INVESTIGATION ON PROPERTIES OF BAMBOO AS REINFORCING MATERIAL IN CONCRETE

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ABSTRACT
The indiscriminate infrastructural growth is leading to rapid environmental degradation. Steel, cement, synthetic polymers and metal alloys used for construction activities are energy intensive as well as cause environmental pollution during their entire life cycle. In order to quantify the energy and CO_2 savings potential by applying best available technologies like vegetable fibers including bamboo, wastes from industry and mining etc., for engineering applications. In this paper an attempt has been made for finding bamboo as reinforcement in concrete by determining the various physical and mechanical properties of bamboo. The investigations conducted for the tested types of bamboo are evaluated using the same accept criteria as that of steel. This study investigates the Moso type bamboo tensile stress, compressive stress, Modulus of Elasticity, Water absorption capacity, Shear stress, and bonding stress. In general the strength of bamboo is as high as mild steel while, their density is as low as carbon fiber. In this investigation two types of Moso Bamboo specimens were considered. First type of specimen contains node at middle and second type of specimen contains nodes at $1/4^{th}$ of length from each end. Tensile, Compressive, Shear and Bond tests for bamboo specimens were conducted on U.T.M and C.T.M the relevant graphs were drawn and are compared with graphs obtained for standard steel.

Keywords **-** Bamboo, Concrete, Nodes, Reinforcement, Steel, Stress.

1. INTRODUCTION

Globally, the iron and steel sector is the second largest industrial user of energy, consuming 616 Millions of tonnes of oil equivalent (Mtoe) in 2007, and the largest industrial source of Carbon dioxide (CO_2) emissions with 2.3 gigatonnes of CO_2 (Gt CO_2). India's iron and steel sector is the largest industrial user of energy in India, consuming 38 million tonnes of oil equivalent (Mtoe) in 2007. It is also the largest industrial source of carbon dioxide (CO_2) emissions with 151 million tonnes of CO_2 (Mt CO_2) [1].

There is urgency need for using naturally occurring products as a construction material to decrease the growth of energy consumption and CO_2 emissions replacement of bamboo in place of steel is widely recognized as one of the most important non-timber forest resources because of the high tensile strength and socio-economic benefits with bamboo based products. Bamboo has been used as a construction material in certain areas for centuries. As a result, many researchers have been trying to find on non-polluting and eco-friendly materials. Recently bamboo was consider to make use as a reinforcement material as it behave in-elastically even in light loads. This experimental research is focused on the use of bamboo as a reinforcing material instead of steel reinforcement in concrete. Bamboo is seismically resisting material and for sustainable environment development without harming our global environment since it absorbs a lot of nitrogen and carbon dioxide from the atmosphere during its growth [2].

2. MATERIALS
Bamboo culms, Water proofing agent, Steel bars, Cement, Aggregate, Cement and Water are used in this investigation.

2.1 Bamboo
Bamboo is a tall grass, fast-growing and typically woody. The bamboo plant is a complex system, consisting of two sets of similarly structured vegetative axes: one above the ground and the other below the ground and the features are shown in Fig 1.The portion between two successive nodes is called an internode. Internodes are invariably, but not always, hollow. They are covered by sheaths at the initial stages of growth, which fall off as the plant matures. The inter-nodal length varies considerably across bamboo species, ranging from 5 to over 60 centimetres. In general, the inter-nodal length increases upwards along the culm from the lower portion to the middle, and then decreases as shown in Fig 1. Mainly cross section of bamboo has fibres from which the mechanical properties of bamboo vary. The properties may vary based on the nature of growth, climatic conditions and soil moisture condition [3].

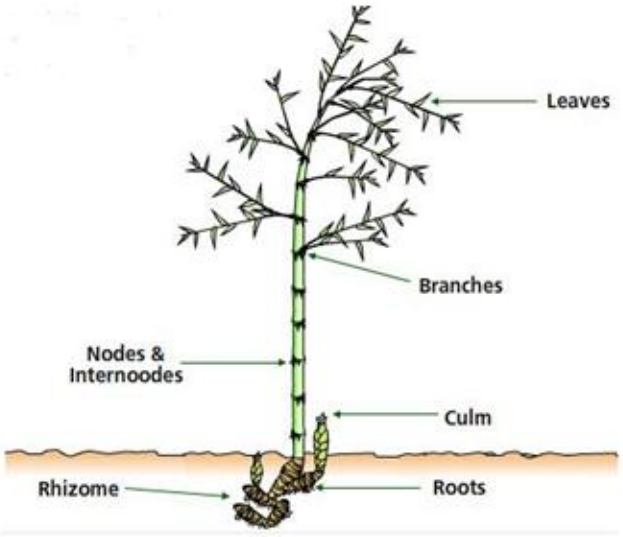

Fig. 1 Structure of Bamboo Plant

Table 1 presents the details of different types of Genus, number of species of bamboo and their occurrence.

Table 1 Genera and number of Species of Bamboos naturally occurring and cultivated in India [4]

S.No.	Genus	Naturally occurri	Introduced/cultivated	Total No. of species
1	Arundinaria	2	0	2
2	Bambusa *	12	14	26
3	Chimonobambus	1	0	1
4	Dendrocalamus *	7	8	15
5	Dinochloa	5	1	6
6	Gigantochloa	2	5	7
7	Melocanna	0	2	2
8	Ochlandra	9	0	9
9	Oxytenanthera	1	1	2
10	Phyllostachys	2	3	5
11	Pleioblastus	1	0	1
12	Pseudosasa	0	1	1
13	Pseudoxytenanth	4	0	4
14	Racemobambos	3	0	3
15	Schizostachyum	17	1	18
16	Sinarundinaria	18	3	21
17	Thamnocalamus	3	0	3
18	Thyrsostachys	0	2	2
	Total	**87**	**41**	**128**

*Locally available bamboo species used in the present study

Selection and Preparation of Bamboo:

The brown colour bamboos are selected, which indicates that the plant is at least three years old [5]. Longest and large diameter culms are selected based on availability. In the preparation of bamboo the culms should be seasoned and split. The culms should be well seasoned before use so that sweetness of the bamboo will be lost and insect attacks will be minimised which is used for construction [6]. The bamboo culms are split or cut by means of hand knife or machine splitting equipment. The bamboos split in to required dimensions based on use called as moso bamboo used in present study.

2.2 Water proof material

When bamboo is used as reinforcement in concrete it gets swelling; it should receive a waterproof coating to minimise swelling. "ALGICOAT RC-104" is used as a water proofing agent in present research.

2.3 Steel bars

HYSD bars are used in this study, for determining bond stress. These values are compared with bamboo bond stress as per IS-456:2000 specifications.

2.4 Concrete

M-30 grade mix concrete used in the present study as per IS-456:2000 specifications. The concrete mix proportion (cement: fine aggregate: course aggregate) is 1:1.5:3 with a 0.54 water-cement ratio for cast cylinders for pull out test.

3. EXPERIMENTAL PROGRAM

Physical and mechanical properties of bamboo as reinforcement are determined. The properties are purely based on the requirements of reinforcement in concrete.

3.1Physical Properties of Bamboo

Brown coloured bamboo specimens were selected and the length, weight, diameter, nodes were determined. The physical properties of bamboo culms are tabulated in table 2.

3.2 Mechanical Properties of Bamboo

The mechanical properties are very important for using any material in construction and design. Mechanical properties of bamboo were determined by conducting the following tests:
(1) Tensile test, (2) Modulus of Elasticity 'E', (3) Compressive test (4) Pull-out test, (5) Shear test and (6) Water absorption test.

3.2.1 Tensile Test

Moso type of Bamboo samples of length 600mm was used. Three types of specimens are used, first type with centre node, second type specimens contains nodes at 1/4th of length from each ends and third type of specimen contains random nodes. The test procedure followed for bamboo is same that of steel. Load and elongation readings for sample placed in UTM are recorded.
The relevant Stress Strain graph were developed as shown is the Fig 5 Ultimate stress values for different specimens obtained are tabulated in in Table 3.

3.2.2 Modulus of Elasticity

Modulus of elasticity test procedure followed for moso bamboo is same as that of steel. Two types of moso bamboo specimens of length 600mm are used for test, first type of specimen with centre node and second type of specimen contains nodes at 1/4th of length from each end. The samples are placed in setup for simply supported action and loads were applied at centre and deflections are recorded at 1/3rd and 1/4th form any one direction of sample. Considering Load Vs. Deflection graphs and simply supported beams deflection formula, modulus of elasticity of bamboo were determined and the results are tabulated in Table 4.

3.2.3Compressive Test

The Hollow culms of 152mm length are cut for compressive test. Three different types of specimens are selected for the test. The first type of specimens contains central node; second type contains end node and third type without nodes. The dimensions of samples are measured and samples were placed in compressive testing machine of capacity 2000KN. The load is applied parallel to fibers of bamboo in gradual increments until the sample failure. From the ultimate load, compressive strength is determined.

3.2.4 Pull-out Test

The measure of the bond strength or interfacial strength between the bamboo and a concrete can be found in this test [7]. Also comparison between bamboo reinforced concrete and steel reinforced concrete are made as per requirement according to IS-456:2000 standards and requirements. Moso type bamboo of 1000mm length each and area based on cross section of bamboo are used. Concrete cylinders of size 150mm dia and 300 length are used for the test. Three types specimens of uncoated bamboo, water proofing material coated bamboo and HYSD steel bars of 8mm dia are used for this test. Concrete of M - 30 grade with 1:1.5:3 (cement, fine aggregate and course aggregate). The bamboos specimens were placed at centre in concrete cylinders while casting. Three samples are prepared for each specimen by varying bond length until the specimen comes out of concrete by means of bond and not by tension while testing. Bond length (L_b) is the length of bamboo which is in contact with concrete in cylinder as shown in Fig 2. The samples were tested after 28 days of curing are tested in universal testing machine of capacity 400KN. The ultimate load is recorded. The test results are tabulated in Table 5. The bond stress is determined from ultimate load using following formula.

$$\text{Bond stress} = z_{bd} = \frac{P}{\pi d L b}; \qquad \text{Units are in N/mm}^2$$

Where 'P' is the ultimate load at failure, 'd' is the diameter of specimen and L_b is the length of bonding.

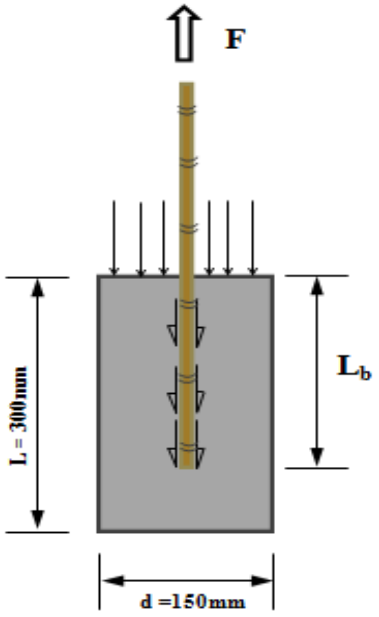

Fig. 2 Schematic diagram of specimen

3.2.5 Shear Test

The samples used for shear test are moso bamboo of 50mm length. Three different types of specimens, the first with central node, second type with end node and third type of specimens without nodes are used in this test. The test procedure followed for bamboo is same as that of steel. The shear shackle used is of double shear action the test is called as double shear test. The test setup consists of placing shear shackle in Universal Testing Machine (UTM) of 400KN capacity and load is applied gradually until the specimen fails as shown in Fig 3. The ultimate load at failure is noted. Shear Stress is determined using formula given below from ultimate load and results are tabulated in Table 6.

$$\text{Shear stress} = V = \frac{\text{Load}}{2 \times \text{Area}} = \frac{P}{2 \times A}$$

Fig. 3 Test setup of Shear shackle arrangement in U.T.M

3.2.6 Water absorption Test

Six samples of uncoated moso bamboo with 1 and 2 nodes samples with different dimensions were selected for determining water absorption capacity. Dry weights of samples were noted and placed in water. The weights were recorded after 1, 3, 9, 15 and 25 days the samples were removed from water and wiping the surface with a cloth. The percentages of water absorption for 6 samples on different days are tabulated in Table 7.

4. TEST RESULTS AND DISCUSSIONS

4.1Physical Properties of bamboo

The physical properties like length, weight, no of nodes and diameter of each bamboo clums are different. No two bamboo properties are same because it is naturally grown, its properties vary based on growth, soil and climatic conditions.

Table 2 Physical characteristics of Bamboo culms

S.No	Length (m)	Weight (Kg)	No. of Inter	Diameter (mm)		
				Base	Middle	Top
1	5.50	9.45	20	77.7	80.1	67.3
2	4.55	7.77	13	72.1	75.2	65.7
3	4.63	6.81	15	75.6	76.0	69.8
4	5.78	11.40	22	89.5	85.4	72.9
5	5.55	10.12	21	76.2	75.3	70.1
6	4.92	6.41	18	72.4	79.7	71.2
7	5.10	8.65	18	87.3	79.6	75.4
8	5.37	9.43	16	77.5	80.2	69.4
9	4.91	8.25	15	71.1	76.7	62.2
10	5.25	9.28	21	89.5	97.4	92.8

4.2 Tensile Test

The failure of bamboo members are observed mainly as node failure due to brittle nature at nodes, because of widely spacing of fibers at the node points. In addition some powder like material is also observed at the node points. The type of failure is the node failure for first specimen samples containing node point at middle. For the second type of specimen samples containing node points at 1/4 length from each end, the failure is of node failure at end node points or split failure at middle of the specimen. For the third type of specimen samples containing random nodes the failure is node failure or splitting failure and combination of both is also observed. The different failure patterns were shown in Fig 4.a to 4.c

4.a Centre node type failed sample in tensile test

4.b Splitting type failed sample in tensile test

4.c Combined node and splitting type failed sample in tensile test

Table 3 Tensile Test Results for Bamboo

Ultimate Tensile stress of Bamboo (N/mm^2)			
S.No	End nodes	Center node	Random nodes
1	244	201	127
2	119	151	128
3	106	102	142
4	90	93	177
5	108	117	180
6	85	113	134
7	125	140	118
8	155	180	108
9	133	135	125
10			114
Average	**120**	**115**	**128**

The average ultimate tensile strength of bamboo from test values is given as 125N/mm^2. The Stress Vs. Strain graph for tested specimens is shown below in Fig 5.

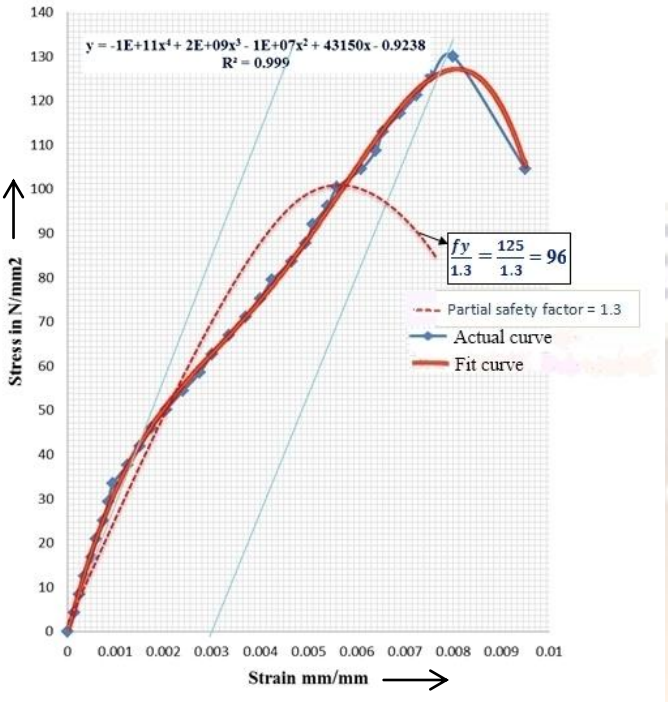

Fig 5 Stress - Strain chart for moso bamboo

4.3 Modulus of Elasticity

The 'E' values obtained for central nodes stress are greater than end node samples, due to stiff and brittle nature at node points so, the nodes may be resists the deflection of bamboo.

Table 4 Modulus of Elasticity test results for bamboo

Modulus of Elasticity (E) of Bamboo (N/mm^2)		
S. No	Center node Stress	End node Stress
1	2.9473 x 10^4	1.5898 x 10^4
2	1.9347 x 10^4	1.40153 x 10^4
3	1.4218 x 10^4	1.3379 x 10^4
4	1.3476 x 10^4	1.14435 x 10^4
5	2.1804 x 10^4	0.9535 x 10^4
6	1.6402 x 10^4	1.27188 x 10^4
7	2.7989 x 10^4	1.7498 x 10^4
8	2.16365 x 10^4	0.9998 x 10^4
9	2.16760 x 10^4	1.9818 x 10^4
10	2.78404 x 10^4	1.0638 x 10^4

The average Modulus of elastic value is taken as 1.5 x 10^4 N/mm^2 for design. The modulus of elasticity of steel is 2 x 10^5 N/mm^2.

4.4 Compressive Test

The failure of bamboo is observed as compression failure as shown in Fig 6. The stress values obtained for central node specimen is greater than that of end node specimen and without node specimen. This is due to widely spacing of fibre and stiff behaviour at node points. The maximum and minimum stress values obtained in central node, end node and random node specimens are 123N/mm^2, 120N/mm^2; 112N/mm^2, 104N/mm^2; 96N/mm^2, 93N/mm^2 respectively. The average compressive stress of bamboos is 108.19N/mm^2.

Fig 6 Failed bamboo samples in compression test

4.5Pull-out test

For first few samples at the time of testing the bamboo were broken in tension without bond failure from concrete so, these values are not considered as bond stress. The samples were again cast by changing bond length L_b i.e., the length of bamboo embedded in concrete was decreased and was tested and the procedure was repeated until bamboo comes out smoothly from concrete while testing and these values obtained are due to bond failure. Pull-out failure occurred due to the shear strength between the bamboo and the concrete. From the table 5 it is observed that bond stress of coated and uncoated bamboo samples is nearly same if it pulls by an amount 0.1mm. It is observed that the bond stress of bamboo is 4.7 times less than that of steel.

Table 5Pull-out test results for Coated and Uncoated Bamboo and Steel

Bond Stress of Bamboo and Steel (N/mm^2)					
S.No	Length of Bonding with concrete (mm)	Bond Stress of uncoated Bamboo	Bond Stress of water proof materia	Bond Stress of Hysd Bar	Remarks (Failed due to)
1	260	1.3	1.05	5.2	Tension
2	260	0.9	0.95	4.8	Tension
3	200	1.2	1.07	6.5	Tension

4	200	1.4	1.25	6.3	Tension
5	150	1.68	1.45	-	Bond
6	150	1.45	1.95	-	Bond
7	150	1.74	1.51	-	Bond
8	130	-	-	11.73	Tension
9	130	-	-	10.62	Tension
10	115	-	-	7.57	Bond
11	105	-	-	7.79	Bond
12	100	-	-	7.90	Bond

4.6 Shear Test

The values of shear strength are shown in Table 6. The failed sample of bamboo in shear test is shown in Fig 7.

Fig 7 Failed bamboo samples in shear test

Table 6 Shear test results of bamboo

Shear Strength of Bamboo			
S.No	**Area of specimen (mm^2)**	**Ultimate load (kg)**	**Shear Strength (N/mm^2)**
1	101.29	597	29.47
2	81.86	538	32.86
3	96.2	520	27.03
4	160.6	938	29.20
5	162.85	993	30.49
6	142.79	646	25.62
		Average	**29.12**

The higher strength values are obtained for center node samples. The average shear strength of bamboo is taken as 29.12N/mm^2.

4.7 Water absorption test

The water absorption capacity of bamboo increases with increase in nodes this may be due to presence of powder like substance at nodes. In this test a main point observed was though the water absorption capacity of bamboo is as high as 50% by weight there is no large amount of swelling in bamboo. The percentages of water absorption values for different samples are shown in Table 7.

Table 7 Water absorption test results for bamboo

Sample.	**Dry weight of Bamb**	**No. of Nodes**	**Thickness of Samp**	**Percentage of water absorption in days**				
				1	**3**	**9**	**15**	**25**
1	0.07	1	6.12	22	30	33	35	35
2	0.13	1	10.2	23	27	36	38	38
3	0.15	1	8.72	20	23	32	36	36
4	0.11	1	8.47	21	26	35	37	37
5	0.03	2	6.49	25	33	33	40	40
6	0.025	2	7.92	16	37	50	50	50

5. CONCLUSIONS

The constitutive relationship of the nodes differs from those of inter-nodal regions. Further the nodes possess brittle behaviour and the inter-nodal regions possess ductile behaviour. The average tensile strength of moso bamboo from present study is 125N/mm^2, which is half the strength of mild steel. There is no failure pattern followed by samples in tensile test. However, the samples with nodes generally failed at higher loads than those samples without nodes.

The compressive strength of bamboo is nearly same as the tensile strength of bamboo and this behaviour is similar to steel. Bond stress of bamboo with concrete is very low compared HYSD steel bars, due to surface smoothness of bamboo. Water absorption of bamboo is very high and waterproofing agent is recommended. From the test conditions, bamboo can potentially be used as substitute for steel reinforcement. As bamboo is eco-friendly material, limiting the use of steel can reduce carbon dioxide emissions. In the green building concept use of bamboo reinforced concrete may be recommendable.

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