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Development of Bamboo Reinforced Concrete Structural Member for Rural Housing

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ABSTRACT: Bamboo splits were used by treating them with Coal tar for water-proofing to avoid bamboo swelling in the mix, rising the bond strength and toughness of bamboo as reinforcement. The M20 grade of concrete was selected for concrete work. The bamboo sticks were seasoned for about three weeks and then were used to reinforced the bamboo reinforced concrete beams.

The PCC (Plain cement concrete) beams failed at an average ultimate load of 13.51 kN and flexural strength was found to be 5.40 MPa. The average deflection of PCC beams while loading was found to be 0.63 mm. The singly reinforced sections i.e., SR₁C (Steel reinforced concrete- singly reinforced), BR₁C (Bamboo reinforced concrete- singly reinforced), and TBR₁C (Treated bamboo reinforced concrete- singly reinforced) beams failed at an average ultimate load of 53.25 kN, 16.37 kN and 34.01 kN respectively. The flexural strength of singly reinforced sections i.e., SR₁C, BR₁C, and TBR₁C was found to be 21.27 MPa, 6.27 MPa and 7.73 MPa respectively. The average deflection while loading for SR₁C, BR₁C, and TBR₁C was found to be 16.77 mm, 18.90 mm and 9.83 mm respectively. The doubly reinforced sections i.e., SR₂C (Steel reinforced concrete- doubly reinforced), BR₂C (Bamboo reinforced concrete- doubly reinforced), and TBR₂C (Treated bamboo reinforced concrete- doubly reinforced) beams failed at an average ultimate load of 65.51 kN, 26.87 kN and 34.01 kN. The flexural strength of doubly reinforced sections i.e., SR₂C, BR₂C, and TBR₂C was found to be 25.83, 10.75 MPa and 12.86 MPa respectively. The outcomes showed, bamboo with suitable treatment is a strong and sustainable substitute for steel reinforced concrete for lightweight construction.

KEYWORDS: Concrete, tensile strength, steel, bamboo, reinforcement, flexural strength

I. INTRODUCTION

Concrete is one of the most common building materials for both commercial and rural structures. It is the most widely used construction material all around the world. Concrete is an “artificial stone” obtained by mixing sand, cement and aggregates with water. It has many advantages including low cost, low maintenance, high availability, high compressive strength and high durability. However, concrete is a brittle material with very low tensile strength. Steel reinforcing bars are typically used for reinforcement. Steel is one of the best materials for compensating the low tensile strength of concrete because of its high tensile strength, over 792 N/mm² [8]. Steel is readily available and affordable in most developed countries, but not everywhere. Buildings in many countries are made entirely of concrete or have very little steel reinforcement. These buildings typically cannot withstand the effects of natural disasters such as earthquakes, storms, and hurricanes.

Even though steel reinforcement is an appropriate material for complementing concrete's low tensile strength, there are various difficulties, including cost, technique, and efficiency. To address these issues, many scientists and engineers have been looking for new materials that can increase the tensile strength of concrete. Specifically, bamboo is one of the most suitable materials to substitute for reinforcing bar in concrete due to its high tensile strength and renewable nature.

In India, different climatic zones have a huge diversity of soil and climatic conditions. It is thus possible to successfully cultivate a variety of tropical and sub-tropical weeds. India has annual bamboo production as 4.6 million tonnes. In Maharashtra annual bamboo production is 2,47,239 tonnes. The Konkan region contributes 70,000 tons of annual bamboo production. Asia alone accounts for 400 species. In India about 136 species in 30 genera occurs [9]. The tensile strength of bamboo is very high and can reach 370 N/mm² [10]. This makes bamboo an alternative to steel in tensile loading applications.



The most reinforcement material for concrete is a steel which requires high energy during its manufacturing process, also it is on its verge of extinction as it is non-renewable in nature. Apart from these it also produces wastewater contaminants, hazardous wastes and solid wastes which poses a threat to the environment. Further with increased demand, the steel costs have risen significantly over the years. This hinders its application for low-cost housing. For steel, the demand was observed to be about 1648 million tonnes across the globe. Also, the extraction of raw materials causes the degradation of land, loss of agricultural land, dust and noise pollution. In addition to this, the transportation of these raw materials results in vehicle pollution, noise pollution and excessive consumption of fuel further deteriorating the environment [1].

When compared to steel and cement, the amount of CO₂ released into the atmosphere by bamboo is 50 times lower. Further, bamboo also consumes around one (1) tone of carbon dioxide during its growth phase [11]. Today, the world is undergoing vast changes. As the population increases, the demand associated with housing also increases. One of the demands is of owning houses, as most of houses are constructed by using steel and concrete, thus it should be a major concern to provide with an alternative option, which will reduce the burden on use of steel leads to reduction in construction cost of houses in the country. Addressing all these problems bamboo is one of the suitable replacement for steel.

A traditional rural building is based on adaptations to the local environment, and is usually built with the labour of the villagers themselves without the necessity for external mechanized inputs. In rural areas low cost, aesthetics, preserving traditions, and living in climatically suitable houses are all fine notions, but the durability of buildings is also an important consideration. A mud building with a thatched roof needs continuous maintenance, whereas a building with conventional materials like cement and steel is far sturdier, and features a longer lifetime. These conventional materials increase the overall cost of construction.

In regions of high rainfall, there is a high risk of damage of houses due to natural disasters like cyclone, earthquake, landslides etc. consequently it required high cost for repairing of houses which are damaged by natural disasters. Bamboo can resist forces created due to natural disasters. Bamboo rural houses can be used in areas of high rainfall and natural disasters like cyclone. So, constructing rural houses reinforced with bamboo is not only a cost-effective solution in comparison to the usual steel but also in the economic development of the rural communities by providing them jobs. The cost of construction is increasing by 50 per cent over the traditional inflation due to hike in the cost of basic building materials and labour. Consequently, even basic housing is now beyond the reach of a common person in rural areas. There's an imperative need to utilize technology options resulting in cost-effective results, which people in rural areas can afford. The life of the rural housing which is made up of load bearing structures can be enhanced by reinforcing it with bamboo of optimum size. Also, the maintenance cost for the bamboo reinforced rural housing will be comparatively less than the load bearing housing. Therefore, it was felt necessary to design and develop bamboo reinforced structural element. With this background study entitled "Development of Bamboo Reinforced Concrete Structural Member for Rural Housing" is under taken.

II. MATERIAL AND METHODS

Fineness of cement

This test was conducted to determine the fineness of the cement by dry sieving cement i.e the cement should pass through the sieve as per the requirements of cement and concrete testing. This testing was done by conforming to the IS: 4031 (1) – 1988 [4]. The formula to calculate the fineness of cement is:

$$\% \text{ Weight of Residue} = \frac{\text{Weight of Sample Retained on the Sieve}}{\text{Total weight of the sample}} \times 100$$

Standard consistency of cement

This test was conducted to measure the consistency of standard cement paste. This testing was done by conforming to the IS:4031 (4) – 1988 [4]. The equation to calculate standard consistency of cement.

$$\text{Standard consistency} = \frac{\text{Weight of water added}}{\text{Weight of cement}} \times 100$$

Initial and final setting times of cement

This test was conducted to determine the initial and final setting times of cement. This testing was done by conforming to the IS: 4031 (5) - 1988 [4]. The initial setting time and final setting time was recorded in minutes.

Specific gravity of cement

This test was conducted to measure the specific gravity of the cement. This testing was done by conforming to the IS:4031 (11) - 1988 [4]. The equation to calculate cement's specific gravity is:

$$\text{Specific Gravity (Sg)} = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4) \times 0.79}$$

Where,

W₁ = Weight of the empty flask, gm.



W_2 = Weight of the flask and cement, gm.

W_3 = Weight of the flask, cement and kerosene, gm.

W_4 = Weight of the flask and kerosene, gm.

Specific gravity of kerosene = 0.79

Design of concrete mix used for reinforcement

The mixes were designated in accordance with IS:10262-2019 mix design method [2]. The mix proportions M20 was designed confirming to IS:456-2000 [8]. Concrete mix with w/c ratio of 0.55 was prepared.

Treatment details

To determine the feasibility of the use of bamboo as reinforcement in concrete, comparison was made with steel i.e., the traditional reinforcement. The standard size of beam (100 mm × 100 mm × 500 mm) was selected. The M20 grade of concrete was selected for concrete work. A nominal cover of 20 mm was provided to the reinforced structural members conforming to IS:456 (2000) [5]. The treatment consists of no reinforcement, steel reinforcement, bamboo reinforcement and bamboo reinforcement coated with tar casted in concrete. Three beam specimens were prepared for each type of treatment. The treatment details of the beam specimens are shown in Table 1.

Table: 1 Treatments of concrete beam structural member

Sr. No.	Treatment	Type of beam	Reinforcement provided
1.	PCC	Plain cement concrete	Not reinforced
2.	SR ₁ C	Steel reinforced concrete (singly reinforced)	Two numbers of 6 mm diameter bars
3.	SR ₂ C	Steel reinforced concrete (doubly reinforced)	Four numbers of 6 mm diameter bars
4.	BR ₁ C	Bamboo reinforced concrete (singly reinforced)	Two numbers of 19 mm diameter bars
5.	BR ₂ C	Bamboo reinforced concrete (doubly reinforced)	Four numbers of 19 mm diameter bars
6.	TBR ₁ C	Treated bamboo reinforced concrete (singly reinforced coated with tar)	Two numbers of 19 mm diameter bars
7.	TBR ₂ C	Treated bamboo reinforced concrete (doubly reinforced coated with tar)	Four numbers of 19 mm diameter bars

Steel reinforced concrete

Steel bars of Fe 415 grade were selected for reinforcing steel reinforced concrete (SRC) beams.

Bamboo reinforced concrete

The bamboos were collected from college of forestry, Dapoli. The bamboo sticks were seasoned for about three weeks and then were used to reinforced the bamboo reinforced concrete (BRC) beams.

Treated bamboo reinforced concrete (coated with tar)

The surface of the bamboo sticks was roughened using knife and then a thin coat of coal tar paint was applied all over the surface. Immediately after that sand was sprinkled over the layer of paint to improve the bonding effect between bamboo sticks and concrete in the beams.

Preparation of cement concrete cube specimens

To check the compressive strength of the M20 grade concrete the compression test on the cement concrete cubes was conducted as per IS:516-1959 [6]. This test gives us the information of the potential strength of the concrete mix from which it is sampled. Also, this test helps in determining whether correct mix proportions of various materials were used to get the desired strength. The compression test of concrete was carried out for six specimens of dimension 150 mm × 150 mm × 150 mm. After casting of the concrete cubes, they were demoulded after 24 hours and were placed for curing and tested after 7 and 28 days of curing.

Preparation of reinforced concrete beam specimens

Selection of bamboo

Only bamboos showing a pronounced brown colour are used. Selection of the longest large diameter culms available was made while as far as possible, straight long bamboos without any deformations and cracks were selected. The bamboos were not cut under wet condition. Bamboo species with the greatest number of nodes were selected.

Preparation of bamboo

Larger culms were split into splints approximately 19 mm wide and 460 mm in length. The bamboo splitting was done by separating the base with a sharp knife and then pulling a dulled blade through the culm (Fig. 1). The bamboo was

cut and allowed to sun dry to reduce moisture content for three to four weeks before using. Copper chrome boron (CCB) was used for treatment of bamboo splits. To attain desired level of treatment, bamboo splits were dipped in CCB solution for 30 days. The 5% concentration of the solution was used for treatment as per IS:9096-2006 [7]. The type of coating used is coal tar. Only a thin coating was applied. A thick coating will lubricate the surface and weaken the bond between the concrete and bamboo. The bamboo was dipped in to hot coal tar and then coarse sand was applied on top of the coated surface. The result of the test is expected to show that coal tar acted as water repellent and the sand sprayed on the coal tar helps to increase the bond.

Mixing of Concrete

The cement fine aggregate and coarse aggregate were mixed dry until the mixture is thoroughly blended and is uniform in colour. The water was then be added and mixed until the concrete appears to be homogeneous and had the desired consistency.

Placement of reinforcing bars

Prior to casting the specimen, the formwork was cleaned properly and coated with oil on the inside. The bamboo or steel was placed in both the tension and compression zone of member.

Compacting

The concrete was filled into the mould in three layers of approximately equal thickness. Each layer was compacted by vibration until the specified condition is attained.

Curing

For proper curing, specimens were submerged in the water tank for 28 days.

Laboratory testing of specimens

Testing of concrete beam specimens

Flexural tests were conducted on beam specimens cured for 28 days. Flexural strength was carried out for both i.e., reinforced and mass concrete beam specimens. According to IS:516 - 1959 standard flexural tests were performed by using Universal Testing Machine with model UTM-10. The test was conducted with two-point loading. Test setup to perform flexural test on beam specimens is as shown in figure 1. Test procedure listed on IS:516 - 1959 was used to perform flexural test [6].

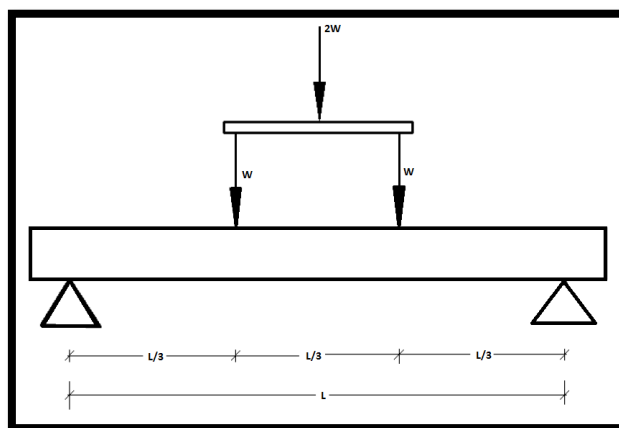


Fig 1: Schematic view of Simply Supported Two Point Load Experimental Setup

The flexural strength of the specimen is expressed as the modulus of rupture f_b .

$$f_b = \frac{(p \times l)}{b \cdot d^2}$$

when 'a' is greater than 133 mm,

or

$$f_b = \frac{(3 p \times a)}{b \cdot d^2}$$

when 'a' is than less 133 mm but greater than 110 mm

Where,

a = distance between the line of fracture and the nearest support, mm

b = measured width of the specimen, mm

d = measured depth of the specimen at the point of failure, mm

l = length of the span on which the specimen was supported, mm and

p = maximum load applied to the specimen, N.

III. EXPERIMENTAL RESULTS

Cement Testing

After conducting the required essentials tests for the specifications of the OPC the following results were obtained:

Table: 2 Physical characteristics of cement

No	Properties	Test results
1.	Fineness test	3%
2.	Standard consistency	31%
3.	Initial setting time	49 minutes
4.	Final setting time	326 minutes
5.	Specific gravity	3.07

Concrete mix proportion

Design of concrete mix proportion of material were selected for the concrete work. The results were obtained for M20 grade of concrete are shown in Table 3.

Table: 3 Quantity of materials for M20 concrete mix for 1m³

	Cement	Fine aggregate	Coarse aggregate	Water
Density	345 kg/m ³	750 kg/m ³	1170 kg/m ³	190 kg/m ³
Portion	1	2.07	3.6	0.55

Compressive strength test of concrete cubes

The concrete of design mix was further tested for its compressive strength. Compression test was carried out on the cubes of grade M20. The results obtained are shown in the Table 4 and Table 5.

Table: 4 Cube tests results for 7 days of curing

Sample No.	Dimensions (mm)	Weight of specimen (kg)	Density (kg/m ³)	Curing Days	Load (kN)	Compressive Strength (N/mm ²)
1.	150 × 150 × 150	8.55	2533.33	7	580	25.78
2.	150 × 150 × 150	8.46	2506.67	7	570	25.33
3.	150 × 150 × 150	8.60	2548.15	7	560	24.89
Average compressive strength = 25.33 N/mm ²						

Table 5 Cube tests results for 28 days of curing

Sample No.	Dimensions (mm)	Weight of Specimen (kg)	Density (kg/m ³)	Curing Days	Load (kN)	Compressive Strength (N/mm ²)
1.	150 × 150 × 150	8.61	2551.11	28	660	29.33
2.	150 × 150 × 150	8.70	2577.78	28	695	30.88
3.	150 × 150 × 150	8.78	2601.48	28	810	36.00
Average compressive strength = 32.06 N/mm ²						

From Table 4 and Table 5 the compressive strength of concrete cubes for 7 days of curing is from 24.89 N/mm² to 25.78 N/mm² and the average compressive strength was found to be 25.33 N/mm². While for 28 days of curing compressive strength ranges from 29.33 N/mm² to 36 N/mm² and average compressive strength was found to be 32.06 N/mm². As per acceptance criteria of IS 456:2000 sample is acceptable which indicates that the design mix of concrete can be used for reinforcement work [8].



Fig 2: Compressive strength of concrete to target strength

Flexural test of concrete beam specimens

The observations for flexural test were recorded after 28 days from concrete beam preparation. Data was analysed to find suitability of bamboo as reinforcement in the concrete work. The beams are tested in their respective test dates under loading frame to study the behaviour of flexural strength and deflection of bamboo beams. The flexural strength of bamboo beams having dimensions 100 mm × 100 mm × 500 mm are calculated by using the ultimate load of beam. From the experimental test the ultimate carrying capacity and the type of failure were recorded.

Plain cement concrete (mass concrete)

The figure 3 showed that in the test beam specimens, the crack was developed in middle third portion of the beam specimen and extended to the bottom surface of beam. The line of fracture developed at 170 mm, 226.6 mm and 208.6 mm from nearer support for first, second and third beam specimen respectively. Finally, the beams failed at an average ultimate load of 13.51 kN. Plain concrete beam specimen failed suddenly and hence showed the brittle failure.



Fig3: Failure pattern of plain cement concrete

Steel reinforced concrete

It was observed from this test that steel reinforced specimens take time for failure. Due to gradual application of load on the steel reinforced beam it bends after load applied which is beyond its limit. Concrete is weak in tension but reinforced steel is good in tension hence load is distributed to the steel.

Singly reinforced beam

In the test beam specimens two cracks were generated. The cracks developed at a slow rate. The cracks occurred vertically from the point of load application which was flexure cracks and the cracks were widened. The line of fracture developed at 142 mm, 163.8 mm and 141.3 mm from nearer support for first, second and third beam specimen respectively. Finally, the beams failed at average ultimate load of 53.25 kN. The pattern of cracks observed in this test beam is shown in the figure 4.



Fig4:Failure pattern of steel reinforced concrete (Singly reinforced beam)

Doubly reinforced concrete beam

In the test beam specimens cracks occurred vertically from the point of load application which was flexure cracks and the cracks were widened. Two cracks were generated in the beam specimens. The crack was starts from the load application and propagates to the support. The cracks developed at a slow rate. The concrete at the support was crushed. The cracks occurred vertically from the point of load application which was flexure cracks and the cracks were widened. The line of fracture developed at 128.7 mm, 135 mm and 132 mm from nearer support for first, second and third beam specimen respectively. The pattern of cracks observed in this test beam is shown in the figure 5. Finally, the beams failed at average ultimate load of 65.51 kN.



Fig5:Failure pattern of steel reinforced concrete (Doubly reinforced beam)

Bamboo reinforced concrete

For this study bamboo was reinforced without coating of bamboo split culms.

Singly reinforced beam

In the test beam specimens, the cracks were started from the load application point and propagates to the middle between support and load application as shown in figure 6. Then the crack got widened. The crack was rising very smoothly and slowly. The concrete at the load application point was crushed. From the failure of the beam, it was observed that there was very less bonding between the concrete and the Bamboo as it was untreated Bamboo. The line of fracture developed at 176 mm, 132 mm and 141.7 mm from nearer support for first, second and third beam specimen respectively. The beam failed at an average load of 15.74 kN.



**Fig6:Failure pattern of bamboo reinforced concrete
(Singly reinforced beam)**

Doubly Reinforced Beam

In the test beam specimens cracking started from the support by widening its width propagates diagonally to the point of load of application. The cracks developed at a very slow rate. As loading progressed, crushing of concrete at point of loading started. The concrete at the support was crushed. A piece of concrete fell out from the bottom part of the beam. This indicates poor bond between the concrete and bamboo, leading to bond failure. This failure is a type of diagonal tension failure which occurred under the action of large shear forces as shown in figure 8. The line of fracture developed at 142 mm, 151 mm and 186.3 mm from nearer support for first, second and third beam specimen respectively. Figure 7 shows the diagonal tension failure that was observed. Finally, an average ultimate load of 26.87 kN was recorded.



**Fig7:Failure pattern of specimens consisting bamboo reinforcement
(Doubly reinforced beam)**

Treated bamboo reinforced concrete (coated with tar)

In this beam specimens thin coat of coal tar paint were applied all over the surface of bamboo splint culms to increase the bonding effect between bamboo splint culms and concrete.

Singly reinforced beam

In this test beam specimens, the initially cracks were started from the load application point and extended to the bottom surface of the beam. Then the crack got widened. The crack was rising very smoothly and slowly. From the failure of the beam, it was observed that there was sufficient bonding between the concrete and the Bamboo as it was treated Bamboo. The line of fracture developed at 134 mm, 152.3 mm and 174 mm from nearer support for first, second and third beam specimen respectively. The beam failed at an average load of 19.35 kN. The pattern of cracks observed in this test beam is shown in the figure 8.



Fig8:Failure pattern of treated bamboo reinforced concrete coated with tar (Singly reinforced beam)

Doubly Reinforced Beam

In the test beam specimens, the initial crack started from the support to the point of loading. As loading progressed crushing of concrete at the point of application of load was observed this was due to bending moment. Longitudinal crack parallel to the reinforcing bar was also observed in both directions which show the poor bondage between concrete and bamboo. It was also observed that during this test it was seen that the reinforced concrete specimens remain uncracked and have large stiffness until the moment reaches the cracking moment. When the cracking moment was reached the member cracked and the stiffness at the cracked section was reduced. As the load was increased further; the more cracks occurred and existing cracks increased in size. The line of fracture developed at 113.3 mm, 136 mm and 130.7 mm from nearer support for first, second and third beam specimen respectively. The beam failed at an average load of 34.01 kN. The pattern of cracks observed in this test beam is shown in the figure 9.



Fig9:Failure pattern of treated bamboo reinforced concrete coated with tar (Doubly reinforced beam)



Fig10: Failure of treated bamboo reinforced concrete coated with tar

Flexural strength comparison of beam specimens

Strength comparison of singly reinforced concrete beam specimens with respect to plain cement concrete beam specimens

Flexural strength of plain cement concrete beam and singly reinforced concrete beam sections were compared. Results of flexural strength of plain cement concrete and singly reinforced sections for M20 grade of concrete are given in figure 11.

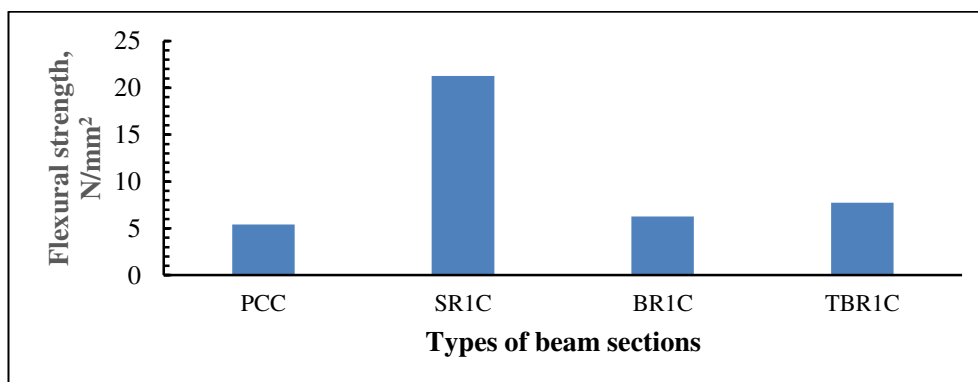


Fig11: Flexural strength of plain cement concrete and singly reinforced sections

The figure 11 revealed that average flexural strength was increased by 1.16 times for BR₁C i.e., bamboo reinforced concrete (singly reinforced) than plain cement concrete beam. In TBR₁C i.e., treated bamboo reinforced concrete (singly reinforced) beam, the average value of flexural strength was increased by 1.23 times than BR₁C i.e., bamboo reinforced concrete (singly reinforced) and 1.43 times increased than plain cement concrete beam. In SR₁C i.e., steel reinforced concrete (singly reinforced) beam, the average value of flexural strength was increased by 3.94 times than that of plain cement concrete beam.

Strength comparison of doubly reinforced concrete beam specimens with respect to plain cement concrete beam specimens

Flexural strength of beam sections was compared. Results of flexural strength of tested plain steel reinforced, bamboo reinforced and treated bamboo reinforced sections for M20 grade of concrete are given in figure 12.

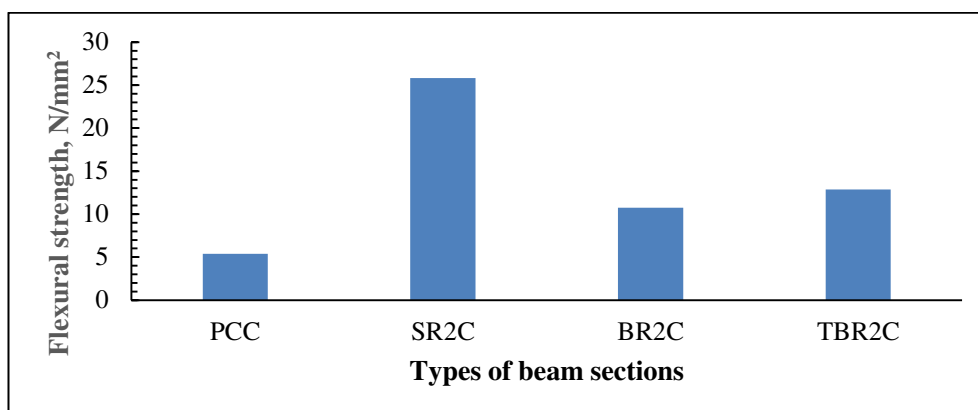


Fig12: Flexural strength of plain cement concrete and doubly reinforced sections

The figure 12 revealed that avg. flexural strength was increased by 2 times for BR₂C i.e., bamboo reinforced concrete (doubly reinforced) than plain cement concrete beam. In TBR₂C i.e., treated bamboo reinforced concrete (doubly reinforced) beam, the average value of flexural strength was increased by 1.2 times than BR₂C i.e., bamboo reinforced concrete (doubly reinforced) and 2.38 times increased than plain cement concrete beam. In SR₂C i.e., Steel reinforced concrete (doubly reinforced) beam, the average value of flexural strength was increased by 4.78 times than that of plain cement concrete beam.

Strength comparison of treatments

Flexural strength of steel reinforced beam specimens, bamboo reinforced concrete beam specimens and treated bamboo reinforced concrete beam sections were compared. Results of flexural strength of tested steel reinforced, bamboo reinforced and treated bamboo reinforced sections for M20 grade of concrete are given in figure 13.

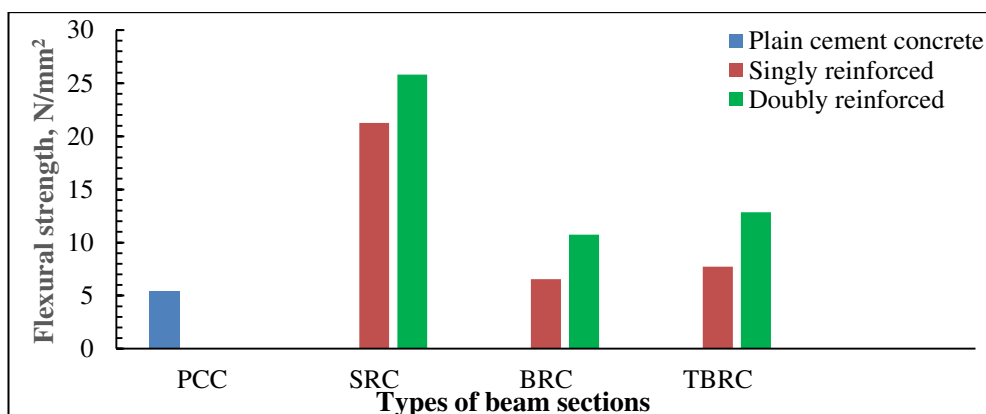


Fig13: Flexural strength of plain cement concrete, singly reinforced and doubly reinforced sections

The figure 13 revealed that flexural strength of PCC beam shows the lowest flexural strength among the all beam specimens. Also, SRC beams shows highest flexural strength among all beam specimens. The flexural strength was increased by 1.18 times for TBR₁C i.e., treated bamboo reinforced concrete (singly reinforced) than BR₁C i.e., bamboo reinforced concrete (singly reinforced). In TBR₂C i.e., treated bamboo reinforced concrete (doubly reinforced) beam, the average value of flexural strength was increased by 1.19 times than BR₂C i.e., bamboo reinforced concrete beam (doubly reinforced). Thus, from strength point of view SR₂C was found to be best among all the treatments. The flexural strength of SR₂C was followed by SR₁C, TBR₂C, BR₂C, TBR₁C, BR₁C and PCC respectively.

IV. CONCLUSION

1. The load carrying capacity of BRC (Bamboo reinforced concrete) beams was higher than PCC (Plain cement concrete) beams but lower than SRC (Steel reinforced concrete) beams.
2. TBRC (Treated bamboo reinforced concrete - coated bamboo) beams possess higher strength than BRC (Bamboo reinforced concrete - without coated bamboo) beams.



3. The use of bamboo-strip as reinforcement in concrete beam increased the load carrying capacity and post cracking ability of the beam as compared to plain cement concrete but not as pronounced as in steel-reinforced beam.
4. The bamboo can be used as reinforcement in concrete for low-cost housing structures for load bearing housing structures.

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