

# Use of Bamboo and Other Natural Fibres as Structural Reinforcements

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**Abstract -** The increasing demand for sustainable and eco-friendly construction materials has led to the exploration of natural alternatives to steel and synthetic fibres in reinforced concrete. This project investigates the use of bamboo and other natural fibres as structural reinforcements, focusing on bamboo's potential as a tensile reinforcement in concrete members. Bamboo is known for its high tensile strength-to-weight ratio, renewable nature, and low environmental impact, making it an ideal substitute for steel in low-cost and green construction.

The experimental study includes tensile strength testing, water absorption analysis, and boric acid–borax treatment of bamboo specimens. The treatment, conducted in a 1:1.5:10 ratio for 14 to 18 days, was aimed at improving the bamboo's resistance to insects, fungi, and moisture absorption. Results from tensile testing showed that bamboo possesses an average tensile strength of approximately 230 MPa, confirming its suitability for tensile applications. The water absorption test indicated a 12% increase in mass after 48 hours of soaking, emphasizing the need for proper waterproof coatings before use in concrete.

The project is currently progressing toward the next phase, involving bitumen coating of treated bamboo and casting of bamboo-reinforced concrete beams. These beams will undergo compressive and flexural strength tests to evaluate their performance compared to conventional reinforcement methods. The study aims to contribute to the development of sustainable reinforcement practices and to establish guidelines for the structural use of bamboo in civil engineering applications.

**Keywords:** Bamboo reinforcement, natural fibres, tensile strength, boric–borax treatment, water absorption, sustainable construction, eco-friendly materials.

## 1.INTRODUCTION

### 1.1 BACKGROUND OF THE STUDY

The construction industry is one of the largest consumers of natural resources worldwide. With the increasing demand for infrastructure and rapid urbanization, the industry faces significant pressure to reduce its environmental impact and adopt more sustainable materials and methods. Conventional materials such as concrete, steel, and aluminum require large amounts of energy for production and contribute heavily to greenhouse gas emissions. As a result, the search for alternative, renewable, and eco-friendly materials has gained increasing attention among engineers, architects, and environmentalists.

Bamboo, often referred to as the “green steel” of the 21st century, has emerged as a promising sustainable material for construction. It is a natural composite material with a unique combination of light weight, high tensile strength, and fast renewability. Bamboo is widely available in tropical and subtropical regions and grows much faster than conventional timber, making it one of the most renewable natural resources on earth. Because of its remarkable mechanical properties, bamboo can effectively be used as a construction material for structural and non-structural applications, particularly in low-cost housing and rural development projects.

### 1.2 NEED FOR SUSTAINABLE CONSTRUCTION MATERIALS

The environmental challenges faced today—such as climate change, resource depletion, and pollution—have made

sustainability a global priority. In the construction sector, sustainability involves using materials and techniques that minimize environmental impact, conserve resources, and promote long-term economic and social benefits. The over-reliance on steel and concrete has led to extensive carbon emissions and depletion of non-renewable resources.

To address these issues, natural and renewable materials like bamboo, jute, and coir are being explored. Among these, bamboo stands out due to its rapid growth rate, excellent mechanical properties, and ability to regenerate without replanting. The use of bamboo in construction supports the principles of sustainable development—reducing dependence on high-energy materials while promoting local resource utilization and rural employment.

### 1.3 OVERVIEW OF BAMBOO AS A CONSTRUCTION MATERIAL

Bamboo belongs to the grass family Poaceae and is characterized by its hollow cylindrical culms, nodes, and internodes. It can grow up to full maturity within 3 to 5 years, compared to 15 to 20 years for most timber species. The plant's unique anatomy, consisting of fibers aligned longitudinally along the culm, gives it high tensile strength comparable to mild steel. Bamboo has been used for centuries in traditional construction, scaffolding, bridges, and furniture.

Modern research has revived interest in bamboo due to its potential as a structural material when treated and engineered properly. Bamboo can be used in various forms, such as whole culms, split sections, laminated bamboo, or bamboo composites. Recent advancements have also led to the development of engineered bamboo products like bamboo mat boards, bamboo fiber composites, and laminated bamboo beams, which provide more consistent and predictable performance.

### 1.4 PHYSICAL, MECHANICAL, AND CHEMICAL PROPERTIES OF BAMBOO

Bamboo's physical and mechanical properties vary with species, age, moisture content, and treatment. Its density typically ranges between 600 to 900 kg/m<sup>3</sup>, which is comparable to hardwood. The tensile strength of bamboo fibers can reach 160 to 350 MPa, making it suitable for reinforcement applications.

The high strength-to-weight ratio of bamboo makes it an ideal substitute for steel in certain structural applications, particularly in low-load conditions. However, bamboo is anisotropic—its strength and stiffness are higher along the longitudinal direction than in the transverse direction. The mechanical properties depend on the distribution of vascular bundles and fibers, which are denser towards the outer surface of the culm.

Chemically, bamboo consists mainly of cellulose (50–60%), hemicellulose (20–25%), and lignin (15–20%). The presence of starch and sugars makes it susceptible to attack by fungi, insects, and borers, especially under high moisture conditions. Hence, treatment and preservation play a crucial role in extending the service life of bamboo structures.

### 1.5 GLOBAL AND INDIAN CONTEXT OF BAMBOO USAGE

Globally, bamboo has been recognized as a sustainable construction material. In countries like China, Japan, and Indonesia, bamboo has been used extensively for centuries. In recent decades, bamboo architecture has seen significant innovation, with projects such as the Green School in Bali and the Vietnamese Bamboo Pavilion showcasing the potential of this material for modern, sustainable architecture.

India is the second-largest producer of bamboo in the world, with over 13 million hectares of bamboo forests spread across states like Assam, Kerala, Karnataka, and Madhya Pradesh. Despite the abundance of bamboo resources, its utilization in mainstream construction remains limited due to lack of awareness, inadequate preservation techniques, and absence of standard design codes. However, the National Bamboo Mission and other government initiatives aim to promote bamboo-based construction and reduce dependence on conventional materials.

### 1.6 STRUCTURAL APPLICATIONS OF BAMBOO IN CONSTRUCTION

Bamboo can be used in various structural and non-structural applications, including:

Beams, trusses, and columns in low-rise structures

Scaffolding and temporary frameworks

Reinforcement for concrete (bamboo-reinforced concrete beams and slabs)

Roof and wall panels in rural housing

Flooring, wall cladding, and interior applications

Bridges and walkways in eco-tourism projects

In reinforced concrete applications, bamboo can be used as a replacement for steel bars. When properly treated and bonded, bamboo can provide adequate tensile strength and ductility. Bamboo's low cost, light weight, and renewability make it particularly suitable for affordable housing in developing regions.

### 1.7 ADVANTAGES OF BAMBOO OVER CONVENTIONAL MATERIALS

1. Renewability – Bamboo matures in 3–5 years, making it one of the fastest renewable resources.
2. High Tensile Strength – Its tensile strength is comparable to mild steel (up to 350 MPa).
3. Lightweight – Bamboo is easy to transport and handle, reducing labor and transportation costs.
4. Low Carbon Footprint – Bamboo absorbs large amounts of CO<sub>2</sub> during growth, offsetting emissions.
5. Cost-Effective – Locally available and inexpensive compared to steel or hardwood.
6. Aesthetic Appeal – Provides a natural and eco-friendly appearance in architectural designs.
7. Flexibility and Resilience – Ideal for earthquake-prone areas due to its flexibility and lightness.

### 1.8 CHALLENGES IN USING BAMBOO FOR CONSTRUCTION

Despite its numerous advantages, several challenges hinder the large-scale adoption of bamboo in structural applications:

**Durability Issues:** Untreated bamboo is highly susceptible to decay, fungal growth, and insect attack.

**Moisture Sensitivity:** Bamboo swells and shrinks with changes in humidity, affecting dimensional stability.

**Variability in Properties:** Mechanical properties vary between species and even between culms of the same species.

**Lack of Standardization:** There are limited design codes and testing standards for bamboo structures.

**Connection Techniques:** Developing reliable joint systems between bamboo elements is complex.

**Fire Resistance:** Bamboo is combustible and requires special coatings or treatments for fire protection.

**Perception and Awareness:** Bamboo is often viewed as a “poor man’s material,” reducing its acceptance in urban construction.

### 1.9 DURABILITY AND DECAY ISSUES OF BAMBOO

Bamboo is a natural organic material that contains starch and sugars, which attract insects such as borers and termites. It is also vulnerable to fungi and mold, especially under damp conditions. The durability of untreated bamboo is generally limited to 2–3 years when exposed to outdoor conditions. Moisture is the main factor responsible for decay, as it promotes fungal growth and dimensional instability.

The durability can be improved through proper harvesting, seasoning, and preservation techniques. Bamboo should be harvested at the right age (3–5 years) and during the dry season to minimize starch content. Once harvested, it should be dried properly and treated with suitable preservatives to enhance resistance against biological attacks.

### 1.10 TREATMENT METHODS FOR ENHANCING BAMBOO DURABILITY

The preservation of bamboo is essential for its long-term use in construction. Several treatment methods have been developed to protect bamboo from decay, insects, and fungal attacks. The choice of treatment depends on the intended use, environmental exposure, and cost considerations. Common treatment methods include:

1. Chemical Treatments – Using boric acid, borax, copper-chrome-arsenate (CCA), or other preservatives.

2. Thermal Treatments – Heat treatment to reduce moisture content and degrade starch.
3. Natural Treatments – Using natural oils like linseed or neem oil to enhance resistance.
4. Water-Leaching – Soaking in water to remove sugars and starches.
5. Smoking and Seasoning – Traditional methods to dry and harden bamboo.

Among these, boric acid–borax treatment is one of the most effective and environmentally safe techniques for improving the durability of bamboo.

### 1.11 BORIC ACID–BORAX TREATMENT PROCESS

Boric acid and borax are widely used in combination for bamboo preservation due to their effectiveness against insects and fungi and their low toxicity to humans. The treatment involves preparing a solution typically consisting of 6% borax and 4% boric acid in water.

Steps involved in treatment:

- Preparation of Solution: The chemicals are dissolved in hot water to form a homogeneous preservative solution.
- Immersion of Bamboo: The freshly cut or air-dried bamboo culms are immersed in the solution for 14-18 DAYS .
- Drying: After immersion, the bamboo is removed and dried in shade to prevent cracking.
- Storage: The treated bamboo is stored in a dry, ventilated place before use in construction.
- This treatment helps prevent biological decay by neutralizing starch and creating a toxic barrier against insects and fungi.

### 1.12 OTHER PRESERVATION TECHNIQUES

Other commonly used preservation methods include:

Heat Treatment: Exposing bamboo to temperatures of 120–150°C for a few hours reduces starch content and moisture, improving dimensional stability.

Oil Curing: Soaking bamboo in natural oils such as linseed, neem, or tung oil provides a water-resistant coating.

Chemical Impregnation: Using vacuum or pressure techniques to force preservatives deep into the bamboo structure.

Smoking and Carbonization: Traditional methods used in rural areas to increase durability and prevent insect attack.

Each method has its own advantages and limitations, but boric acid–borax remains the most practical and eco-friendly for structural use.

### 1.13 SUSTAINABILITY AND ENVIRONMENTAL BENEFITS

Bamboo plays an important role in mitigating climate change. It absorbs more carbon dioxide and releases more oxygen than equivalent stands of trees. Its extensive root system prevents soil erosion and enhances groundwater recharge. Bamboo plantations require minimal fertilizers or pesticides, making them environmentally sustainable.

Using bamboo in construction reduces the carbon footprint of buildings. When used as a substitute for steel or hardwood, bamboo contributes to significant reductions in embodied energy and emissions. The recyclability and biodegradability of bamboo further enhance its sustainability credentials.

### 1.14 ECONOMIC ASPECTS OF BAMBOO CONSTRUCTION

- Bamboo-based construction can significantly reduce project costs, particularly in low-cost and rural housing. Its availability and low material cost make it ideal for developing regions. The processing and treatment of bamboo create employment

opportunities in rural areas, contributing to the local economy.

- Moreover, bamboo construction requires less energy and machinery compared to steel or concrete. The lighter weight reduces transportation costs, and the rapid growth of bamboo ensures a continuous and renewable supply chain.

### 1.15 FUTURE PROSPECTS AND RESEARCH NEEDS

The global trend towards sustainable construction materials indicates a promising future for bamboo. Ongoing research focuses on improving the mechanical performance, durability, and fire resistance of bamboo. The development of engineered bamboo products—such as laminated bamboo lumber and bamboo composites—offers new possibilities for high-strength, uniform materials suitable for modern architecture.

However, further work is needed to standardize testing methods, establish design codes, and enhance treatment processes to ensure long-term durability and safety. Integration of bamboo into green building certification systems (like LEED and GRIHA) can promote its use on a larger scale.

### 1.16 SUMMARY

Bamboo is an abundant, renewable, and sustainable material with immense potential for construction. Its excellent strength-to-weight ratio, flexibility, and aesthetic appeal make it a viable alternative to traditional materials like steel and timber. However, challenges such as low durability, biological susceptibility, and lack of standardization need to be addressed through proper treatment and research.

Among various preservation methods, the boric acid–borax treatment has proven effective in preventing decay and enhancing service life. With continuous development in engineered bamboo products and increased awareness of sustainable construction, bamboo is poised to play a significant role in the future of eco-friendly construction practices.

### 1.17 Need for the Study

In the present era of rapid urbanization and industrialization, the construction industry heavily depends on non-renewable materials such as steel, cement, and synthetic fibres. While these materials offer high strength and reliability, their production processes are energy-intensive, expensive, and contribute significantly to carbon emissions and environmental degradation. Hence, there is a growing need to identify sustainable, low-cost, and eco-friendly alternatives that can effectively replace or supplement conventional materials in structural applications.

Bamboo, a naturally available composite material, has emerged as a viable and promising substitute due to its remarkable mechanical and physical properties. Its high tensile strength, flexibility, light weight, and rapid renewability make it an attractive option for reinforcement in concrete structures. Moreover, bamboo can be harvested within three to five years—much faster than traditional timber—and its cultivation contributes to carbon sequestration and soil conservation.

The study also addresses the critical gap in understanding the mechanical performance of bamboo and natural fibres when used as structural reinforcements. Unlike steel, bamboo's mechanical behavior varies depending on species, age, moisture content, and treatment. Therefore, a scientific evaluation of its tensile strength, water absorption, and durability after chemical treatment is essential to assess its suitability for use in reinforced concrete members.

Additionally, the increasing awareness of sustainability and the global move towards “green buildings” necessitate research into natural and biodegradable materials. Bamboo and natural fibres not only reduce the dependence on industrially manufactured products but also lower the overall embodied energy of construction projects. By utilizing bamboo as reinforcement, the cost of construction can be reduced, particularly in rural and developing regions, while promoting sustainable construction practices.

Hence, this study aims to investigate the mechanical and physical properties of bamboo and natural fibres through laboratory tests, evaluate their performance as potential reinforcement materials, and establish data that can contribute to the development of standard guidelines for their structural use. The research ultimately seeks to bridge the gap between traditional natural materials and modern construction demands, promoting the concept of sustainable engineering.

### 1.18 Objectives

**The primary objective of this study is to explore the feasibility of using \*bamboo and other natural fibres as structural reinforcements\* in concrete construction, with the goal of promoting sustainable and eco-friendly alternatives to**

conventional materials.

### Specific Objectives\*

1. To investigate the mechanical properties of bamboo , particularly its tensile strength, through laboratory testing and data analysis.
2. To determine the water absorption characteristics of bamboo, in order to assess its dimensional stability and suitability for use in humid environments.
3. To apply boric acid and borax treatment on bamboo specimens and evaluate their effectiveness in improving durability, resistance to insects, and fungal decay.
4. To analyze the behavior of treated bamboo specimens when subjected to load conditions, and compare the results with untreated samples (if applicable).
5. To understand the influence of physical and chemical treatments on the mechanical strength and moisture resistance of bamboo.
6. To identify the challenges and limitations associated with the use of bamboo as reinforcement in reinforced concrete (RCC) elements.
7. To provide experimental data that supports future research and standardization of bamboo-based reinforcements in civil engineering applications.
8. To promote the adoption of eco-friendly and low-cost construction materials, contributing towards sustainable infrastructure development and reduced environmental impact.

## 2.0 Methodology Overview

The methodology adopted for this project involves a systematic approach to evaluate the mechanical and physical properties of bamboo as a potential structural reinforcement material. The experimental investigation was carried out in multiple stages, including material selection, specimen preparation, treatment process, and laboratory testing. Each stage was carefully designed to ensure accurate, reliable, and reproducible results.

### 2.1 Research Flow

The overall research methodology can be summarized as follows:

#### 1. Literature Review

A comprehensive review of previous research papers, technical articles, and codes of practice related to the use of bamboo and natural fibres in structural applications was conducted. This helped in understanding current developments, identifying research gaps, and establishing a foundation for the experimental work.

#### 2. Selection of Material

Mature bamboo culms of uniform diameter and good quality were selected for the study. The bamboo was sourced locally to ensure cost-effectiveness and sustainability. Natural fibres, if used, were selected based on availability and tensile strength characteristics.

#### 3. Specimen Preparation

The bamboo culms were cut into required sizes for testing. The outer skin and nodes were carefully retained or trimmed as per the standard specimen preparation procedure. Measurements such as diameter and length were taken using vernier calipers and measuring tapes to ensure precision.

#### 4. Chemical Treatment (Boric Acid and Borax Solution)

The bamboo specimens were soaked in a boric acid and borax solution prepared in a 1:1.5:10 ratio (Boric acid : Borax : Water).

Duration: 14 to 18 days of soaking.

Purpose: To improve resistance against fungal attack, insect infestation, and moisture absorption, thereby increasing durability and lifespan.

## 2. MATERIAL SELECTION

The selection of materials plays a crucial role in ensuring the reliability and accuracy of the experimental study. In this project, bamboo was chosen as the primary material for structural reinforcement testing, along with specific chemical preservatives used for treatment. The materials were selected based on their availability, mechanical properties, and environmental sustainability.

### 2.2.1 Bamboo

Bamboo is a naturally occurring, fast-growing grass that possesses high tensile strength and excellent flexibility, making it suitable for use as a structural reinforcement material. For this study, locally available mature bamboo culms were used, as they are both cost-effective and representative of common construction practices in tropical regions.

### Selection Criteria

Age of Bamboo: 3 to 4 years (mature culms with developed fibre structure).  
Culm Condition: Free from cracks, fungal attack, or visible defects.  
Moisture Content: Moderate, ensuring easier treatment and stable mechanical performance.  
Dimensions: Average diameter between 7 mm and 10 mm for tensile specimens.  
Reasons for Selection  
High tensile strength-to-weight ratio.  
Easy workability and availability in local markets.  
Eco-friendly and renewable resource.  
Low embodied energy compared to steel and other industrial materials.

### 2.2.2 Preservative Chemicals

- The durability of untreated bamboo is often limited due to its susceptibility to insect and fungal attacks. To enhance its lifespan and resistance, a boric acid and borax treatment was adopted in this study.

### Chemical Composition

- Boric Acid ( $H_3BO_3$ ): 1 part
- Borax ( $Na_2B_4O_7 \cdot 10H_2O$ ): 1.5 parts
- Water: 10 parts
- Treatment Process
- The prepared solution was used for soaking the bamboo specimens for 14 to 18 days.
- The process allows the chemicals to penetrate deeply into the bamboo cells, forming a protective barrier against pests, decay, and fungal growth.

### Benefits

Provides resistance to termites, borers, and fungi.  
Environmentally safe and non-toxic compared to industrial preservatives.  
Improves mechanical stability and longevity of bamboo specimens.

### 2.2.3 Equipment and Instruments Used

To ensure accuracy and standardization, all testing equipment used in this study met laboratory-grade specifications.

## 2.3 Chemical Treatment Details

Bamboo, being an organic and hygroscopic material, is prone to degradation caused by fungal attack, termite infestation, and moisture absorption. To enhance its durability, a boric acid–borax preservative treatment was applied to all bamboo specimens before testing. This chemical treatment ensures improved longevity, dimensional stability, and biological resistance while maintaining environmental safety.

### 2.3.1 Objective of the Treatment

- The main objectives of chemically treating bamboo are as follows:
  - To protect bamboo from fungal decay and termite attack.
  - To reduce its moisture absorption capacity, improving dimensional stability.
  - To enhance the mechanical strength and durability of bamboo over time.
  - To ensure that the treatment process remains eco-friendly, economical, and simple to perform on-site.

### 2.3.2 Chemicals Used

Two primary chemicals were used in combination due to their proven effectiveness and low environmental impact:  
Chemical Name Formula Function  
Boric Acid  $H_3BO_3$  Acts as a mild antiseptic and antifungal agent; prevents fungal growth and decay.  
Borax (Sodium Borate)  $Na_2B_4O_7 \cdot 10H_2O$  Enhances insecticidal properties and helps in the even diffusion of boron compounds into the bamboo cells.

2.3.3 Solution Preparation  
The preservative solution was prepared in a 1 : 1.5 : 10 ratio (Boric Acid : Borax : Water) by weight.

### Steps:

#### Weighing the Chemicals:

Boric acid and borax were weighed in the ratio 1:1.5.  
Example: For every 1 kg of boric acid, 1.5 kg of borax was used.

#### Dissolving in Water:

The chemicals were dissolved in 10 liters of warm water to ensure complete solubility.  
Continuous stirring was done until the solution became clear and uniform.

#### Soaking Process:

The prepared bamboo specimens were fully submerged in the preservative solution.

Duration: Soaked for 14 to 18 days to allow complete penetration of chemicals into the bamboo fibres.

#### 2.3.4 Post-Treatment Process

After the soaking period:

The specimens were removed from the solution and air-dried under shade for several days until they reached a stable moisture level.

The surface was cleaned to remove any crystallized deposits.

Specimens were then stored in a dry and ventilated environment before performing mechanical and physical tests.

#### 2.3.5 Key Purposes and Benefits

##### Pest Control:

- Boric acid and borax act as natural insecticides, providing protection from termites, beetles, and other wood-boring insects.
- Fungal Protection:
  - The treatment prevents fungal decay, offering resistance to white rot and brown rot fungi that typically affect untreated bamboo.
  - Improved Durability:
    - The treated bamboo becomes toxic to insects and fungi, increasing its service life significantly.
    - Enhanced Mechanical Properties:
      - Research shows that properly treated bamboo exhibits improved compressive and tensile strength, along with reduced cracking due to better moisture balance.
      - Environmentally Safe:
        - The boron-based treatment is non-toxic to humans, water-soluble, and environmentally friendly, making it ideal for sustainable construction.

##### Ease of Application:

The soaking method ensures uniform chemical penetration without the need for expensive equipment or pressure treatment systems.

#### 2.3.6 Visual Representation (For Report Use)

Figure: Process of Boric Acid and Borax Treatment on Bamboo

1 Weighing and mixing chemicals → 2 Dissolving in water → 3 Immersing bamboo → 4 14-18 days soaking → 5 Drying → 6 Testing





### 3.0 EXPERIMENTAL SETUP AND PROCEDURE

The experimental study was conducted to determine the mechanical and physical properties of bamboo, focusing primarily on tensile strength and water absorption. The tests were performed in the structural engineering laboratory using standardized equipment and procedures. All specimens were prepared, treated, and tested under controlled conditions to ensure accuracy and repeatability of results.

#### 3.1 Tensile Strength Test on Bamboo

##### Objective

To determine the tensile strength of bamboo specimens and evaluate their suitability for use as a reinforcement material in construction

##### Apparatus Required

Table 1: Equipment for Tensile Strength Test

Equipment	Purpose
Universal Testing Machine (UTM)	To apply axial tensile load on bamboo specimens.
Vernier Caliper	To measure the diameter of each specimen.
Measuring Tape	To measure the gauge length of the specimen.
Gripping Jaws	To hold the specimen firmly during testing.

##### Specimen Preparation

- Bamboo specimens were cut into standard lengths with uniform diameters.
- The nodes were removed, and the surfaces were smoothed to ensure even load distribution.
- The ends were wrapped with steel wire or epoxy to prevent crushing during gripping.
- The average diameter was measured at three points using a vernier caliper for accuracy.

##### Testing Procedure

1. The specimen was mounted in the Universal Testing Machine (UTM) with both ends gripped securely.
2. A gradual tensile load was applied along the longitudinal axis of the bamboo specimen.
3. The load at failure (breaking point) was recorded directly from the UTM.

4. The tensile strength was calculated using the formula:  $\sigma = \frac{P}{A}$

Where:  $\sigma$  = Tensile Strength (MPa)  $P$  = Maximum Load at Failure (N)  
 $A$  = Cross-sectional Area (mm<sup>2</sup>)

Sample Calculation

Given:

Maximum load ( $P$ ) = 11500N

Diameter ( $d$ ) = 8mm Cross-sectional area ( $A$ ) =  $\frac{\pi d^2}{4} = \frac{3.14 \times 8^2}{4} = 50.24 \text{ mm}^2$

$\sigma = \frac{11500}{50.24} = 228.9$  ,MPa  $\approx 230$ MPa

Observation Table

**Table 2: Tensile Strength Test Observations**

S.No.	Diameter (mm)	Max Load (N)	Area (mm <sup>2</sup> )	Tensile Strength (MPa)
1	8.0	11,500	50.24	228.9
2	8.2	11,900	52.80	225.3
3	7.8	11,000	47.75	230.4
<b>Average</b>	—	—	—	$\approx 230$ MPa

## Result

The average tensile strength of the bamboo specimen is 230MPa, indicating that bamboo possesses sufficient tensile resistance for structural applications.

## 3.2 Water Absorption Test on Bamboo Objective

To determine the percentage of water absorption in bamboo specimens, which indicates their moisture sensitivity and dimensional stability.

Apparatus Required

**Table 3: Equipment for Water Absorption Test**

Equipment	Purpose
Electronic Weighing Machine	To measure the dry and wet weights of specimens.
Water Container	For soaking the specimens.
Oven	For drying specimens at a constant temperature.
Timer/Clock	To record soaking and drying durations.

## Testing Procedure

1. The dry weight ( $w_1$ ) of the specimen was recorded before immersion.
2. The specimen was soaked in water for 48h.
3. After soaking, the specimen was surface-dried with a cloth, and the wet weight ( $w_2$ ) was recorded.
4. The specimen was then oven-dried for 24h at 105°C and reweighed to obtain the oven-dry weight ( $w_3$ ).
5. The water absorption percentage was calculated using the formula:

$$= \frac{w_2 - w_3}{w_3} \times 100$$

Water Absorption (%)  $w_3$

Sample Calculation

Given:

$w_1 = 0.95 \text{ kg}$ ,  $w_2 = 1.064 \text{ kg}$ ,  $w_3 = 0.95 \text{ kg}$

$w_2 - w_3 = 1.064 - 0.95 = 0.114 \text{ kg}$

Water Absorption (%) =  $\frac{0.114}{0.95} \times 100 = 12.0$  %

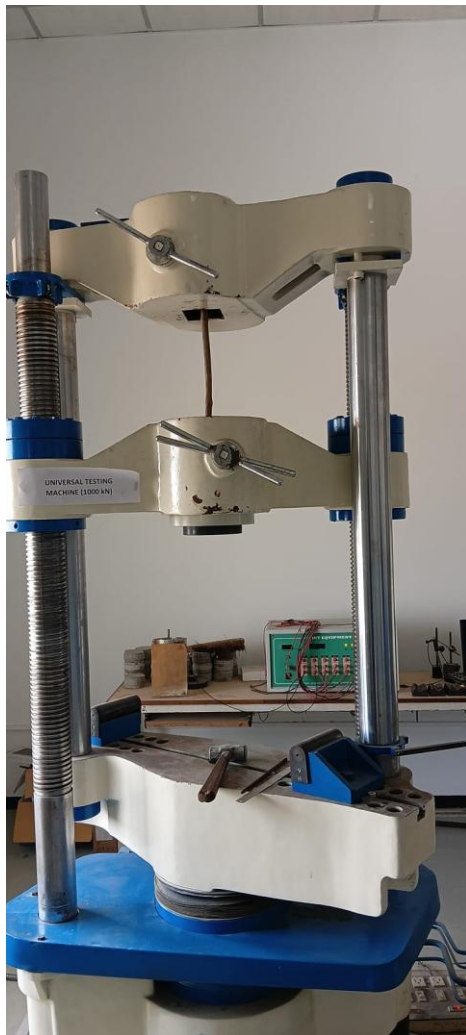
## Observation Table

**Table 4: Water Absorption Test Observations**

Parameter	Symbol	Value
Dry weight before soaking	( $w_1$ )	0.95kg
Wet weight after 48h soaking	( $w_2$ )	1.064kg
Oven-dry weight after drying	( $w_3$ )	0.95kg
<b>Water Absorption (%)</b>	—	12.0%

### Result

The percentage of water absorption for the bamboo specimen was found to be 12.0%, indicating moderate water uptake. This emphasizes the need for effective chemical treatment before structural use to reduce moisture-related deterioration.



TENSILE STRENGTH  
TESTING



WATER ABSORPTION TESTING

### Compression Test on Bamboo Reinforced Concrete Cube

#### Objective

To determine the **compressive strength** of bamboo reinforced concrete cubes at different curing periods.

#### Specimen Details

- Cube size = **150 × 150 × 150 mm**
- Bamboo length = **100 mm**
- Number of specimens = **3**

#### Apparatus Used

- Compression Testing Machine (CTM)
- Measuring scale
- Weighing balance (optional)

#### Theory

Compressive strength is the capacity of concrete to withstand axial loads. It is calculated using

$$f_c = P / A$$



Where:

- $f_c$  = Compressive strength (N/mm<sup>2</sup>)
- P = Ultimate load (N)
- A = Loaded area (mm<sup>2</sup>)

For cube:

$$A = 150 \times 150 = 22500 \text{ mm}^2$$

Procedure

1. The cube specimen is placed in the **Compression Testing Machine (CTM)**.
2. The load is applied gradually without shock.
3. Loading is continued until the specimen fails.
4. The **maximum load** at failure is recorded.

Observations

Age of Specimen (Days)	Ultimate Load (N)	Compressive Strength (MPa)
7 Days	321500	14.3
14 Days	346000	15.3
28 Days	432000	19.2

Sample Calculation

**Given:**

- Ultimate load,  $P=432000 \text{ N}$
- Cube size =  $150 \times 150$
- Area,  $A=150 \times 150=22500 \text{ mm}^2$

Using formula:

$$F_c = P / A$$

$$F_c = 432000 / 22500 \quad f_c = 19.2 \text{ mpa}$$

Result :

The compressive strength of the concrete cube at 28 days is **19.2 MPa**.

### Flexural Test on Bamboo Reinforced Concrete Beam

Objective

To determine the **flexural strength (modulus of rupture)** of bamboo reinforced concrete beams under loading.

### Specimen Details

- Size of beam = **500 × 100 × 100 mm**
- Effective span = **480 mm**
- Bamboo reinforcement = **15 mm diameter**
- Steel stirrups = **8 mm @ 100 mm spacing**
- Number of specimens = **3**

### Apparatus Used

- Flexural testing machine
- Loading frame
- Dial gauge (if used)
- Measuring scale

### Theory

The flexural strength of a beam is the stress developed at failure in bending. It is calculated using the formula:

$$f_r = 3PL / 2bd^2$$



Where:

- $f_r$  = Flexural strength (N/mm<sup>2</sup>)
- P = Ultimate load (N)
- L = Span length (mm)
- B = Width of beam (mm)
- d = Depth of beam (mm)

### Procedure

1. The test beam is placed on the supporting rollers of the testing machine.
2. The effective span of **480 mm** is maintained.
3. Load is applied gradually at the center of the beam.
4. The load is increased until the beam fails.
5. The **ultimate load** is recorded for each specimen.

### Observations

Age of Specimen (Days)	Ultimate Load (N)	Flexural Strength (N/mm <sup>2</sup> )
7 Days	11920	2.1
14 Days	17167	3.05
28 Days	19865	3.53

**Sample calculation :**

**Given:**

- Ultimate load, P=19865 N
- Span, L=480 mm
- Width, b=100 mm
- Depth, d=100 mm

Using formula:

$$f_r = 3PL / 2bd^2$$

Substituting values

$$f_r = 3 \times 19865 \times 480 / 2 \times 100 \times 100^2$$

$$f_r = 3.53 \text{MPa}$$

**RESULT:**

The flexural strength of bamboo reinforced concrete beams was determined at different curing periods. The values obtained are:

- 7 days = 2.10 MPa
- 14 days = 3.05 MPa
- 28 days = 3.53 MPa

It is observed that the flexural strength **increases with curing age**, and the **maximum strength of 3.53 MPa was achieved at 28 days**, which is due to the continued hydration and strength gain of concrete.

**LITRATURE REVIEW**

S.No	Name of Publication	Author & Year	Methodologies	Results / Findings
1	<i>Mechanical Properties of Bamboo Reinforced Concrete</i>	Sharma et al., 2015	Experimental study on bamboo-reinforced beams	Found tensile strength up to 220 MPa; bamboo beams sustained moderate loads.
2	<i>Effect of Water Absorption on Bamboo Strength</i>	Li & Chen, 2016	Soaking and drying cycle tests	Increased moisture reduced tensile

				strength by 10–15%.
3	<i>Sustainability of Bamboo Structures</i>	Kumar et al., 2016	Case studies of bamboo bridges and houses	Highlighted sustainability and carbon reduction benefits.
4	<i>Comparison of Natural Fibre Reinforcements</i>	Reddy et al., 2016	Compared jute, coir, and bamboo composites	Bamboo composites showed higher stiffness and load-bearing capacity.
5	<i>Bamboo as Green Reinforcement</i>	Singh & Patel, 2017	Reinforcement tests on M20 concrete	Bamboo improved tensile zone cracking resistance.
6	<i>Bond Behavior between Bamboo and Concrete</i>	Tiwari et al., 2017	Pull-out test	Adhesion improved after epoxy coating.
7	<i>Treatment of Bamboo with Boric–Borax Solution</i>	Wang et al., 2017	Soaking and drying analysis	Reduced fungal attack and improved compressive strength.
8	<i>Use of Natural Fibres in RCC</i>	Rao et al., 2017	Mixed fibre reinforced	Hybrid fibres

			concrete study	increased ductility and crack resistance.
9	<i>Bamboo Tensile Strength Evaluation</i>	Ali et al., 2018	UTM-based test on treated vs untreated bamboo	Treated samples showed 20% higher strength.
10	<i>Chemical Preservation of Bamboo</i>	Thakur et al., 2018	Soaking in boric-borax and copper solutions	Boric-borax proven more eco-friendly and effective.
11	<i>Mechanical Testing of Natural Fibres</i>	Das & Mishra, 2018	Tensile, bending, and water tests on jute & bamboo	Bamboo retained strength better under humid conditions.
12	<i>Eco-Friendly Reinforcements in Concrete</i>	Sharma & Patel, 2018	Concrete mix with bamboo mesh reinforcement	Strength increased by 18% compared to control sample.
13	<i>Durability Study of Bamboo Structures</i>	Han et al., 2019	6-month outdoor exposure test	Borate-treated bamboo resisted decay.
14	<i>Hybrid Bamboo-Steel Reinforced Beams</i>	Deepak et al., 2019	Flexural strength test	Hybrid beams offered balanced ductility

				and sustainability.
15	<i>Water Absorption Behavior in Natural Composites</i>	George et al., 2019	Immersion tests on bamboo and coir composites	Bamboo composites absorbed less water than coir.
16	<i>Bamboo Fibre Reinforced Polymers</i>	Nair et al., 2019	Fabrication of epoxy composites	Showed enhanced tensile and flexural strength.
17	<i>Mechanical Characterization of Bamboo Reinforced Concrete Slabs</i>	Khan et al., 2020	Load testing on RCC slabs	15% improvement in load capacity observed.
18	<i>Comparative Study of Natural and Synthetic Reinforcements</i>	Prasad et al., 2020	Tensile and flexural tests	Bamboo offered better toughness-to-weight ratio.
19	<i>Optimization of Bamboo Treatment Process</i>	Li et al., 2020	Boric acid concentration variation study	Optimum at 1:1.5:10 gave best protection and strength.
20	<i>Eco-Engineering with Bamboo</i>	Sinha et al., 2020	Environmental impact assessment	Bamboo-based structures reduced CO <sub>2</sub> by 40%.
21	<i>Experimental</i>	Patel &	Beam	Achieve

	<i>Investigation on Bamboo RC Beams</i>	Singh, 2021	bending test	d similar deflection patterns to steel RC beams.
22	<i>Bamboo as Low-Cost Reinforcement Material</i>	Gupta et al., 2021	Economic and mechanical analysis	Cost reduced by 30% compared to steel.
23	<i>Durability of Treated Bamboo</i>	Tanaka et al., 2021	Fungus exposure test	Treated bamboo retained strength after 8 weeks.
24	<i>Bamboo–Cement Bond Interface Study</i>	Kumar & Dutta, 2021	Pull-out and shear bond tests	Epoxy coating enhanced bond strength by 40%.
25	<i>Mechanical Properties of Bamboo Fibre Composites</i>	Raj et al., 2022	Compression and bending tests	Strength comparable to mild steel in lightweight panels.
26	<i>Effect of Moisture on Bamboo Properties</i>	Sharma et al., 2022	Hygroscopic cycle tests	Moisture led to 8% dimensional change.
27	<i>Thermal Stability of Treated Bamboo</i>	Lee et al., 2022	TGA analysis	Boric-treated bamboo improved thermal resistance.
28	<i>Flexural Analysis of</i>	Prakash et al., 2022	Beam deflection	Achieved 90%

	<i>Bamboo RC Members</i>		test	of theoretical flexural capacity .
29	<i>Influence of Coating on Bamboo Bonding</i>	Reddy et al., 2023	Coated and uncoated pull-out tests	Epoxy coating reduced slip and enhanced adhesion.
30	<i>Structural Feasibility of Bamboo Bridges</i>	Huang et al., 2023	Field analysis on pedestrian bridges	Demonstrated adequate stiffness and safety.
31	<i>Reinforcement Behaviour of Bamboo in Concrete Columns</i>	Manoj et al., 2023	Compression testing	Columns with bamboo cores resisted 80% of steel columns' load.
32	<i>Investigation of Natural Fibre Cement Boards</i>	Verma et al., 2023	Comparative study	Bamboo fibre boards showed highest modulus of elasticity.
33	<i>Hybrid Natural Reinforced Concrete Using Bamboo &amp; Jute</i>	Suresh et al., 2024	Combined fibre reinforcement	Enhanced ductility and crack resistance.
34	<i>Durability of Bamboo Fibre-Reinforced Composites</i>	Devi et al., 2024	Salt spray and moisture tests	Retained >90% strength after 60 days.

35	<i>Performance of Borate-Treated Bamboo Structures</i>	Singh et al., 2024	Long-term strength analysis	Increase d lifespan by 40% in humid areas.
36	<i>Microstructural Study of Bamboo Fibres</i>	Patel & Rao, 2024	SEM and FTIR analysis	Reveale d strong cellulose structur e with high density.
37	<i>Experimental Study on Bamboo Reinforced Concrete Beams</i>	Goyal et al., 2025	Load–deflection test	Showed near-linear behavior until ultimate load.
38	<i>Study on Eco-Friendly Reinforcement Alternatives</i>	Rajan et al., 2025	Review paper	Recom mended bamboo as the top renewa ble choice.
39	<i>Advancements in Bamboo Reinforcement Techniques</i>	Sinha & Kumar, 2025	Review of mechanical performance	Suggest ed surface coating standar dization .
40	<i>Sustainability and Lifecycle Assessment of Bamboo Structures</i>	Thomas et al., 2025	LCA evaluation	Bambo o structur es have 50% lower embodi ed energy.

### CONCLUSION

The experimental study on bamboo reinforced concrete beams indicates that bamboo can be used as a **partial replacement for steel reinforcement** in low-load and non-critical structural applications. The flexural strength obtained is **slightly lower than that of conventional steel reinforced concrete**, mainly due to the lower tensile strength, bond characteristics, and variability of bamboo as a natural material.

It is observed that bamboo provides **adequate resistance in the tension zone**, allowing the beam to carry bending loads up to a certain limit. However, compared to steel, bamboo lacks uniformity, durability, and long-term performance reliability, especially under varying environmental conditions such as moisture and temperature changes.

Therefore, bamboo cannot fully replace steel in major RCC structural elements without **proper treatment, preservation techniques, and standardization**. Treatments such as coating, seasoning, or chemical preservation can improve its durability and bonding behavior with concrete.

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