumar Y. M. and Y. R. Meena (2022), in their research paper published in the *International Journal for Research in Applied Science and Engineering Technology (IJRASET)*, studied the flexural behavior of bamboo-reinforced concrete beams. Their results showed that BRC beams could reach up to 70% of the strength of steel-reinforced beams, making them suitable for lightweight or low-cost buildings, especially where high strength is not the main requirement.

The Ministry of Housing and Urban Affairs (MoHUA), Government of India, supported bamboo-reinforced concrete in its Global Housing Technology Challenge (GHTC-India) report in 2021. The report described bamboo as a clean and affordable building material. It also pointed out bamboo's good tensile strength and low environmental impact, suggesting that it can be used in housing if it is properly treated and combined with concrete.

These Indian studies show that bamboo has real potential as a building material and support more research and testing, like the present study, to explore its use in construction.

2.4 Durability Concerns

Bamboo is organic and prone to decay, swelling, and insect attack when left untreated. In concrete, untreated bamboo can deteriorate over time, especially under moist conditions. To improve durability, bamboo is commonly treated with boric acid–borax solution, bitumen, epoxy, or lime water. These treatments enhance moisture resistance and improve bonding with concrete.

2.5 Research Gaps

Despite progress, there are still some major research gaps:

- Most studies are limited to small-scale or short-term tests.
- Long-term performance under real environmental conditions is underexplored.
- Many researchers have not used proper treatment methods, affecting bonding and durability.
- Few comparative studies exist between BRC and RC beams under flexural loading.
- There are no standardized design guidelines for BRC.

This study addresses these gaps by testing treated BRC beams under flexural loading and comparing them with conventional RC beams to assess strength, deflection, and durability.

III. MATERIALS AND METHODS

3.1 Introduction

This chapter outlines the materials and procedures used to prepare and test bamboo-reinforced concrete (BRC) beams. Materials were selected based on local availability and standard specifications. All testing was conducted in a controlled laboratory environment to evaluate the flexural strength and durability of BRC.

3.2 Materials Used

The primary materials included bamboo, cement, fine and coarse aggregates, water, and steel (for control beams).

3.2.1 Bamboo

Locally sourced bamboo from the Shamli district (25–30 mm diameter) was used.

Fig 3.1: Bamboo Specimens Used in the Study

Strips were cut, cleaned, and soaked in a 1:1 boric acid–borax solution for 72 hours to enhance durability. After air-drying in the shade for 10–12 days, the bamboo was coated with used engine oil to reduce moisture absorption. All strips were also coated with cement slurry before placement to improve the bond with concrete.

3.2.2 Cement
UltraTech OPC 53-grade cement, conforming to IS: 12269–2013, was used. It provided good early strength and ensured durability in the concrete mix.

3.2.3 Fine Aggregate
Well-graded, clean river sand passing through a 4.75 mm sieve (as per IS 383:2016) was used as the fine aggregate, selected for its bonding properties and local availability.

3.2.4 Coarse Aggregate
Crushed angular aggregate (maximum size 20 mm), free from impurities and compliant with IS 383:2016, was used. Its interlocking properties enhanced the strength and workability of the concrete.

3.2.5 Water
Clean, potable water was used for both mixing and curing, in accordance with IS 456:2000, ensuring no adverse effect on concrete strength or setting time.

3.2.6 Steel Reinforcement
For comparison, RC beams were reinforced with 12 mm diameter Tehri 550+ TMT bars, conforming to IS 1786:2008. This allowed for an accurate comparison between BRC and conventional RC beams under flexural loading.

3.2.7 Bamboo Treatment Summary
To ensure long-term durability and effective bonding:
- Bamboo was chemically treated using a boric acid–borax solution.
- It was air-dried in the shade to prevent cracking.
- Coated with used engine oil to resist moisture absorption.
- Cement slurry was applied to enhance the bond with concrete.

3.3 Concrete Mix Design
M25 grade concrete (mix ratio 1:1:2) was used, as it is commonly recommended for structural elements such as beams. The mix was designed in accordance with IS 456:2000 guidelines. A consistent water–cement ratio of 0.45 was maintained to ensure adequate workability and the desired target strength.

3.4 Beam Design and Reinforcement Details
Beam Dimensions:
- Width: 150 mm
- Depth: 150 mm
- Length: 1200 mm
- Effective Span: 1000 mm
- Concrete Cover: 25 mm on all sides

Table 3.1: Reinforcement Details of BRC and RC Beams

Reinforcement Type	BRC Beams	RC Beams
Tension Reinforcement	2 bamboo strips (25–30 mm diameter)	2 TMT steel bars (12 mm diameter)
Compression Reinforcement	2 bamboo strips (20–25 mm diameter) (used in both)	2 bamboo strips (20–25 mm diameter) (used in both)
Shear Reinforcement	Stirrups tied with binding wire	Closed mild steel stirrups at 150 mm c/c spacing

This uniform reinforcement layout enabled a direct comparison of the flexural performance between bamboo and steel reinforcements.

3.5 Casting and Curing Procedure
Beam moulds were cleaned and oiled to prevent sticking and to allow easy demoulding. Treated bamboo strips and steel bars were securely placed according to the design, with stirrups tied to maintain alignment during casting.

Concrete was mixed in a mini electric mixer, with manual batching using a *tasla*. As per IS 456:2000, mixing continued for at least 2 minutes to ensure

uniform consistency. The concrete was poured in layers and compacted manually with a 16 mm tamping rod to eliminate air voids.
After 24 hours, the beams were demoulded and submerged in clean water for 28 days of curing to ensure proper strength development and durability.

3.6 Experimental Test Setup
The test setup was designed to compare the flexural strength and durability of BRC and RC beams under identical conditions.

3.6.1 Flexural Strength Test
A two-point loading test was conducted using a Universal Testing Machine (UTM) with a 1000 mm effective span. Beams were placed horizontally on supports, and loads were applied symmetrically at one-third of the span from each end.

The load was gradually increased until failure, and both the applied load and mid-span deflection were recorded. This helped evaluate bending resistance and compare the ultimate load capacity of BRC and RC beams.

3.6.2 Durability Tests
The durability of the bamboo reinforcement was evaluated through visual observations before and after curing, and during flexural testing. Key aspects examined included:

- Cracks or decay in the bamboo post-curing
- Bond performance between bamboo and concrete
- Signs of moisture absorption or swelling

3.7 Test Observations and Measurements
The following parameters were recorded during testing:

- Initial crack load and ultimate failure load
- Crack type and pattern (flexural, shear, or combined)
- Mid-span deflection under increasing loads
- Mode of failure (brittle or ductile)
- Comparison of flexural strength between BRC and RC beams
- Post-failure condition of bamboo (e.g., bond slip, crushing, or splitting)

IV. RESULTS AND DISCUSSIONS

4.1 Flexural Test Results
The flexural strength of six beams i.e. three bamboo-reinforced (BRC) and three steel-reinforced (RC) was tested using two-point loading. The first crack load for BRC beams ranged from 10.5 to 11.0 kN, while RC beams exhibited higher values between 14.2 and 14.5 kN. The ultimate load capacity of RC beams was consistently higher (average 26.5 kN) than that of BRC beams (average 18.6 kN), indicating an approximate 30% reduction in load-bearing capacity for BRC beams.

Table 4.1: Flexural Test Results

Beam	First Crack Load (kN)	Ultimate Load (kN)	Deflection (mm)
BRC Beam 1	10.5	18.2	10.4
BRC Beam 2	11.0	19.0	11.1
BRC Beam 3	10.8	18.6	10.8
RC Beam 1	14.2	26.3	9.1
RC Beam 2	14.5	26.7	9.3
RC Beam 3	14.3	26.5	9.2

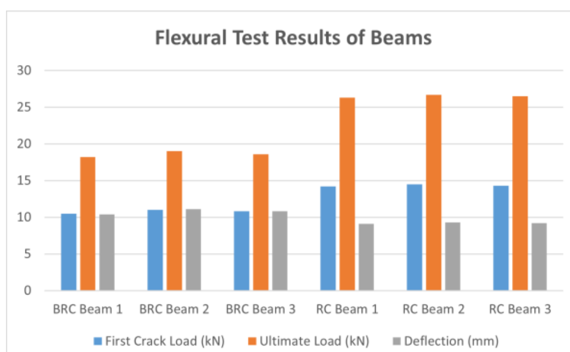

Figure.4.1: Flexural Test Results of Beams

Flexural stress values followed a similar trend, with an average of 3.97 N/mm² for BRC beams and 5.65 N/mm² for RC beams.

Table 4.2: Avg. Flexural Stress

Beam Type	Avg. Flexural Stress (N/mm²)
BRC Beams	3.97 N/mm²
RC Beams	5.65 N/mm²

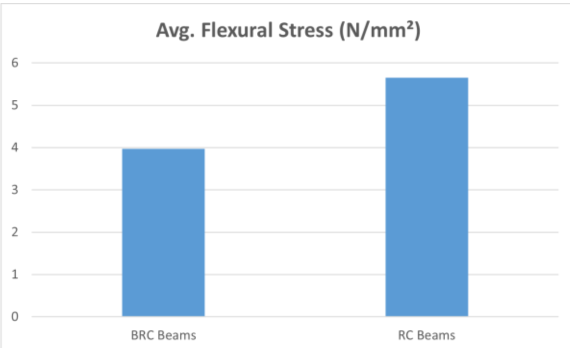

Figure.4.2: Avg. Flexural Stress

4.2 Crack Pattern and Failure Mode

Cracks in BRC beams appeared earlier due to the lower tensile strength and stiffness of bamboo. The failure was gradual and ductile, characterized by wider crack spacing and visible bond slips. In contrast, RC beams exhibited fine and closely spaced cracks, with failure occurring later and more suddenly. The bamboo-reinforced beams displayed progressive failure, which may help prevent sudden collapse in real-world use.

4.3 Deflection Characteristics

BRC beams showed higher deflection at ultimate load, averaging 10.77 mm, compared to 9.20 mm in RC beams.

This is due to the lower stiffness and elastic modulus of bamboo compared to steel. While high deflection may not be desirable in all applications, it indicates that bamboo can absorb more energy before failure, beneficial in seismic or impact-prone structures.

4.4 Durability Test Results

No decay or insect damage was observed in the treated bamboo after curing and testing. The boric–borax treatment and engine oil coating effectively prevented moisture-related deterioration. The cement slurry coating enhanced the bond with concrete, and no significant slippage was observed during testing. Overall, the durability of bamboo within concrete was found to be satisfactory for short-term use.

4.5 Comparison with Conventional RC Beams

- The load-carrying capacity of BRC beams was approximately 70% that of RC beams.
- Deflection was higher in BRC beams but remained within acceptable limits.
- Flexural stress in BRC beams was 3.97 N/mm², compared to 5.65 N/mm² in RC beams.
- RC beams performed better in terms of strength and crack control, whereas BRC beams provided a sustainable and cost-effective alternative for low-load or non-critical applications.

Table 4.3: Comparison of Average Flexural Performance Between BRC and RC Beams

Parameter	BRC Beams	RC Beams	% of RC Value
Avg. First Crack Load	10.77 kN	14.33 kN	~75%
Avg. Ultimate Load	18.60 kN	26.50 kN	~70%
Avg. Flexural Stress	3.97 N/mm²	5.65 N/mm²	~70%
Avg. Deflection	10.77 mm	9.20 mm	+17% more

4.6 Discussion and Interpretation of Results

While bamboo cannot fully replace steel in high-strength structures, it demonstrates strong potential in light-duty structures, particularly in rural or cost-sensitive areas. Its ductility, sustainability, and local availability support its use in eco-friendly construction. The approximately 30% lower strength of BRC beams is acceptable for non-critical structures. Proper treatment significantly enhanced bamboo's performance. Future research should explore long-term durability and hybrid reinforcement techniques.

V. CONCLUSION AND FUTURE SCOPE

This study concludes that treated bamboo can be a viable and sustainable alternative to steel in light-duty concrete structures, especially in rural or cost-sensitive areas. Although BRC beams were about 30% weaker than RC beams, they exhibited gradual and ductile failure, which is advantageous in preventing sudden collapse. The use of 25-30 mm treated bamboo strips improved overall performance, narrowing the gap with conventional RC beams. Bamboo's eco-friendliness, local availability, and low cost make it suitable for sustainable construction.

However, this study was limited to short-term laboratory testing with a small sample size and only one bamboo size. Long-term performance and behavior under dynamic and seismic loads were not evaluated.

Future research should focus on:

- Real-world durability
- Hybrid reinforcement techniques
- Different bamboo species and treatment methods
- Development of standard design codes for BRC
- Performance under seismic and impact loads, particularly in low-rise and disaster-prone structures

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