Performance Evaluation of Bamboo Reinforced Concrete Beam

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***Abstract*— Traditionally steel is used as reinforcement in concrete. But because of cost and availability, replacement of steel with some other suitable materials as reinforcement is now a major concern. Though bamboo has been used as a construction material, especially in developing country, until today its use as reinforcement in concrete is very limited due to various uncertainties. Since bamboo is a natural, cheap and also readily available material, it can be a substitute of steel in reinforcing of concrete. In this paper, aptness of bamboo as reinforcement in concrete will be evaluated. To assess this, tensile strength test of bamboo having three and five nodes are performed. 1 m bamboo sticks of varying cross sections are used in this test. Also flexural strength test of bamboo reinforced beam is done to characterize the performance of bamboo as reinforcement. Singly and double bamboo reinforced beams of 750 mm length having 150 mm width and depth are compared with plain concrete beam to carry out in this test.**

***Index Terms*— Bamboo Reinforcement, Tensile Strength, Flexural Strength, Deflection**

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, environmental 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. Bamboo is natural, cheap, widely available and most importantly strong in both tension and compression. The tensile strength of bamboo is relatively high and can attain 370 MPa [1], 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 [2]. Bamboo is also an environmental friendly plant because it absorbs a lot of nitrogen and carbon dioxide in the air [3].

In this paper, tensile property of bamboo is observed and evaluation of the use of bamboo as reinforcing bar in concrete with replace of steel is done.

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II. Materials Properties

A. Cement

In concrete mix, Ordinary Portland Cement was used in this project. Some physical and chemical properties of that cement are shown in Table I & II, which were collected from the cement manufacturer.

TABLE I
PHYSICAL PROPERTIES OF CEMENT

Description		ASTM Standard Requirement	Test Result
Fineness	Sieve No. 200 residue (%)	-	1.84
	Blaine (m^2/Kg)	280	321.9
Setting Time	Consistency (%)	-	27.30
	Initial Setting (min)	Not Less Than 45 min.	155
	Final Setting (min)	Not More Than 375 min.	260
Compressive Strength (MPa)	Age (Day)	MPa	MPa
	3	Min 12	21.20
	7	Min 19	28.43
	28	Min 28	41.92

TABLE II
CHEMICAL COMPOSITION OF CEMENT

Components	%
SiO_2	35.84
Al_2O_3	4.23
Fe_2O_3	2.68
CaO	49.13
MgO	1.8
SO_3	1.49
F/CaO	1.06
IR	0.62
LOI	2.56
Sum	99.41

B. Fine aggregate

In this research wok, local sand was used as fine aggregate. Determination of fineness modulus of fine aggregate was performed according to ASTM C136 [4]. Fine aggregate was in surface saturated dry (SSD) condition and the FM value was found 2.69.

C. Coarse aggregate

Crushed stone was used as coarse aggregate in sample beam preparation. The maximum aggregate size of coarse aggregate was 20 mm. Gradation of coarse aggregate was performed according to ASTM C136 [4]. Coarse aggregate was in surface saturated dry (SSD) condition. The Gradation Curve for Coarse Aggregate is shown in figure 1.

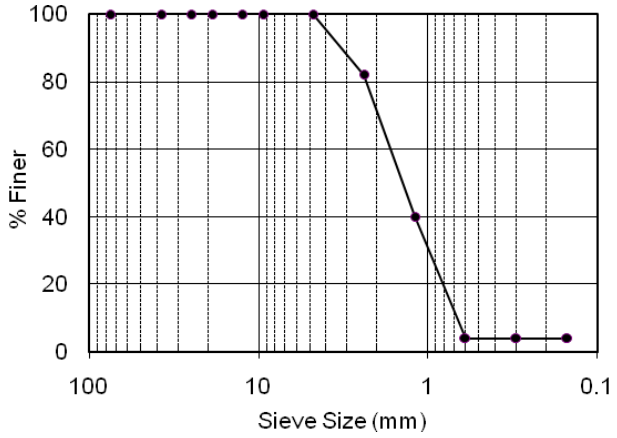

Fig. 1. Gradation Curve. This curve shows the gradation of course aggregate used.

D. Bamboo

Bamboo culms are cylindrical shells as shown in Figure 2, and are divided by nodes as solid transversal diaphragms. The strength distribution is more uniform at the bottom of bamboo than at the top or at the middle of it since it is subjected to maximum bending stress due to wind at the top portion of the culms [1].

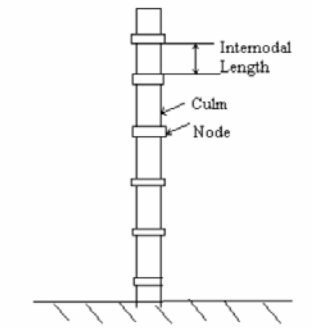

Figure 2 Whole Bamboo Culm [5]

The following criteria should be considered in the selection of bamboo culms (whole plants) for use as reinforcement in concrete structures:

1. At least three years old plant should be used showing a pronounced brown color.
2. The longest large diameter culms available should be selected.
3. Whole culms of green, unseasoned bamboo should not be used.
4. Bamboo cut in spring or early summer should be avoided since they are generally weaker due to increased fiber moisture content.

In this research, three year old bamboo plants of pronounced brown color were selected. Samples of each of 1 m were collected from the bottom of the plant having three and five nodes.

III. SAMPLE PREPARATION

A. Bamboo Sticks

Bamboo sticks are generally more popular than whole culms in construction works. After cutting the bamboo plant, it should be allowed to dry and season for three to four weeks before using.

In order to conduct the tensile strength test, it was necessary to prepare the bamboo sample. To prepare the sample, bamboo sticks of 1m length and around 20 mm width were cut and allowed to dry and season for 30 days as shown in figure 3.

Figure 3. Bamboo Specimen

The thickness of the sample varies throughout its length since it is a natural material whose properties cannot be controlled strictly. The dimensions were measured at five points along the length of the sample to calculate the average dimension of the sample. During the period of season, all bamboo sticks were supported at regular interval to prevent warping.

B. Concrete Mix Design

The concrete to be used in the beams was made using Ordinary Portland Cement, sand as the fine aggregate and

stone chips as coarse aggregate with a maximum size of 20 mm. the concrete mix proportion was 1:1.5:2.8 by volume and a water cement ratio of 0.52. The mix was designed for 25 MPa at 28 days strength and slump value was found of 50 to 70 mm.

C. Cylindrical Specimen

The resulting concrete was poured in cylindrical moulds of 150 mm diameter and 300 mm height. After casting, the concrete samples were kept in wet place and demoulded at 24 hours age. They were submerged in open water tank for curing up to 28 days as required for the test.

D. Beam Specimen

Concrete was poured in moulds of 150 mm width, 150 mm depth and 750 mm length. In this research, three types of beam were used namely plain concrete beam, singly reinforced beam and doubly reinforced beam having same dimensions. In plain concrete beam, no bamboo stick was used. Two bamboo sticks were placed at the bottom with 1 inch clear cover in singly reinforced beams. Similarly, two bamboo sticks were placed at the top and bottom with 1 inch clear cover in the case of doubly reinforced beams. Figure 4 and 5 show the dimensions and cross section of sample beams.

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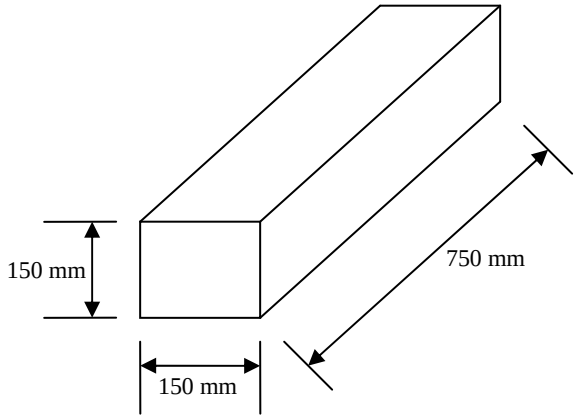

Figure 4. Dimensions of Sample Beam

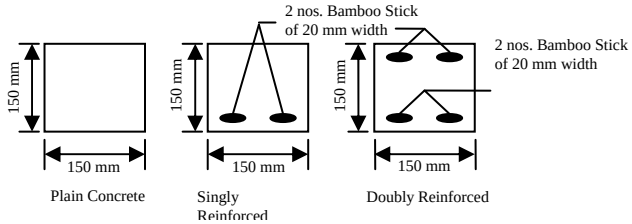

Figure 5: Cross-Section of Sample Concrete Beam with and without Bamboo Reinforcement

After 24 hours, samples were demoulded and submerged in open water tank for curing for 28 days as required for the test.

Curing for cylindrical and beam specimen was not performed at a constant temperature. The averages of three days temperatures are shown in table 3.

TABLE III
CURING TEMPERATURE

Days	Temperature (^{0}C)	
	8 AM	5 PM
1-3	28.0	29.2
4-6	28.7	30.1
7-9	30.2	30.6
10-12	28.5	31.1
13-15	29.4	32.3
16-18	27.9	30.5
19-21	30.3	32.4
22-24	29.2	31.8
25-27	28.6	30.2

IV. EXPERIMENTAL PROGRAM

In addition to the strength test of the cylindrical concrete specimens, sieve analysis for each material was also examined. Tensile strength test of bamboo stick and flexural strength test of beam were performed in this project. The testing procedures are summarized in this section.

A. *Compressive Strength Test*

Compressive strength test of cylindrical concrete specimen of 150 mm diameter and 300 mm height was performed according to ASTM C 39 [6].

Cylindrical specimens were tested at 28 days using Universal Testing Machine at a constant loading rate. In order to ensure uniform loading on the cylinder, each Specimen was capped with sulfur. The maximum strength of each specimen was recorded and the average of three samples was considered the compressive strength at the specific day.

B. *Splitting Tensile Strength Test*

Splitting tensile strength test of cylindrical concrete specimen of 150 mm diameter and 300 mm height was done according to ASTM C 496 [7].

A cylinder was placed along its long side and tested at 28 days using Universal Testing Machine at a constant loading rate. Three bearing rods were used to distribute the load applied along the length of the cylinder. The maximum load sustained by the specimen was divided by appropriate geometrical factors to obtain the splitting tensile strength. The maximum strength of each specimen was recorded and the average of three samples was considered the splitting tensile strength at the specific day.

C. *Tensile Strength Test of Bamboo Stick*

The tensile strength test was performed using Universal Testing Machine (UTM) as shown in figure 6. Specimen was placed in UTM and tensile load was being applied until rupture. Elongation was measured at regular interval of applied tensile load.

Fig. 6. Tensile Strength Test of Bamboo Stick.

D. *Flexural Test of Beam:*

The beam was carefully placed under the testing machine and supports were placed at the measured location of 125 mm inside from each end. Dial gauges are also provided at midspan to calculate the deflection. After placing the beam, one point loading at the midspan of the beam was applied gradually by controlled pumping unit. The deflection of the beam at midspan was measured at regular interval of loading. Figure 7 illustrates the test setup.

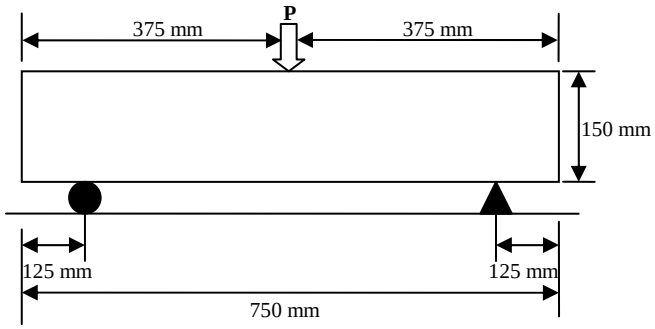

Fig. 7: Test Setup for Flexural Test of Beam

V. RESULTS AND DISCUSSIONS

A. *Compressive and tensile strength of concrete*

Table IV shows the compressive strength and tensile strength test results of cylindrical concrete of 150 mm diameter and 300 mm height for 28 days.

TABLE IV
COMPRESSIVE AND TENSILE STRENGTH OF CYLINDRICAL SAMPLE

Sample No.	Compressive Strength	Average Compressive Strength	Tensile Strength	Average Tensile Strength
	(MPa)			
1	25. 34		2.67	
2	24.38	24.74	2.79	2.77
3	24.50		2.84	

B. *Tensile strength of bamboo sticks*

The first set of tensile tests was conducted on bamboo samples having 3 nodes and second set of tensile tests was conducted on bamboo sticks having 5 nodes. During these tensile tests, all tensile specimens were failed at node point. Table V shows the tensile test results of different tensile bamboo specimens.

TABLE V
TENSILE STRESS OF BAMBOO SPECIMEN

Sample No.	No. of Node	Area	Weight	Ultimate Load	Stress	Average Stress
		(mm^2)	(gm)	(kN)	(MPa)	(MPa)
1		201.4	160.0	23.87	118.52	
2	3	257.3	217.2	28.53	110.88	110.66
3		229.7	171.0	23.56	102.57	
1		251.6	181.5	24.39	96.94	
2	5	274.6	223.0	29.35	106.88	102.54
3		260.1	201.0	27.00	103.81	

From Table V, it can be seen that all specimens are not of same properties such as area as well as weight since bamboo is a natural material. There is also no significant change in stress because of number of node present in bamboo specimen. So, average stress can be taken as about 105 MPa, neglecting the presence of node.

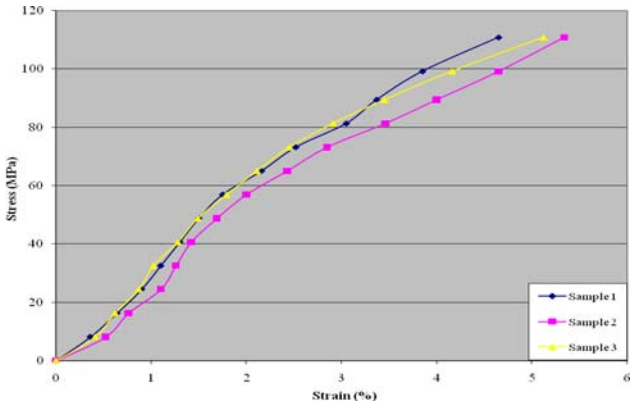

Fig. 8. Stress Strain Diagram for Bamboo Sticks with 3 Nodes.

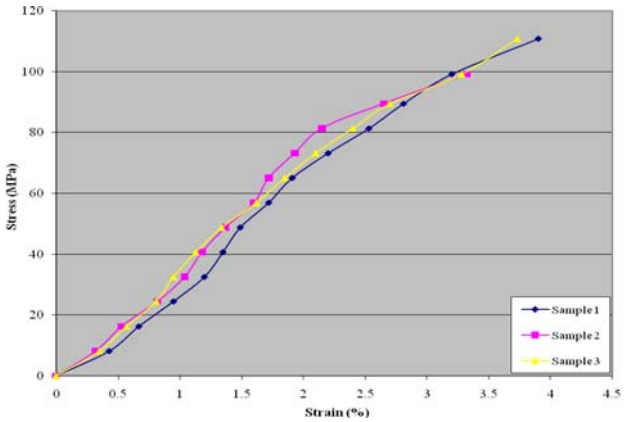

Fig. 9. Stress Strain Diagram for Bamboo Sticks with 5 Nodes.

From figure 8 and 9, it can be seen that all samples exhibit almost same trend lines. Though there is a moderate variation in the total strain in percent, maximum stress is almost same for all three samples.

C. *Flexural Strength of beam:*

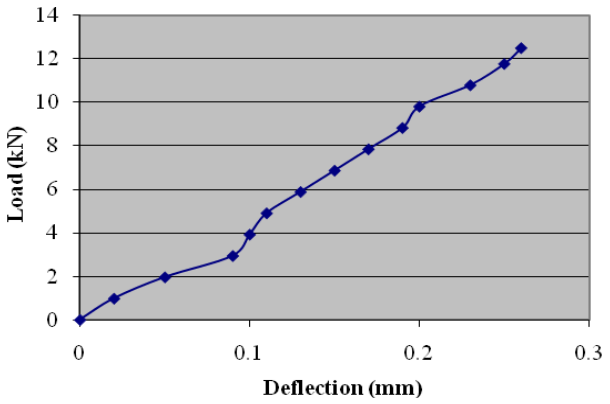

Fig. 10. Load-Deflection Curve for Plain Concrete Beam

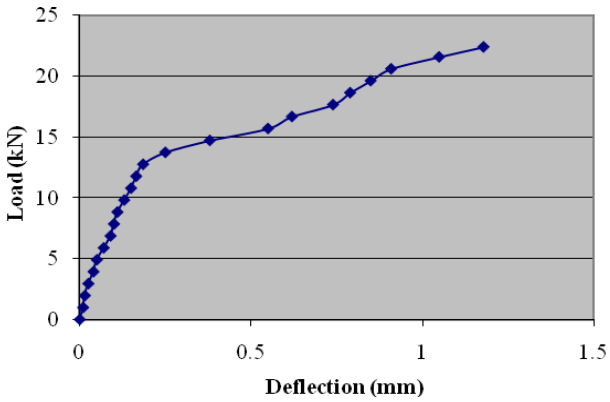

Fig. 11. Load-Deflection Curve for Singly Bamboo Reinforced Concrete Beam.

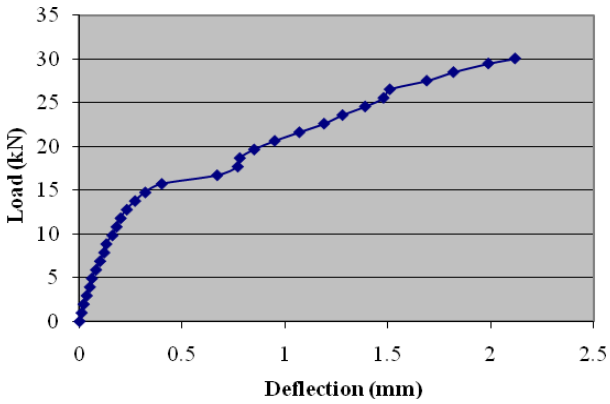

Fig. 12. Load-Deflection Curve for Doubly Bamboo Reinforced Concrete Beam.

Table VI shows the ultimate load carrying capacity and maximum deflection of plain concrete beam (PC), Singly Reinforced Beam (SR) and Doubly Reinforced Beam (DR) at 28 days of the average of three samples.

TABLE VI
ULTIMATE LOAD CARRYING CAPACITY AND MAXIMUM DEFLECTION OF BEAM SPECIMENS

Sample ID	Ultimate Load (kN)	Maximum Deflection (mm)
PC	12.5	0.26
SR	22.4	1.18
DR	30.0	2.12

VI. CONCLUSIONS

This work provides bamboo as a potential reinforcement in concrete. From stress-strain curves of bamboo, it can be seen that bamboo possesses low modulus of elasticity compared to steel. So, it cannot prevent cracking of concrete under ultimate load. But from the flexural test of bamboo reinforced beam, it has been seen that using bamboo as reinforcement in concrete can increases the load carrying capacity of beam having the same dimensions. For singly bamboo reinforced concrete beam, the load carrying capacity increased about 2 times and that for doubly bamboo reinforced concrete beam about 2.5 times than that of plain concrete beam having same dimensions. The maximum deflection of singly reinforced beam and doubly reinforced beam are about 4.5 and 8 times respectively than that of plain concrete.

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