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ANALYSIS OF EPOXY-COATED BAMBOO REINFORCED CONCRETE BEAMS

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Abstract. These days, the production of steel is implanting numerous hazards on mother nature. The cost of steel has been ever-increasing. Bamboo, also referred to as "Green Steel" is an affordable, natural resource which is a potential substitute for construction steel as it has higher tensile strength and flexural strength. New researchare being developed to preserve the mechanical properties of Bamboo with different engineering coatings. In this paper, the Bamboo coated with epoxy resin and wrapped with glass fibre was made as a composite material to enhance the bonding and boost tensile strength. On replacing steel with Bamboo, the performance of the Bamboo-Composite Reinforced Cement Concrete (BCRCC) beam has been analyzed. Compared with conventional Reinforced Cement Concrete (RCC) beams, BCRCC beam is found to be greatly compatible in strength and extremely low in cost. This approach can be suitably used in the construction of structural components like beams, slab, columns, walls and footing.
Keywords: Bamboo, green steel, epoxy, glass fiber, bamboo-composite, low cost.

Introduction

The demand for steel in the construction industry is increasing day by day. There are situations when the production of steel is not enough to face the steel demand. Hence it is essential to have an alternative that is worth compared to steel. Bamboo is abundant in nature. Hence, bamboo can face the demand which is for reinforcing material and become an ideal replacement for steel. The tensile strength property which is the main requirement of reinforcing material is seen as appreciable in bamboo, compared with other materials including steel. Experimentally, it has been found that the ultimate tensile strength of bamboo is comparable to that of mild steel & it varies from 140 N/mm2 to 280 N/mm2. M. Al-Fasih, et. al in. 2021 performed a series of experimental tests on four untreated species of bamboo to investigate the effect of strip's shape, bamboo's types, and moisture content on the tensile strength of bamboo strip. It was found that the load carrying capacity of BRC beam was affected by cross sectional area of beam. The specimen with bar has higher tensile strength than presence of node which reduced strength by 50% [1]. P. Kumar, et. al. 2021 studied the concept of BRC and assessed the mechanical performance of bamboo as an alternative to steel. The tests regarding the compressive, tensile, and flexural strength of the bamboo showed surprisingly comparable results to the alternative steel. While performing the pull-out test it was reported that the bond stress was higher. Hence bond enhancing method should be done before using the bamboo [2]. D. Bhagat, et. al. 2021described the fabrication, experimental evaluation and theoretical analysis of a sustainable high-capacity flexural beam based on the concept of Fibre Reinforced Bamboo composites (FRBC). The bamboo clums with epoxy adhesive and propylene fibres were used in beam. The composite beam on removal of load was resilient to regain its shape. The failure occurred by local crushing of outermost bamboo. The beam showed effective ductility [3].P. Mali and D. Datta 2020 experimentally studied the flexural behaviour of concrete beams reinforced with bamboo strips. Total 30 beam specimens were tested under four-point bending test (pure bending). It is observed that both types of BRC beams have shown significantly higher shear as well as flexural strength than PCC beams. Failure mode observed in both type of BRC beams were different from that of PCC and RCC beams [4]. D. Bhonde, et. al evaluated BRC beam with four-point loading. The load elongation curve was plotted and load at first crack, ultimate bending moment at failure was studied. The tensile strength of bamboo varied on various factors such as type of species, land type of cultivation, environmental conditions. As high-water absorption of bamboo degrades the bond strength, it is advised in this study to take care of coating the bamboo with appropriate water sealant [5]. A. Javadian, et. al. studied in detailed the correlations between mechanical properties including tensile strength, modulus of rupture and modulus

of elasticity in flexure and tension and culm physical properties. The results demonstrated that specific density is directly correlated with all these mechanical properties of bamboo while the moisture content values were correlated only with value of modules of rupture. An epoxy -based coating with sand particles provided better protection with increased bonding[6]. R. Pandi, et. al. focused on the possibilities in replacement of reinforcement with seasoned bamboo. The bamboo attains equivalent flexural strength to steel reinforcement. It is cost-effective and reduces environmental effects caused by steel production [7].
N. Rahman, et. al. studied durability of bamboo composite material and effectiveness of protective epoxy coating by subjecting samples to various corrosive environment. Samples were immersed in water, simulated acidic rain solution and simulated concrete pore water solution for 28 days were observed. The results revealed that epoxy coating is a highly effective approach to enhance the bamboo composite's resistance towards water and acid attacks and improve its bond strength with concrete [8]. A. Sethia and V. Baradiya worked on concept of using bamboo as a potential reinforcement in concrete. This included one beam of steel reinforcement, one beam of plain concrete, and four beams of untreated bamboo reinforcement. From the flexural test of bamboo reinforced beam, it was seen that using bamboo as reinforcement in concrete can increase the load carrying capacity of beam [11]. A. Nayak, et.al. studied cost-wise comparison of steel reinforcement with bamboo reinforcement. A slab, two beams, a column and a footing of steel reinforcement and bamboo reinforcement each were considered. The results showed that the bamboo reinforced members were 33% cheaper than steel reinforced members [12]. K. Ghavami investigated bamboo reinforced beams. The classification of seven bamboos studied in accordance to their physical and mechanical properties. The results of this investigation showed that for the bamboo-reinforced lightweight concrete beam, the ultimate applied load was increased up to 400% as compared with the concrete beams without bamboo reinforcement [14].

Problem Statement

At present, the most commonly used building materials in the world are steel and concrete. The concrete has high compressive strength but poor tensile strength. Therefore, to strengthen the concrete, steel is used. As opposed to concrete, steel has a very high tensile strength, but there are certain issues associated with it. Some of them are high energy usage during its production and High production costs. They are a non-renewable resource and a significant amount of carbon emissions take place during their production. The desire to solve these issues without compromising the tensile ability of reinforced concrete has prompted engineers to look for locally sourced materials as a substitute for conventional steel reinforcement. Most of the studies carried out are small studies that made little progress in providing a design method for bamboo reinforced concrete, improving the bond, little progress has been achieved on other aspects of using bamboo as reinforcement in a beam. There are currently few models that depict the deflection, cracking, and bonding behavior of BRC beams. The current research investigates how to model the flexural and shear capacities of BRC beams. In addition, the research investigates solutions to mitigate the problems of, bond, deflection, and cracking.

Experimental program

The experimentation has been carried out in the following steps:

- General characteristics of bamboo reinforcement
- Surface treatment on bamboo
- Casting of beam models
- Tests and result

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General Characteristics of Bamboo Reinforcement

The bamboo samples chosen for the study were between 4 and 5 years of age. At this age, this species shows the highest performance in terms of its mechanical and physical characteristics. It is ensured that the overall geometry is straight enough and free from fungus or damage so that the final samples represent well-distributedfibers. Bamboo samples were first cleaned manually to remove any natural substances attached to their exterior surface, then these samples were cut into the size required for reinforcement (i.e., 2m in length). These selected bamboo specimens were further subjected to surface treatment to eliminate shrinkage of bamboo inside the concrete and to enhance the tensile strength of bamboo.

Bamboo Surface Treatment and Procedure

In the present work for bamboo surface treatment, a mixture of Epoxy resin and hardener was used. The surface treatment was carried out in two steps. In the first step, a solution of Epoxy resin and hardener was prepared, this consisted mixing of two parts, part A and part B as per the standard proportion mentioned by the manufacturer, i.e., 100:50 by volume, it was then applied to the bamboo strips prepared for making BRC beam specimensas shown in Fig. 1a. This coating will ensure that the bamboo strips remain water repellent. Immediately after the coating of Epoxy resin and hardener, the bamboo strips were wrapped with a single layer of Glass Fiber sheet as shown in Fig. 1b. Finally, the coated specimen was vacuumed. This Glass Fiber Coated Bamboo is used to prepare another BRC beam sample.

In the present work Epoxy resin was used to coat the exterior surface of the bamboo strip. The quantity (weight based) of this mixture required to form a uniform thin coating on the plain bamboo strip (2m) is about 25 ml, which cost Rs. 20/-. Cost of 2m Bamboo is Rs.12/- and Glass Fiber (2m) is required for wrapping bamboo,which costs Rs. 20/-.Therefore, total cost of Epoxy Coated bamboo is Rs. 32/- and that of Epoxy and Glass fiber-coated bamboo is Rs. 52/-. The percentage cost reduction in treated bamboo is 56-76%. Hence cost wise treated bamboo strips are more economical than that of steel.

(a)Coatingofepoxy resin (b) Glass fiber coating on the bamboo

Fig. 1 Bamboo surface treatment

3.2.1 Water Absorption Test

A water absorption test was carried out to understand the property of bamboo after the treatment of epoxy coating. The samples of untreated bamboo and treated bamboo were kept in a curing tank at room temperature for one week as shown in Fig. 2.

Fig. 2. Water absorption test on bamboo

Table 1. Percentage weight gain after water absorption test

No. of specimen	Type of specimen	Dry weight (gm)	Weight after water absorption (gm)	Percentage weight gain (%)
1	Uncoated Bamboo	109.2	122.62	10.94
2		115.6	127.4	9.26
3	Epoxy coated Bamboo	105.1	108.4	3.04
4		117.4	119.8	2

From Table 3.7, the water absorption by epoxy-coated bamboo reduces by 75% more than uncoated bamboo. We can say that we can use epoxy resin coating to improve water repellent nature of bamboo.
3.2.2 *Tensile Strength Test*

According to the test, the splitting end grip failure was observed. The splitting failureinitiated at the gripping area and finally smashed. If failure at grip could have been avoided,the specimen would take more load. To avoid failure at the grip a steel rod of a diameter similar to the inner diameterof the bamboo specimen is inserted on both sides of the specimen up to the grip length. Thefailure loads of these samples are shown in Table 2. From these results, it can be said thatthe tensile strength is nearly uniform andthe failure pattern is very similarfor bamboospecimens where failure at grip was avoided. The failure pattern of the bamboo specimen wastypical splitting without any slip at the grip as shown in Fig. 3. The tensile strength ofbamboospecimens with prepared ends (to avoid gripfailure) isalwayshigher than thecorrespondingbamboospecimenswithoutpreparedends(failureatgrip).

Fig. 3. Splittingfailureofthebamboospecimen

Table. 2 ResultofTensileTest oftheSpecimen withoutGripFailure

ecimenNo.	Typeofspecimen	Averagearea(mm^2)	'ailureLoad(KN)	Tensilestrength(MPa)	AverageTensile Strength(MPa)	ailuretype
1	UncoatedBamboo	113.1	20.8	183.9	181.56	Splitting
2		118.4	21.22	179.22		
3	Glass fiber-coatedBamboo	136.1	39.2	288.02	285.045	Splitting
4		140.6	39.66	282.07		

The tensile strength of Glass fiber-coated bamboo without grip failure is 37% higher than thatof uncoated bamboo without grip failure which helps to achieve good reinforcement.

Casting of Beam Models

3.3.1 Selection of type of concrete

Only one grade of concrete (M20) was used as concrete is a common part of this work. The mix design and testing of concrete specimens (cube) was carried out as per the guidelines of IS 10262 and IS 456]. The final mix proportion along with other important properties are shown in Table 3. In the mixed design, the coarse aggregate quantity was used as a combination of 20 mm and 10 mm in size aggregate in the ratio of 70:30 to easily accommodate andestablish bamboo-concrete interlocking. The cement used is Ordinary Portland Cement (OPC) 53 grade complying with IS 12,269.After casting and 28 days of curing of concrete specimens these were tested for determining important properties, as reported at Table 3.

Table 3. Quantity for mix proportion

Sr. No.	Materials	Quantity
1	Cement	345 kg
2	Fine Aggregate	750 kg
3	Coarse Aggregate (20mm)	1170 kg
4	Water	190 L

3.3.2 Casting of the beams test specimen

The construction processes for steel-reinforced concrete beams and the bamboo-reinforced concrete beam are very similar, simply the steel is replaced with bamboo. Four different types of bamboo reinforced beams were casted differing in coating treatments and numbers of bamboo. They are Uncoated Bamboo Reinforced Concrete (UBRC) beam, Epoxy Coated Bamboo Reinforced Concrete (ECBRC) beam, Epoxy and Glass Fiber coated Bamboo Reinforced Concrete (EGFBRC) Beam 1 and 2.The RCC beam of sizes 200mm x 250mm x 2000mm was cast. The formwork was prepared to the size of the beam. These formworks were cleaned and oiled properly. For meshing the reinforcement details like bar size, cutting length of the bar, and spacing of top bars and bottom bars are taken into consideration. The beams are designed as under-reinforcedsections according to IS 456-2000. In this work, steel of grade Fe 500 is used. It is reinforced with 2 bars of 10 mm dia. at the bottom, and 2 bars of 10 mm dia. at the top using 8mm dia. stirrups @ 300mm c/c. The reinforcement is placed into its position with the provision of a clear cover of 25 mm. The concrete mix is then poured into the formwork in batches. Further, fresh concrete is compacted adequately by tamping in order to mould it within the forms and around the reinforcement to eliminate stone pockets, honeycomb, and entrapped air.The performances of these four beams were compared with conventional beam performance. The main reinforcement cage prepared for BRC as well as the RCC types of the beamis shown in Fig 4The concrete mix is then poured into the formwork in batches. Further, fresh concrete is compacted adequately by tamping to mould it within the forms and around the reinforcement to eliminate stone pockets, honeycomb, and entrapped air. The beam specimen were cured for 28 days.

(a) RCC reinforcement (b) UBRC reinforcement

(c) EBRC reinforcement (d) EGFBRC 1 and EGFBRC 2 reinforcement

Fig. 4 Beam reinforcements

Tests and Results

Loading frame is equipment used to test the various structural elements like beams, columns, slabs and portal frames or any other structural element for its compression and flexural strength. Testing specimen i.e., beamspecimen is lifted by manual hydraulic crane using lifting belts; precautions are taken while handling the specimen as shown in Fig. 5a.The test specimen to be mounted on the spacers which is on the horizontal supporting beams (girders). Required capacity load cell has to be fixed to the hydraulic jack using height adjustment fixtures.Loading can be done by entering the certain value in 'enter rate of loading'. Increase the load step by step until the test specimen bends/breaks. Two-point load was applied to the beams as shown in Fig. 5b. Load readings will be displayed and recorded in our Data Acquisition System (DAS) screen.

(a) Placing Beam Specimen

(b) Load the Specimen by Giving Axial Load

Fig. 5 Test Setup for Beam Specimen

Results

All five beam specimens of sizes 200m x 250mm x 2000mm each were tested one-by-one under loading frame machine by applying two-point loading condition at L/3 from each end. We get pure bending by this condition of loading. The following observations were made during and after testing.
1. Ultimate Load Carrying Capacity
2. Deflection
3. Failure pattern
4. Cost Comparison

Ultimate load Carrying Capacity

The ultimate load carrying capacity is the load taken by the beam at the point of its failure. The ultimate load carrying capacity of the beams is given in the Table 4.

Table 4. Ultimate Load Carrying Capacity

Specimen	Ultimate Load Carrying Capacity in KN	Compatibility with RCC beam
RCC Beam	85.4	-
UBRC Beam	48	56.21 %
ECBRC	53.7	62.82 %
EGFBRC 1	66.3	77.64%
EGFBRC 2	75.7	88.65 %

The performance of UBRC was found to be lowest amongst all the specimens of beams as the bamboos in this beam were swollen and became weak resulting in weak performance of the beam. The load carrying capacity of ECBRC 1 was higher than that of ECBRC. The EGFBRC 2 performance results were best, it shown 88.65% compatibility with baseline RCC beam.

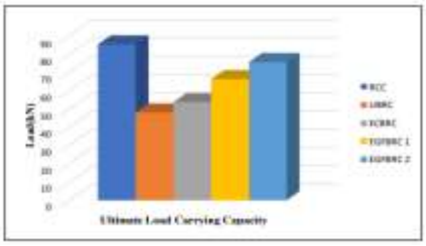

Fig. 6 Ultimate Load Carrying Capacity

Deflection

Fig. 7 shows the comparison between the deflections in all the five beams along with the loads. The EGFBRC 2 beam has taken loads similar to the baseline RCC beam. EGFBRC 2 beam performed in the same way as the baseline RCC beam performed.

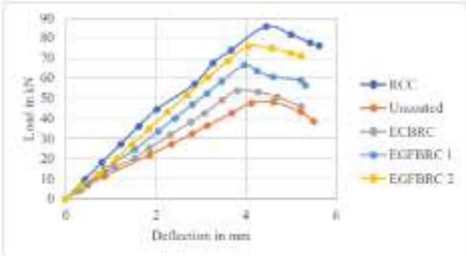

Fig.7 Load vs Deflection of all Beam Specimen

Failure Pattern

The failure of baseline RCC beam occurred in a pattern, in which the crack commenced near to the support and centre of beam from the tension zone propagating diagonally to the compression zone. The cracks in bamboo beams occurred almost at L/3 distance from the ends. These cracks propagated mostly vertically upward. The UBRC beam cracks were premature, quite larger in width and longer length.

(a)RCC Beam (b) UBRC Beam

(c)EGFBRC 1 Beam(d)EGFBRC 2 Beam

Fig. 8 Crack Pattern of Beams

Cost Comparison

Sr. No.	Bamboo Specimen	Cost Reduction	Strength Compatibility of Beams
1.	Steel Bar	-	-
2.	Uncoated Bamboo	90%	56.21%
3.	Epoxy Coated Bamboo	73%	62.82%
4.	Epoxy and Glass Fibre Coated Bamboo	56%	88.65%

Conclusion

1. The epoxy resin coat on bamboo reduces water absorption by 76% than uncoated bamboo.
2. On coating bamboo with epoxy and glass-fiber, the tensile strength increased by 36.3% than uncoated bamboo.
3. The EGFBRC 2 beam showed appreciable 89% compatibility in strength with the baseline RCC beam. It also showed 37% better load carrying capacity than UBRC beam.
4. The deflections in EGFBRC 2 beam and RCC beam are nearly equal. This proves that steel can be replaced with bamboo composite in minimal loading conditions in structural application.
5. The uncoated bamboo proves to be 10 times cheaper and epoxy coated bamboo to be 4 times cheaper than a steel bar used in the research.
6. The use of epoxy and glass fiber coated bamboo composite reduces the overall cost of by 56% than RCC component cost.
7. It can be concluded that the use of epoxy and glass fiber coated bamboo composite is a potential substitute to steel which provides appreciable economic feasibility and strength compatibility.

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