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Bamboo as Reinforcement Material: A Review and Research Framework

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Abstract: In growing construction industry demand for sustainable, affordable, and eco-friendly alternatives to traditional materials like steel has increased. The steel offers excellent strength and ductility, it has notable disadvantages such as high embodied energy, substantial carbon emissions, susceptibility to corrosion, and volatile market prices. These problems have led researchers to explore renewable and low-carbon material options. bamboo as a reinforcing material can be a promising option. The use of bamboo in place of steel is used as a whole and as a combination of both bamboo and steel. It is used as such to ensure the reduction in weight and economic advantages with its strength compromised to a slight and safe level. This study investigates use of bamboo's as a reinforcement material in concrete, especially for low-rise buildings. Bamboo, a renewable and fast-growing material with high tensile strength and an excellent strength-to-weight ratio, was tested in both untreated and chemically treated forms to evaluate its structural, mechanical, and durability properties in comparison to steel reinforcement. Test were conducted on M25 grade concrete using cubes, cylinders, and beams reinforced with steel rods and bamboo splints. The Tests find out tensile strength, bond strength, water absorption, flexural performance, and cyclic load behavior. Results showed that although steel-reinforced beams had the highest load capacity and energy absorption, bamboo-reinforced beams performed well, reaching up to 72% of the strength of steel-reinforced concrete and outperforming plain concrete significantly. Coatings like bitumen, epoxy, and boron-based treatments improved the bond between bamboo and concrete and reduced water absorption, thus enhancing durability. The bamboo's properties like light weight, renewability, low embodied carbon, and cost-effectiveness make it a feasible, sustainable substitute for low-cost housing, disaster-resistant structures, and rural infrastructure.

Bamboo is an abundant, fast-growing, renewable material with high specific strength and a low embodied-energy profile. This paper reviews recent literature on the feasibility of using bamboo as a reinforcement material in concrete and geopolymer matrices. Key challenges—bonding with concrete, durability, variability between species, and low modulus of elasticity compared with steel—are identified alongside mitigation strategies. The review highlights where bamboo can be a viable low-cost, low-carbon reinforcement and where current evidence still favors conventional steel reinforcement.

Keywords: bamboo reinforcement, bamboo-reinforced concrete (BRC), bond strength, sustainability, durability.

I. INTRODUCTION

Steel reinforcement dominates modern reinforced concrete due to its predictable mechanical properties, ductility, and bond with cementitious matrices. However, steel production carries high carbon and economic costs. Bamboo, used for centuries in vernacular construction, offers high tensile strength per unit weight and very fast renewability, making it an attractive alternative in sustainable construction.

1.1 TYPES OF REINFORCEMENT

1.1.1 Steel Reinforcement

Steel reinforcement refers to steel bars embedded within plain cement concrete to convert it into **Reinforced Cement Concrete (RCC)**. These bars, commonly known as *rebars*, work with concrete to form a composite material. Concrete has excellent compressive strength but performs poorly in tension. When tensile stresses develop, concrete tends to crack. Steel reinforcement compensates for this weakness by providing the tensile and shear resistance required in structural members.

In RCC design, engineers combine the strengths of both materials:

- **Concrete** carries compressive loads,
- **Steel** absorbs tensile and shear forces.

This coordinated action makes RCC a dependable material for modern structural systems.

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1.1.2 Types of Steel Reinforcement

- **Hot-Rolled Deformed Bars:**
  Produced by hot rolling and provided with ribs to improve mechanical bond with concrete.
- **Cold-Worked Steel Bars:**
  Manufactured through cold drawing or twisting, resulting in increased tensile strength but reduced ductility.
- **Mild Steel Plain Bars:**
  Smooth bars with lower strength, typically used for stirrups, ties, and light reinforcement.
- **Prestressing Steel:**
  High-strength wires or strands used in prestressed and post-tensioned concrete to introduce beneficial compressive stresses.

1.1.3 Bamboo Reinforcement

Bamboo is increasingly being explored as an ecological and cost-effective alternative to steel for reinforcing concrete. It exhibits significant tensile strength—an essential requirement for any reinforcement material—and, with proper treatment, can be used effectively in structural components.

The basic approach for bamboo-reinforced concrete remains similar to steel-reinforced systems. Concrete mix proportions, casting procedures, and design principles do not change; only the reinforcement material is substituted with bamboo strips or rods.

Bamboo has long been used as a construction material, especially for traditional shelters and lightweight structures. Modern interest in bamboo reinforcement was strengthened by research conducted at **Clemson Agricultural College**, which highlighted its potential as a structural reinforcement.

As steel consumption increases rapidly, particularly in developing economies, the search for affordable substitutes has become important. Bamboo is widely available, fast-growing, resilient, and renewable, making it a practical reinforcement option for specific structural applications where sustainability and cost efficiency are priorities.

1.1.4 Fiber Reinforcement

Fiber-Reinforced Concrete (FRC) is a composite material that incorporates **short fibers** dispersed uniformly throughout the concrete matrix. These fibers enhance structural performance by improving toughness, crack resistance, and durability.

Common fiber types include:

- **Steel fibers**
- **Glass fibers**
- **Synthetic fibers** such as polypropylene and polyester
- **Natural fibers** including jute, coir, and sisal

The behavior of FRC depends on the type, size, orientation, distribution, and amount of fiber used. A key descriptor of fibers is the **aspect ratio**, defined as the length divided by the diameter of the fiber.

Fibers are added primarily to:

- Reduce plastic and drying shrinkage cracks,
- Improve impact and fatigue resistance,
- Lower permeability and water bleeding.

As a result, fiber reinforcement is commonly used in industrial flooring, pavements, overlays, and structural elements requiring improved post-crack performance.

II. LITERATURE REVIEW

Rakesh J Ghante1, Dr. K.P Shivananda(2019): - The present study reports the flexural strength of BRC (Bamboo Reinforced Concrete) beams and the durability of bamboo as structural reinforcement. In this study, normal bamboo and modified bamboo were used in 1.25% and 2.50% as reinforcement in the beams. Also, bamboo splints without coating and with bitumen coating were dipped in normal water, magnesium sulfate, and potassium chloride solution for alternate wetting and drying of 7,14,28,56 and 72 cycles for the durability analysis. The flexural strength of the BRC beams was studied after 7,14,28 days of curing. The durability of the bamboo was determined through the Tensile strength test. From the results, it is found that the flexural strength of the modified bamboo reinforced beams with 2.50% reinforcement carried more load than the normal concrete beams and untreated bamboo reinforced beams. The Tensile strength of the bamboo splint got reduced after 56 cycles and 72 cycles of alternate wetting and drying in magnesium sulfate and potassium chloride solutions. It could be concluded that bamboo can be used as an alternative material to the rebars in low-cost housing projects. Treated bamboo is more efficient and economical in low-cost housing projects. Suitable treatment must be done for bamboo rebars if in case it is to be used in coastal areas.

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Ikechukwu Etienne Umeonyiagu & Chidozie Chukwuemeka Nwobi-Okoye (2019):- In this research, the costs, as well as the flexural and tensile strength of bamboo reinforced concrete material, were predicted and optimized using artificial neural network (ANN) and non-dominated sorting genetic algorithm-II (NSGA-II). The inputs to the ANN were curing days and percentage bamboo content in the bamboo reinforced concrete material, while the outputs were cost, flexural, and tensile strength. The ANN predicted the experimentally determined values of the tensile strength, flexural strength, and costs of the bamboo reinforced concrete material excellently with correlation coefficients of 0.99635, 0.99739, and 1, respectively. Subsequently, the ANN was used as the fitness function for NSGA-II for multi-objective optimization of the cost, flexural, and tensile strength of bamboo reinforced concrete material. The Pareto optimal solution obtained could serve as a design guide for engineers for the optimal design of structures using cost, flexural, and tensile strength of bamboo reinforced concrete material.

S.karthik RM Rao Paul Awoyera. (2018):- In this study, beneficiated pozzolans, ground granulated blast furnace slag (GGBS), and metakaolin (MK) were used as partial replacement of ordinary Portland cement in bamboo-reinforced concrete. In the mixtures, river sand and granite were used as fine and coarse aggregates, respectively. The compressive strength of concrete cubes, split-tensile strength of concrete cylinders, and flexural strength of reinforced concrete beams were determined after stipulated curing regimes. The morphology and mineralogy of bamboo and selected concrete mixtures were obtained using a scanning electron microscope and X-ray diffraction, respectively. The concrete samples having blended cement were found to have better compressive and split- tensile strength than those made with conventional binders. Also, the mechanical characteristics of the samples improved up to 40% GGBS substitution. However, steel- reinforced concrete developed better flexural strength than the bamboo-reinforced concrete (BRC). The study recommends pretreatment of bamboo to ensure its adequate bonding with the cement paste, to achieve optimum performance of BRC.

Abhijeet Dey&Nayanmoni Chetia (2018):- This is a comparative study of bamboo reinforced concrete beams with various frictional properties. The frictional properties of bamboo reinforced concrete beams have been achieved by rolling the bamboo reinforcements with sand, G.I wire and coir. The web material essentially consists of steel stirrups which helps in resisting shear of bamboo reinforced concrete beams. Eighteen such beams have been tested to failure under a four-point bend test. Flexural strength of 28, 45, and 60 days have been taken into consideration for comparison purposes. At failure, it has been observed that beams subjected to higher curing periods and greater reinforcement sizes perform better as compared to beams with lower curing periods and smaller reinforcement sizes. Moreover, higher bond stress has been achieved for beams with G.I rolled bamboo reinforcements. Hence it can be recommended that bamboo can act as a good potential reinforcement for low-cost housing and can replace steel conveniently thereby saving natural resources to a considerable extent.

III. MATERIALS

3.1 Ordinary Cement

The cement used in this research was **Ordinary Portland Cement (OPC), 53 grade**, meeting the specifications of **IS 12269:1987**. The cement was recently manufactured, showed uniform coloration, and contained no lumps or foreign particles. Its physical characteristics were evaluated following **IS 4031 (Part 1–1988)**, while the chemical properties were assessed according to **IS 4031 (Part 2–1985)** to ensure that the material met the requirements for high-quality concrete production.

Fig. 1.1 Cement

3.2 Fine Aggregate

The fine aggregate consisted of clean river sand. It passed through a **4.75 mm IS sieve** and was retained on the **600 µm sieve**,complying with **ZoneII grading of IS383:1970**. The sand used was free from impurities such as clay, silt, organic matter, or debris. Its clean and well-graded nature made it suitable for producing consistent and workable concrete mixes.

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Fig.1.2 Fine Sand

3.3 Coarse Aggregate

Crushed granite obtained from nearby quarries served as the coarse aggregate for this study. Aggregates with nominal sizes of **10 mm and 20 mm** were used.

The aggregates were tested for essential physical properties—such as specific gravity, impact strength, and water absorption—following the guidelines of **IS 2386 (Part 1, 3, and 4):1963**.

These tests confirmed that the aggregates met the required standards for use in structural concrete.

Fig.1.3 Coarse Aggregate

3.4 Bamboo

Bamboo intended for reinforcement must undergo a series of preparatory steps to make it suitable for structural applications. These steps include:

- Weathering
- Chemical preservation
- Surface modification

These processes enhance durability, reduce moisture-related issues, and improve bonding with concrete.

3.5 Weathering

Because bamboo is **hygroscopic**, it naturally contains a high percentage of moisture—often around **50–60%** in its fresh state. To stabilize the material and reduce its susceptibility to fungal or insect attack, bamboo is **air-dried** until its moisture content drops to approximately **15%**. This drying process also minimizes later shrinkage, swelling, or dimensional changes once the bamboo is embedded in concrete.

3.6 Chemical Treatment

Before use, bamboo must be chemically treated to protect it from biological deterioration.

Common preservative agents include:

- **Boric Acid**
- **Copper Sulphate**
- **Potassium Dichromate**

These chemicals are typically combined in the proportion **1.5 : 3 : 4 (by weight)** and diluted in water. The treatment not only prevents attack from termites and fungi but also increases the expected service life of bamboo in concrete. Depending on the application method—soaking, pressure treatment, or diffusion—the level of protection can range from moderate to long-term.

3.7 Surface Treatment

Surface treatment plays a crucial role in improving the bond between bamboo and concrete.

Since bamboo has a naturally smooth exterior, it must be textured to ensure proper adhesion.

The treatment procedure involves:

1. Coating the bamboo with **epoxy resin**,
2. Applying a fine layer of **sand** over the wet epoxy,
3. Allowing the coated surface to **dry thoroughly** before use.

This creates a roughened exterior similar to the ribs of deformed steel bars, which significantly enhances grip and load transfer

3.8 Stirrups

Stirrups are closed-loop reinforcements placed in beams and columns to carry **shear forces** and resist **diagonal tension**.

In beams, these are called stirrups, while in columns they function as lateral ties.

Their primary purposes include:

- Holding longitudinal bars in position,
- Increasing the shear resistance of the structural member,
- Improving ductility,
- Providing confinement to the concrete core.

IV. TEST RESULTS AND DISCUSSION

This chapter presents the observations made from testing concrete in both fresh and hardened conditions. The experimental program focused on evaluating the **workability** and **flexural behavior** of beams measuring **150 mm × 150 mm × 700 mm**.

To examine the effect of using bamboo as reinforcement, the beams were categorized into three different reinforcement stages.

Reinforcement Categories

- **Stage 1:**
  Two bamboo sticks (16 mm) placed in the compression zone
  Two bamboo sticks (16 mm) placed in the tension zone.
- **Stage 2:**
  Two bamboo sticks (16 mm) in the compression zone
  Three bamboo sticks (16 mm) in the tension zone.
- **Stage 3 (Reference Beam):**
  Two mild steel bars of 10 mm diameter in the compression zone
  Two steel bars of 12 mm diameter in the tension zone.

All beams from the three stages were tested for flexural performance after **3 days**, **7 days**, and **28 days** of curing to understand the development of strength over time.

4.1 Flexural Strength Test

The flexural strength (modulus of rupture) was determined using two-point loading on beams sized **150 × 150 × 700 mm**.

For each stage, **three specimens were tested**, and the average value was considered as the representative flexural strength.

Specimen Dimensions

- Width (b): 150 mm
- Depth (d): 150 mm
- Length: 700 mm

Cross-Sectional Area

A=150×150=22500 mm2A = 150 \times 150 = 22500\ \text{mm}^2A=150×150=22500 mm2

Formula for Flexural Strength

Flexural strength was computed using the standard expression:

$fr = P \cdot L / b \cdot d^2$

Where:

- fr = Flexural strength (N/mm²)
- P = Maximum applied load at failure
- L = Distance between fracture location and nearest support
- b = Average width of specimen
- d = Average depth of specimen

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The tabulated values and graphical comparison clearly show how bamboo reinforcement responds at early and later curing ages when compared to conventional steel reinforcement.

V. CONCLUSION

The overall study indicates that bamboo can function as a practical substitute for steel reinforcement in specific applications, especially where cost, availability, and sustainability are key considerations. Based on the results obtained, the major conclusions are listed below:

• Reduction in Weight

Bamboo is significantly lighter than steel, and replacing steel bars with bamboo results in a notable reduction in the self-weight of reinforced concrete components.
This advantage makes bamboo suitable for lightweight construction systems.

• Flexural Performance

Comparison of flexural strength across stages led to the following observations:

1. **Stage 1 (Bamboo)** at 28 days achieved strength comparable to the **Stage 3 (Steel)** beam at 3 days.
2. **Stage 2 (Bamboo)** at 28 days approached the strength of the **Stage 3 (Steel)** beam at 7 days.

This shows that although bamboo cannot match the ultimate strength of steel, it develops adequate strength over time, making it suitable for low-demand structural elements.

• Cost Benefits

Bamboo is much more affordable than steel and widely available in many regions.
Its low cost, combined with its renewability and minimal environmental impact, makes it a highly appealing reinforcement option for economical construction.

• Percentage Reduction in Reinforcement Weight

- Using **four bamboo bars** reduced the reinforcement weight by approximately **44.3%** compared to an equivalent steel layout.
- Adding a fifth bamboo bar further reduced the overall reinforcement mass, highlighting its advantage in lightweight applications.

• Practical Applications

Given its performance and characteristics, bamboo-reinforced concrete can be used effectively in:

- Small cabins and guard rooms
- Car parking sheds
- Public toilets
- Temporary structures
- Light-load rural buildings

These structures benefit from bamboo's low weight, low cost, and ease of installation.

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