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Comparative Study on Normal Reinforced Concrete with Bamboo Reinforced Concrete

N. Sathyakumar [a,*], M. Arun [b], S. Elayaraja [b]

[a] Department of Civil Engineering, Sri Shakthi Institute of Engineering and Technology, Coimbatore, India

[b] PSG Institute of Technology and Applied Research, Coimbatore, India

* Corresponding Author: sathyakumarcivil@siet.ac.in

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Abstract: Concrete is a commonly utilized building material due to its durability and affordability. It has properties that allow it to resist fire and provide earthquake protection. However, a major drawback of concrete is its limited tensile strength. Steel is one of the most effective materials for compensating for concrete's low tensile strength, it has high tensile properties. Therefore, steel bars are incorporated for reinforcement. Unfortunately, the natural resources required for steel are dwindling, necessitating alternative materials. Some structures worldwide have been constructed using only plain concrete or bricks without steel reinforcement. These structures are vulnerable to the impacts of natural disasters like earthquakes, hurricanes, and storms. Bamboo emerges as an excellent material to replace reinforcing bars in concrete. As a composite material, bamboo consists of long, parallel cellulose fibers, granting it notable flexibility and toughness. It fully matures in just a few months, achieving its peak mechanical strength within a few years. While the strength of bamboo can increase with age, its maximum strength is usually reached at 3 to 4 years, after which it may begin to decline. Bamboo features nodes throughout its length, which help prevent buckling. Remarkably, bamboo can bend significantly, even touching the ground, without fracturing. This characteristic sets bamboo apart from other wooden materials. Additionally, bamboo is widely available, found in nearly all tropical and subtropical regions. This availability reduces construction costs while enhancing the structural integrity of buildings that otherwise lack reinforcement. Its lightweight design and impressive strength render bamboo a favorable building material. Bamboo possesses high tensile strength. This project focuses on evaluating the effectiveness of bamboo as a reinforcement material in concrete beams, specifically analyzing the flexural strength and comparing the results to those of steel-reinforced concrete beams.

Keywords: Bamboo, Reinforced, Compressive Strength, Tensile Strength

1. Introduction

Although steel reinforcement is an excellent material for enhancing concrete's limited tensile strength, various challenges related to economics, techniques, and efficiency must be addressed. To tackle these issues, there is an urgent need for alternative materials that can enhance the tensile capacity of concrete. Bamboo possesses a high tensile strength that can reach up to 370 N/mm^2, making it a superior alternative to steel for withstanding tensile stress. There is currently a lack of extensive data on the flexural analysis of bamboo reinforced concrete suitable for Indian climatic conditions. Thus, it is important to provide an initial contribution to the study of the flexural characteristics and behavior of bamboo reinforced beams. Additionally, as steel resources are depleting, there is a pressing need for alternative materials.

Bamboo is a composite substance composed of long, parallel cellulose fibers embedded in a lignin-rich matrix. The fiber density in the cross-section of a bamboo stalk varies with its thickness, resulting in a functionally graded material that has evolved based on the stress distribution in its natural surroundings. The fibers are denser towards the outer layers. This aligns with how stress is distributed when the culm experiences wind forces, which influences the mechanical properties of bamboo within the elastic range; the composite materials' mixing rule is applied. The properties of both the fibers and the matrix, along with their volumetric ratios, are considered.

1.1 Mechanical properties of Bamboo and its behaviour in Structural Concrete

The tensile strength of bamboo can go up to 370 N/mm^2, making it a viable substitute for steel in applications requiring tensile strength. This is attributed to the fact that bamboo's tensile strength-to-weight ratio is six times higher than that of steel. Additionally, the strength of bamboo increases with age, reaching its peak between 3 to 4 years; however, after this point, its strength starts to decline. The average fracture toughness at the nodes is less than the minimum value found across the entire culm, indicating that the fibers in the nodes do not add to the material's fracture resistance. Various physical and mechanical properties depend on factors like diameter, length, age, type, position along the culm, and moisture content. Performance may differ among species even when tested under the same conditions, and bamboo behaves differently based on its type and maturity. In contrast to steel rods, bamboo presents numerous challenges regarding durability, as it can be susceptible to fungi and insect damage due to its high nutrient content. It requires protection against temperature and moisture, among other factors.

While there are design handbooks for steel-reinforced concrete, the equations and procedures can be adapted for bamboo-reinforced concrete by substituting its mechanical properties in place of steel reinforcement. Given bamboo's low modulus of elasticity, flexural elements will frequently exhibit cracking under standard service loads. When cracking is not acceptable, designs should rely on steel reinforcement or consider unreinforced sections.

Practical experience indicates that split bamboo tends to outperform whole culms when used as reinforcement. A stronger bond is established between bamboo and concrete when the reinforcement is split, which also allows for more compact reinforcement layers. It is advisable to split large-diameter culms into 3/4-inch-wide strips. (In the subsequent examples, references to strips will be interpreted as 3/4-inch-wide splints of a specified thickness, unless stated otherwise.

1.2 Overview of Literature

Pankaj R. Mali and Debarati Datt (2019) found through pull-out tests that while bamboo concrete bond strength is adequate without any coating, an epoxy-based coating mixed with sand particles can offer additional protection without compromising bond strength [1]. Khosrow Ghavami (2005) indicated that bamboo possesses beneficial qualities when used as reinforcement in test beams, slabs, and columns, contributing to its eco-friendly characteristics; the findings revealed that using bamboo at 3% of the cross-sectional area of the concrete beam allowed for the highest load capacity, highlighting the importance of drying and water-repellent treatments, and concluded that bamboo could effectively replace steel [3].

Leena Khare (2005) stated that the load-carrying capacity of bamboo-reinforced beams exceeded that of plain concrete beams by 250% and was 35% greater than that of steel-reinforced concrete beams [2].

M. M. Rahman (2011) investigated the potential of bamboo as a reinforcement material for concrete by performing flexural strength tests on singly and doubly reinforced bamboo beams to evaluate their performance, ultimately concluding that bamboo has promising qualities as a concrete reinforcement [4].

Nindyawati et al. (2016) reported their findings on the bond strength of bamboo reinforcement in lightweight concrete, where bamboo splints were painted and sand was sprinkled on them; the results showed that the bond strength of bamboo achieved 60% of that of steel [5].

Alireza Javadian et al. (2016) examined the bond behavior between bamboo and concrete using pull-out tests, focusing on the chemical interactions at the interface with various treatments including coatings, sandblasting, and steel wire wrapping; the findings indicated that treated, grooved bamboo reinforcement attained the greatest bond strength [6]. The review of existing literature suggests that bamboo is a highly effective and economical choice for low-cost construction projects. The studies mentioned earlier indicate that when properly harnessed, the mechanical properties of bamboo can make it a viable material for reinforcement. As a result, this research aims to analyze the flexural strength of bamboo-reinforced beams, adhering to the specimen selection and preparation guidelines established in previous studies.

2. Preparation of reinforcement

2.1 Steel Reinforcement

In accordance with the design, there are 2 rods with a diameter of 8mm placed in both the tension and compression zones as the primary reinforcement. The longitudinal reinforcement is secured using stirrups made of 6mm mild steel, spaced at 150mm center to center.

2.2 Bamboo Reinforcement

According to literature, the optimal width for bamboo strips is 20mm (3/4 in), which offers the largest area with minimal curvature. Given that the beam measures 750mm in length, it was concluded that the bamboo culms should be cut to 724mm, allowing for a 13mm overhang on each side of the reinforcement and maintaining a width of 20mm without altering their thickness, as this might compromise the strength of the bamboo strips. The bamboo strips were obtained from whole bamboo.

2.3 Splicing of Bamboo

Once the bamboo was harvested, it underwent a waterproofing process. Prior to applying the waterproof coating, it is essential to roughen the bamboo's surface with sandpaper. After roughening the surface, a thin layer of wood primer was brushed on. A thin application is important to minimize any adverse bonding effects that the waterproofing may exert on the bamboo. The strips were then left to dry. As per the design specifications, six bamboo strips, each rectangular in cross-section measuring 20 mm, are to be utilized. Given the limitations of the beam's cross section, they will be arranged in two sets at the bottom. For the compression reinforcement, four bamboo strips were required. Therefore, two strips were bundled together, creating two sets that were positioned as the top reinforcement.

2.4 Placement of bamboo

Bamboo reinforcement must be positioned no closer than 1.5 inches from the concrete surface. When using entire culms, alternate the top and bottom ends of the stems in each row, and stagger the nodes or collars. This approach will ensure a relatively uniform cross-section of the bamboo along the entire length of the member, and the wedging effect from the nodes will significantly enhance the bond between the concrete and the bamboo.

The spacing between bamboo rods or splints should be at least the size of the largest aggregate plus an additional 1/4 inch. The reinforcement ought to be evenly distributed and tied together with short sticks oriented perpendicular to the main reinforcement. If multiple layers are necessary, these layers should also be secured together. It is preferable for ties in critical members to be constructed using wire.

Before pouring the concrete, bamboo must be firmly secured in place. It should be anchored at intervals of 3 to 4 feet to prevent it from rising during concrete placement and vibration. For flexural members, one-half to two-thirds of the bottom longitudinal reinforcement should be bent upwards near the supports. This practice is highly recommended for members spanning several supports. Near the supports, additional diagonal tension reinforcement in the form of stirrups is required. The vertical stirrups can be made from wire or packing case straps when available, and can also be created from split bamboo sections bent into a U-shape and securely tied to both the bottom longitudinal reinforcement and the bent-up reinforcement. The maximum spacing for the stirrups should not exceed 6 inches.

2.5 Anchorage and Splicing of Reinforcements

Reinforcement dowels for columns and walls need to be embedded in the concrete to a depth sufficient to ensure that the bond between bamboo and concrete can withstand the permissible tensile force in the dowel. This required depth is typically around 10 times the diameter of whole culms or 25 times the thickness of 3/4 inch wide splints. Often, footings may not be this deep; in such cases, dowels must be bent into an L-shape. These dowels should either loop around the footing reinforcement or be securely tied to it to ensure they are completely anchored. The dowels must rise above the footings and be trimmed so that no more than 30 percent of the splices occur at the same level. Additionally, all splices should have a minimum overlap of 25 inches and must be tightly secured. When splicing reinforcement in any component, the overlap should also be at least 25 inches be provided. Splices should be avoided in areas that experience high stress, and under no circumstances should more than 30 percent of the reinforcement be spliced at a single location.

3. Casting of beams

3.1 Preparation of Moulds

A steel mold measuring 750 mm x 150 mm x 150 mm was prepared, and the interior was thoroughly greased. Cover blocks of 25 mm were positioned at the base of the reinforcement as well as on the two sides, as illustrated in Figure 1. The reinforcement was then positioned inside the mold resting on top of the cover block.

3.2 Pouring of Concrete

The beams were constructed using Ordinary Portland Cement (OPC) grade 53, with fine aggregate sourced from river sand that meets zone I specifications, and coarse aggregate sized at 10 mm. The mix proportions for the concrete were set at 1:1.5:3 (cement: fine aggregate:

coarse aggregate), and the water-to-cement ratio was established at 0.43. Figure 2 illustrates the process of pouring and compacting the concrete.

Figure 1. Bamboo reinforcement arrangement

Figure 2. Pouring and compaction of concrete

3.3 Mix proportions of Concrete

The concrete having the materials with the following mix proportions as shown in Table 1.

Table 1. Mix proportions of concrete

Water (l)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)
193.5	450	649.56	967.56
0.43	1	1.44	2.17

4. Strength of the concrete

4.1 Compressive strength of concrete cube

The compressive strength of concrete cube is determined at 7 day and 28 day as per IS 516:1958 as shown in Table 2 and Table 3.

Table 2. Test Results for 7 days Cube Strength

Specimen No	Area under Loading	Maximum Load	Compressive Strength
	mm^2	kN	N/mm^2
1	22500	458	20.35
2	22500	524	23.23
3	22500	510	22.66

Table 3. Test Results for 28 days Cube Strength

Specimen No	Area under Loading	Maximum Load	Compressive Strength
	mm^2	kN	N/mm^2
1	22500	836	37.15
2	22500	811	36.04
3	22500	944	41.95

The average compressive strength of the concrete cube at 7th day is 22.08 N/mm^2. The average compressive strength of the concrete cube at 28th day is 38.38 N/mm^2

4.2 Flexural strength of concrete beam (M20)

The flexural strength of the beam was evaluated using a Universal Testing Machine, yielding the results presented below. The results are illustrated in Table 4 and Table 5, with Figure 3 depicting the flexural strength of M20 grade of concrete.

Table 4. Maximum failure load of M20 Grade of concrete

Beam type		7 days of curing (kN)	28 days of curing (kN)
Bamboo reinforced	Specimen 1	64.14	76.15
	Specimen 2	60.31	71.43
Partially reinforced	Specimen 1	51.70	59.15
	Specimen 2	52.15	58.70
Steel reinforced	Specimen 1	67.65	77.00
	Specimen 2	67.80	78.92

Table 5. Maximum failure load of M25 Grade of concrete

Beam type		7 days of curing (kN)	28 days of curing (kN)
Bamboo reinforced	Specimen 1	61.62	70.8
	Specimen 2	63.84	72.5
Partially reinforced	Specimen 1	55.55	64.35
	Specimen 2	53.49	66.62
Steel reinforced	Specimen 1	77.80	83.05
	Specimen 2	73.15	84

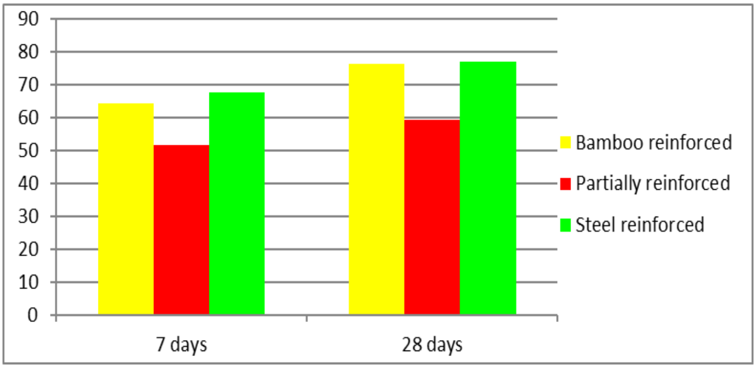

Figure 3. Comparison of Flexural strength of M20 grade concrete

5. Conclusion

After a curing period of 28 days, the strength of a beam reinforced with bamboo nearly matches that of a beam reinforced with steel, due to the bamboo area being three times larger than the area of steel reinforcement used. There was a slight reduction in both compressive and flexural strength when the beam was partially reinforced with bamboo. The flexural strength of bamboo surpasses that of the steel-reinforced beam. It presents a viable option for cost-effective construction, as bamboo is resistant to corrosion and can be utilized in marine environments. Bamboo grows very rapidly, reaching full maturity three times faster than hardwoods, and is recognized for its strength, which is comparable to that of steel. It is easy to cut, manage, repair, move, and maintain without requiring advanced tools or equipment. Due to its remarkable physical properties, Guadua bamboo is ideal for various types of structures and construction projects. Bamboo is eco-friendly and does not produce any parts that could be considered waste. Rather than contributing to landfill issues like traditional construction waste, any unused portions of bamboo can be returned to the soil as fertilizer or processed into bamboo charcoal. Bamboo can serve both permanent and temporary construction needs. Each of its nodes features a transverse wall that enhances strength and allows for bending, thereby preventing breakage when bent. This remarkable feature makes bamboo structures exceptionally resistant to earthquakes. The fiber composition in bamboo walls allows it to be cut lengthwise or across into pieces of any size using simple manual tools such as a machete.

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