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# Mechanical Behaviour of Bamboo Reinforced Beam

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**ABSTRACT:** The present study determines the feasibility of bamboo as a replacement of steel reinforcement of concrete beams. The mechanical properties and behavior of steel reinforced concrete have been thoroughly studied and well documented but there exists no comprehensive data describing bamboo reinforced concrete. Therefore, the aim of this research is to study mechanical properties of bamboo and behavior of bamboo reinforced beams. In concrete, reinforcement is put in place to provide tensile strength, a property that concrete lacks. Therefore, if bamboo is to be used as concrete reinforcement, it is necessary to understand how bamboo behaves in tension. Three different cross-sections of bamboo reinforcement namely circular, triangular and square were considered. These bamboo reinforcements tested with the help of Universal Testing Machine (UTM). Once all the data had collected, a series of stress vs. strain graphs have constructed and analyzed to determine tensile properties of bamboo.

**KEYWORDS:** Bamboo reinforcement, Mechanical properties, Tensile test, Double point loading, Cross sections.

## I. INTRODUCTION

Concrete is a widely used construction material for its various advantages such as low cost, availability, fire resistance etc. But it cannot be used alone everywhere because of its low tensile strength. So, generally steel is used to reinforce the concrete. Though steel has a high tensile strength to complement the low tensile strength of concrete, use of steel should be limited since it is very costly and also so much energy consuming in manufacturing process. Thus a suitable substitute of this with a low cost, environment friendly and also a less energy consuming one, is a global concern; especially for developing country. Addressing all these problems, bamboo is one of the suitable replacements of reinforcing bar in concrete for low cost constructions [1][2]. Bamboo is natural, cheap, widely available and most importantly strong in both tension and compression [3][4]. The tensile strength of bamboo is relatively high and can attain 370 Mpa which makes bamboo an attractive substitute to steel in tensile loading applications. Bamboo is commonly introduced as a giant grass rather than a tree. It grows very rapidly as most growth occurs during first year and becomes matured by fifth year. The strength of bamboo increases with its age and reaches to the maximum strength at 3-4 years and then starts to decline in strength. Bamboo is also an environment friendly plant because it absorbs a lot of nitrogen and carbon dioxide in the air. In some parts of the world many buildings are constructed only with concrete or mud-bricks. This is dangerous in case of seismic activity. These buildings have little hope of standing in the case of an earthquake. Steel reinforcement would be an ideal solution, but cost is a considerable problem. Scientists and engineers are constantly seeking for new materials for structural systems; the idea of using bamboo as possible reinforcement has gained popularity.

Ghavami et al.[5][6] found that bamboo's compressive strength was much lower than its tensile strength, and there was high strength along the fibers, but a low strength transverse to the fibers. Masani et al.[7] investigated that bamboo reinforcement area should be 5 times the typical steel reinforcement area, and that even when fine cracks develop on the surface of bamboo, the load carrying capacity of the member is not reduced. The only negative properties of bamboo given are its susceptibility to attack by insects, fungi and dried bamboo is prone to catch fire.



Mechanical properties of bamboo-glass fiber reinforced composites depends on fiber length, fiber weight ratio and adhesive characteristics between fiber and matrix [8][9]. Natural fibers exhibit high tensile strength and low modulus of elasticity [10].

## II. EXPERIMENTAL PROGRAM

Bamboo samples from Bareilly zone (Uttar Pradesh, India) were collected for the investigation. Experimental program were made to find out the mechanical properties of Bareilly species bamboo. Then experimental program on tensile strength, expansions and water absorption of bamboo and flexural strength of concrete beam were performed.

Experimental program of this research consisting of tensile testing of bamboo materials as shown in Table-1 and two-point load bending tests of bamboo reinforced concrete beams. Tensile tests involve specimen preparation, test set-up and instrumentation. Beam testing includes beam design, concrete mix design- summary of material proportion per meter cube has been shown in Table-2 (mix proportion is 1:1.46:3.29), bamboo preparation, reinforcement preparation, form preparation, concrete casting and the conduction of the tests. Tensile tests were conducted on Universal Testing Machine with model 70-C0807/C. According to ISO 22157-1 the load should be applied continuously throughout the test at a rate of motion of the movable cross head of 0.01mm/s. To get this rate assuming 20,000N/mm<sup>2</sup> modulus of elasticity of bamboo the rate of the testing machine was adjusted to 1N/mm<sup>2</sup>/s. When clamping made, rubbers were attached from the outside and inside surface of test pieces. This minimizes the failure of grip. After a light clamping of the test pieces, the test machine was made on to start test. Then, during the time of testing, tightening of the test pieces was made. If it would have been fixed totally before the testing started, initial compression force would be applied to the test specimen and causes buckling of the test pieces which make out of use. But this causes slippage when the axial force acts on the specimen.

Table 1- Tensile test specimen for bamboo and steel

Specimen Code	Shape	Sample Position	Cross- section in mm	Cross sectional area in mm <sup>2</sup>
T <sub>1</sub> SC <sub>1</sub>	Circular		10	78.5
T <sub>2</sub> SC <sub>2</sub>	Circular		10	78.5
T <sub>3</sub> BC <sub>1</sub>	Circular	With node	10	78.5
T <sub>4</sub> BC <sub>2</sub>	Circular	Without node	10	78.5
T <sub>5</sub> BS <sub>1</sub>	Square	With node	10 × 10	100
T <sub>6</sub> BS <sub>2</sub>	Square	Without node	10 × 10	100
T <sub>7</sub> BT <sub>1</sub>	Triangular	With node	10 × 10	50
T <sub>8</sub> BT <sub>2</sub>	Triangular	Without node	10 × 10	50

Table 2- Summary of material proportion per meter cube

Water	200Kg/m <sup>3</sup>
W/C	0.55
Cement	364Kg/m <sup>3</sup>
Fine aggregate	530Kg/m <sup>3</sup>
Coarse aggregate	1200Kg/m <sup>3</sup>



**Preparation of Bamboo**

The bamboo was cut with sharp saw. During cutting great care was taken not to split the specimen, because splitting will result in continuous tearing of fiber. For test purpose I have cut three shape of bamboo one is circular and second is square and third is triangular cross-section. Length of each specimen were 670 mm, average diameter of circular bamboo were 10 mm, average cross of square bamboo were 10×10 mm and size of triangular bamboo were 10 mm base×10mm height. After selecting and sizing, water proof coating is applied because it reduces swelling when the bamboo contacted with concrete. Without coating, bamboo will swell before the concrete has developed sufficient strength to prevent cracking and the member may be damaged. The bamboo reinforcement was coated with varnish to prevent water absorption during construction and curing which may otherwise crack the beam due to swelling of bamboo. A thick coating will lubricate the surface and weaken the bond between the concrete and bamboo.

**Swelling of Bamboo**

The determinations of swelling were made according to ISO 22157-1 standard as shown in Table-3. Based on this standard, the determination was made by taking inter nodal full bamboo culms section near the test specimens, which has a height of 1000mm. To compute the swelling, recording of outer diameter D and height h of the specimen before and after wetting were carried out. Then the radial swellings were calculated as follow:

$$Sw(\%) = \frac{I - F}{I} \times 100$$

Where ,

Sw= swelling in %

I= Initial reading of average diameter

F= Final reading of average diameter

Table 3- Percentage swelling of bamboo

Sample (Bamboo)	Point	Initial Circumference in mm	Final Circumference in mm	Sw(%)
Circular	1	40	41	2.5
	2	43	44	2.32
	3	40	41	2.50
	4	43	44	2.32
	5	36	37	2.77
Rectangular	1	40	41	2.50
	2	46	46	0.00
	3	39	40	2.56
	4	39	40	2.56
	5	41	42	2.44
Triangular	1	37	37.5	1.35
	2	44	45	2.27
	3	37	38	2.70
	4	36	37	2.77
	5	38	38	0.00



**Moisture Content**

The mechanical property, moulds attack and durability of bamboos are highly related to the moisture content. As the moisture content reduces the strength of the element increase and less prone to moulds attack. The moisture content of the bamboo was determined according to ISO 22157-1 and 2, tabulated in Table-4. The specimen for moisture content was prepared for each mechanical specimen immediately after test near the place of failure. The test pieces have an average width of 10mm, a length of 1000mm.

The moisture content of a test piece is calculated as the loss in mass, expressed as a percentage of the oven dry mass, according to the Equation below.

$$MC(\%) = \frac{m_0 - m}{m} \times 100$$

Where;

MC = moisture content in %

m<sub>0</sub> = the mass of the specimen before wetting

m = the mass of the test specimen after wetting

Table 4- Moisture content in bamboo

Sample (Bamboo)	Initial weight in Kg	Final weight in Kg	MC(%)
Circular	0.0846	0.1083	28.01
Rectangular	0.0849	0.1073	26.38
Triangular	0.0611	0.0755	23.56

**Beam Design**

Since it is the purpose of this research to determine the feasibility of the use of bamboo as reinforcement in concrete, it is necessary to compare its behaviours to steel, the traditional reinforcement. Therefore beam designs were in accordance Limit State Method, by using IS 456 (2000) code. For this purpose we have designed beam with singly reinforced in under reinforced condition. Size of the beam were 15cmx15cmx70cm and used M20 concrete, effective cover from bottom are 25mm and from side 15mm. Detailing of reinforcement has been tabulated in Table-5.

Table 5- Detailing of reinforcement in tabular form

Sample	Cross- section of reinforcement in mm	Area in mm <sup>2</sup>	Number of reinforcement
Mild steel (circular)	10	314	4
Circular bamboo	10	471	6
Square bamboo	10 × 10	500	5
Triangular bamboo	10 × 10	500	10

For resisting the shear force in each beam provide:

Diameter of stirrups= 6mm, 2 legged

Number of stirrups= 8

Spacing of stirrups= 95mm

**Compressive Strength of Concrete**

Out of many test applied to the concrete, this is the most important which gives an idea about all the characteristics of concrete. By this single test one judge that whether concreting has been done properly or not. For cube test two types of specimens either cubes of 15cmx15cmx15cm or 10cmx10cmx10cm depending upon the size of aggregate are used For most of the works cubical moulds of size 15cmx15cmx15cm are commonly used. This concrete is poured in the mould





and tempered properly so as not to have any voids. After 24 hours these moulds are removed and test specimens are put in water for curing. The top surface of these specimens should be made even and smooth. This is done by putting cement paste and spreading smoothly on whole are of specimen.

These specimens are tested by compression testing machine after 28 days curing. Load should be applied gradually at the rate of 140kg/cm<sup>2</sup> per minute till the specimens fails. Load at the failure divided by area of specimen gives the compressive strength of concrete has been shown in Table-6.

Table 6- Compressive strength of concrete

Sample	Size of cube in mm	Area in mm <sup>2</sup>	Force in KN	Compressive strength in Mpa
1	150 × 150 × 150	22500	480	21.33
2	150 × 150 × 150	22500	465	20.67
3	150 × 150 × 150	22500	485	21.55
4	150 × 150 × 150	22500	500	22.22
5	150 × 150 × 150	22500	490	21.78
6	150 × 150 × 150	22500	460	20.44

### III. EXPERIMENTAL RESULTS

#### Tensile Strength Result

The tensile test carried out with UTM machine with a constant rate of 1N/mm<sup>2</sup> and then drawn stress- strain curve, from this tensile strength and the modulus of elasticity were analyzed. Finally, flexural tests were made by varying the cross-section of bamboo and different number of treated bamboo reinforced concrete beams to investigate the feasibility of bamboo as reinforcement and see the effect of treatment. The two point bending test used as a load that was applied at a steady rate and then drawn the load verse deflection graph.

Test designations were done by starting with “T” to represent tensile test number followed with bamboo or steel and then the shape of bamboo or steel indicated in each case. For example:- T<sub>1</sub>BS<sub>1</sub> represents tensile test number one with bamboo reinforcement which is square in shape. Stress- strain curve for various bamboo samples has been shown in Fig. 1

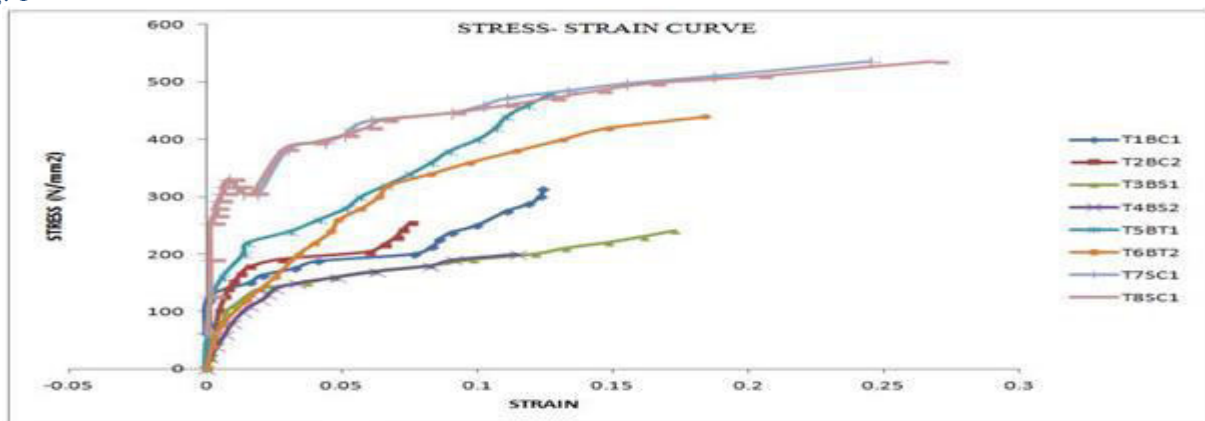


Fig. 1- Stress-Strain curve for various bamboo samples

**Result of Flexural Strength**

A Two- point bending test was conducted on all beam specimens. Flexural failure and shear failure of beam specimens has been shown in Fig. 2 and Fig. 3 respectively.



Fig. 2- Flexural failure of beam with circular and triangular bamboo as reinforcement



Fig. 3- Shear failure of beam with mild steel as reinforcement and beam after crack

**IV. DISCUSSION**

The effect of using of different cross-section of bamboo as reinforcement of partial replacement of steel reinforcement was investigated in terms of tensile strength of bamboo and mild steel, ultimate load on beam, flexural strength and shear strength. The results were summarized in tabular form.

**Tensile Strength**

Bamboo were tested with different cross-section one is circular, second is square and third is triangular, each cross-section of specimens was tested by considering one with node and second without node.

**Comparison of Two- Point Bending Beam Test**

**Average value of different types of beams**

Test designations were done by starting with “B” to represent beam followed with bamboo or steel and then the shape of bamboo or steel indicated in each case. For example:- BBS represents beam with bamboo reinforcement which was square in shape. Comparison of average ultimate load and average deflection of different beam specimens and variation of average flexural strength and shear strength of different beam specimens have been shown in Fig. 4.

From Fig. 4, it is clear that ultimate load in BBS is 0.697 times less than BSC, average ultimate load in BBC is 0.61 times less than BSC and average ultimate load in BBT is 0.53 times less than BSC. Average deflection at ultimate load in BBS is 0.43 times less than BSC, average deflection at ultimate load in BBC is 1.42 times more than BSC and average deflection at ultimate load in BBT is 1.08 times more than BSC.

From Fig. 5, it is clear that average flexural strength in BBS is 0.70 times less than BSC, average flexural strength in BBC is 0.58 times less than BSC and average flexural strength in BBT is 0.50 times less than BSC. It is clear that average shear strength in BBS is 0.68 times less than BSC, average shear strength in BBC is 0.55 times less than BSC and average shear in BBT is 0.46 times less than BSC.

Load-deflection curve of bamboo reinforced beam and RCC beam for average dial gauge reading has been shown in Fig. 5

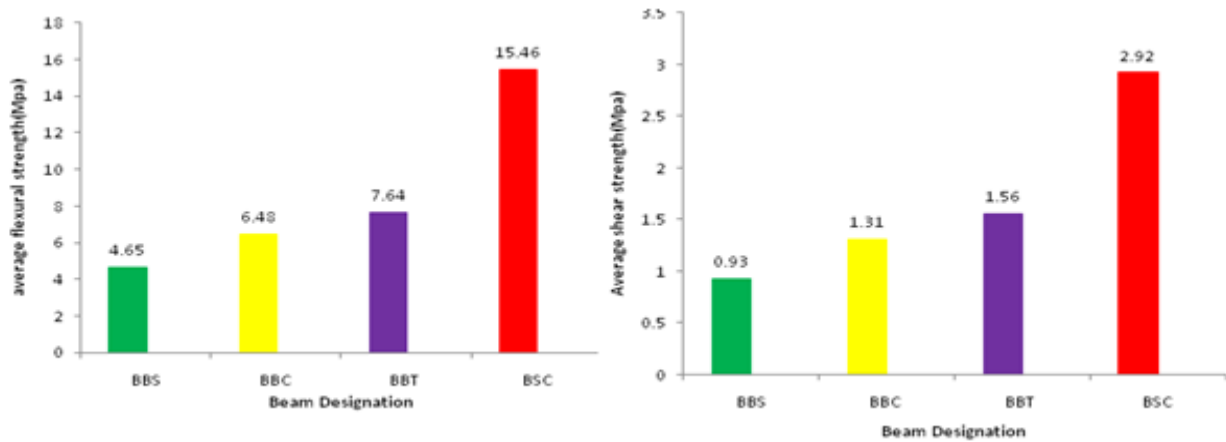


Fig. 4 -Variation of average flexural strength and shear strength of beam

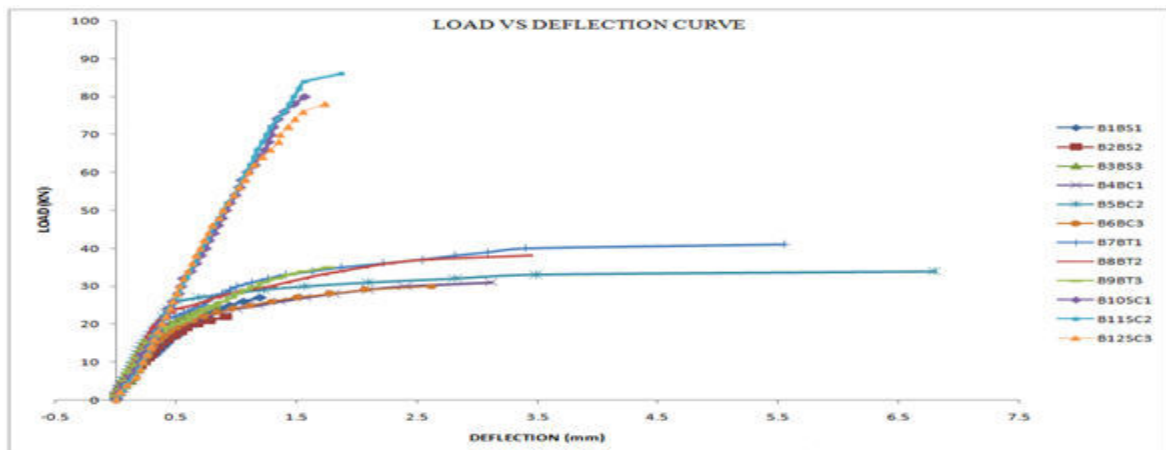


Fig. 5- Load-deflection curve for all beam samples

**Discussion of Test Results obtained**

Reinforced concrete members carry load and respond to these loads by bending. The moment-curvature relationship for a segment of the simply supported concrete member can be used for understanding the situation. During the test it was seen that reinforced concrete specimen remains uncracked and have a large stiffness until the moment reaches the cracked moment. When the cracking moment is reached, the member cracked and the stiffness at the cracked section is reduced. As the load (and hence the moment) is increased further, more cracks occurred and existing cracks increased in size. Eventually, the reinforcement yielded. After reaching the yield load, the member displayed large increase in deflection for small increase in load (moment). In the reinforced concrete members, the flexural strength relies on the surface of tensile force, commonly known as bond, between the longitudinal reinforcement and the surrounding concrete. The quality of the bond depends on the surface pattern of the bar, the dimension of the member and the position and inclination of the bars. Bond is achieved by the combination of adhesion and a small amount of friction between two materials.

**V. CONCLUSION**

On the basis of experimental results, the following conclusions have been drawn.

1. The load carrying capacity of the beam using triangular cross section of bamboo as reinforcement was higher than that of beam with circular and square cross section of bamboo as a reinforcement. From test it was found that average first load in BBS is 0.70 times less than BSC, average first crack load in BBC is 0.653 times less than BSC and average first crack load in BBT is 0.572 times less than BSC and ultimate load in BBS is 0.697 times less than BSC and average ultimate load in BBT is 0.53 times less than BSC.



2. Average deflection of beam with square cross section of bamboo as a reinforcement was less as compared to beam with triangular and circular cross section of bamboo as reinforcement. This indicating that square cross section of bamboo is in more ductile manner. From test it was found that average deflection at first crack in BBS is 0.52 times less than BSC, average deflection at first crack in BBC is 0.43 times less than BSC and average deflection at first crack in BBT is 0.159 times less than BSC and average deflection at ultimate load in BBS is 0.43 times less than BSC, average deflection at ultimate load in BBC is 1.42 times more than BSC and average deflection at ultimate load in BBT is 1.08 times more than BSC.
3. The constitutive relationship of the nodes differs from those of intermodal regions with nodes having a brittle behavior while intermodal regions exhibit a more ductile behavior.
4. The waterproofing agent chosen provided poor bonding. Bond-enhancing applications should be required to strengthen the bonding between the concrete and bamboo.
5. Based on the limited number of testing conducted, it was concluded that bamboo can potentially be used as substitute steel reinforcement. However, for regions of the world that availability of steel is limited and plain concrete members are commonly being used, the use of reinforcement bamboo concrete is highly recommended.
6. The breaking patterns of the tensile tests were overall inconclusive. However, there was an indication that the fracture points of the tensile samples containing nodes occurred at the nodes, which was also verified in the beam tests.
7. The failure load patterns of the tensile samples were overall inconclusive. However, the samples with nodes generally failed at higher loads than those samples without nodes.
8. Flexural strength was more in beam with triangular cross section of bamboo reinforcement as compared to that of beam with square and circular cross section of bamboo reinforcement. From test it was found that average flexural strength in BBS is 0.70 times less than BSC, average flexural strength in BBC is 0.58 times less than BSC and average flexural strength in BBT is 0.50 times less than BSC.
9. Shear strength was more in beam with triangular cross section of bamboo reinforcement as compared to that of beam with square and circular cross section of bamboo reinforcement. From test it was found that average shear strength in BBS is 0.68 times less than BSC, average shear strength in BBC is 0.55 times less than BSC and average shear strength in BBT is 0.46 times less than BSC.

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