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Bamboo as Green Alternative to Steel for Reinforced Concrete Elements of a Low Cost Residential Building

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ABSTRACT

Concrete has found to have excellent compressive strength but poor in tensile strength, to take care of the tensile stresses steel is commonly used as reinforcing material in concrete. Production of steel is a very costly business and its use in concrete as reinforcing material increases the cost of construction by many folds. Also production of steel emits a large amount of greenhouse gases causing considerable deterioration of the environment. It is here that engineered bamboo can be of great value to Civil Engineers owning to its several net worthy features. Production of every tone of bamboo consumes about a tone of atmospheric CO_2 in addition to releasing fresh O_2. From structural point of view bamboo has been used as a structural material from the earlier times as it possesses excellent flexure and tensile strength as well as high strength to weight ratio. The study focuses on investigating the various physical and mechanical properties of bamboo by conducting a variety of laboratory tests to, check the feasibility and reliability of using bamboo as a reinforcing material in concrete structural elements of a low cost dwelling, in addition to select and prepare the most appropriate kind of bamboo specimen to be used in concrete element as reinforcement.

KEYWORDS: Bamboo culm, Bamboo splints, Initial Moisture Content Test, Density Test, Water Absorption Capacity Test, Tension Test, Compression test.

INTRODUCTION

Bamboo is a versatile, strong, renewable and environment-friendly material. It is a member of the grass family, Gramineae and the fastest growing woody plant on earth. Most bamboo species produce mature fiber in 3 years, sooner than any other tree species. Some bamboos grow up to1 meter in a day, with many reaching culm lengths of 25 meter or more. Bamboo can be grown quickly and easily and sustainably harvested in 3 to 5 years cycle. In grows on marginal and degraded land, elevated ground, along acting as soil stabilizer, an effective carbon sink and helping to counter the greenhouse effect. Bamboo seems to be a promising material for the future. It is expected that in the near future the world will be witness to more participations of bamboo in construction and creation of simple yet aesthetically pleasing buildings, encouraging healing of the environment to some extent. India is the second richest country in bamboo genetic resource after China. Sharma(1987) reported 136 species of bamboo occurring in India. 58 species of bamboo belonging to 10 genera are distributed in the North-Eastern states alone. Due to its several net worthy features researchers have found application of bamboo as a structural material. ***Francis E. Brink*** **and** ***Paul J. Rush*** has presented about the procedure of the selection and the preparation of the bamboo. They have also described about the construction principles and the design principles. ***Harish Sakaray, N.V. Vamsi Krishna Togati and I.V. Ramana Reddy*** carried out investigations on the Moso type Bamboo tensile stress, compressive stress, modulus of elasticity, water absorption capacity, shear stress and bonding stress. They concluded that the node poses ductile behavior. The compressive strength of the bamboo is similar to the tensile strength and the behavior is same as that of steel. The water absorption in bamboo is high so the water proofing to bamboo is required. ***Khosrow Ghavami*** in his study has focused about the summary of the information about the Bamboo as a structural member. His study also reflects about the design of the flexure and axially loaded elements. The conclusion part of study throws light on the satisfactorily substitution of bamboo against steel. ***Leela Khare*** has conducted four point bending test on the bamboo reinforced beam. Also the tensile test on the bamboo was conducted, the study reflects that the moso bamboo reinforced beam shows better results than that of solid bamboo reinforced beam. ***Markos Alitohas*** very well describes the various usefulness of the bamboo in various areas. He also describes about the various physical and mechanical properties of bamboo and its various tests. He has presented his study on the test performed on the RCC beam reinforced with bamboo. The mid span test was performed. He concluded that the bamboo reinforced concrete design is similar to steel reinforced concrete design if its mechanical properties are properly utilized. It identifies the potential for an alternative method for low-cost construction for areas where steel reinforcement is costly. ***Maulik D.Kakkad and Capt. C.S.Sanghvihave*** presented their studies on comparison of bamboo construction with the modern construction practices. They concluded that the seismic force in bamboo housing system is very less as compared to the modern housing system. ***M.M.Rahman, M.H. Rashid, M.A. Hossain, M.T. hasan and M.K. Hasan*** *has* carried out tensile test on bamboo and flexure test on the bamboo reinforced flexure element. The study reflected that the bamboo has a low modulus of elasticity and it can’t prevent cracking of concrete. ***IS8242:2004*** provides the methods of test for bamboo splints. ***IS6874:2008*** provides the detailed methods for conducting various tests on bamboo culm for determining its physical and mechanical properties.

METHODOLOGY

To check the feasibility and reliability of using bamboo splints as reinforcing material in concrete elements & to select and prepare the most appropriate kind of bamboo specimen to be used in concrete element as reinforcement. The following tests were performed till date on different bamboo specimens: -

1) Density test.
2) Initial moisture content test.
3) Water absorption test.
4) Compression test.
5) Tension test.

DENSITY TEST

- The density test was performed to find out the basic mass per volume or density of bamboo. The density of bamboo can be used as an appropriate parameter for classification of bamboo because unlike other physical and mechanical properties of bamboo, it depends only on the green volume and the oven dry mass. Hence density is an indicator of purity of a material.

- The test specimens for determining the basic mass per volume was taken from different positions of the culm (base, middle, top). The samples were 25mm in length and 25mm in width with full wall thickness. As shown in Fig. 1.
- The green volume (V) was measured by water displacement method as shown in Fig.2 After determining the green volume the test specimen were dried in a hot oven for 24 hrs at 1000 C to obtain the oven dry mass(m).
- Basic mass per volume was calculated using the below formula for each of the 12 samples individually.
- Mass per volume, kg/m^3 = $\frac{m}{V}$

Figure 1: Samples for density test

Figure 2: Water displacement method for determining the green volume

INITIAL MOISTURE CONTENT TEST

- Bamboo is an hygroscopic material which means moisture content changes with change in relative humidity and temperature of surroundings. Free and bound water exists in bamboo, however the amount of free water is small as compared to bound water hence bamboo starts to shrink as soon it losses moisture. The shrinkage of bamboo occurs in the direct proportion to the amount of water content lost. When bamboo splints present inside the concrete elements as reinforcement losses moisture, the bamboo splints shrinks creating additional stresses and creating spaces or gaps between the bamboo and concrete, eventually decreasing the bamboo-concrete bond and member fails in bond

- Three different types of total 12 bamboo splints were taken from different portions of bamboo culm for the test as shown in Fig.3.
- Type-1: Zero internodes present
- Type-2: One internodes present
- Type-3: Two internodes present
- The initial weight of all specimens was taken individually on a digital weight machine. All the specimen were kept in an oven at 1000°C for 24 hours. After 24 hours the specimen were taken out from the oven and the final dry weight of all specimens was measured individually on a digital weight machine.
- Using the below mathematical expression the initial moisture content of all the specimen was obtained individually and was expressed in terms of percentage by weight.
- Moisture content %= (Initial weight(gm)-Dry weight(gm))/(initial Weight(gm))×100

Type-1-zero nodes present

Type-2-One node present

Type-3-Two nodes present

Figure 3: Samples for Initial Moisture content test.

WATER ABSORPTION TEST

- Bamboo like wood changes its dimension when it loses or gains moisture. Bamboo is a hygroscopic material, tending to absorb moisture from air and surroundings. The water absorption capacity of bamboo splints is more than 50% by weight, hence it absorbs and reduces a part of water added in the concrete mix for hydration reactions. In green concrete bamboo splints absorb moisture and swells, when the concrete becomes dry the bamboo splints contracts and creates spaces between the contacts the bamboo-concrete bond strength decreases and member fails in bond.
- Three different types of total 6 bamboo splints were taken from different portions of bamboo culm for the test as shown in Fig. 3.

TYPE-A-NON TREATED	**TYPE-B-TREATED (Coated with Bitumen For making bamboo waterproof)**
TYPE-A-1: zero internodes present **TYPE-A-2**: one internodes present **TYPE-A-3**: Two internodes present	**TYPE-B-1**: zero internodes present **TYPE-B-2**: one internodes present **TYPE-B-3**: Two internodes present

- To remove all the initial moisture content present in the bamboo splints, the specimen were kept in an oven at 100^0C for about 24 hours. Type-A and Type-B kind of specimens were prepared The initial dry weight and initial thickness of all the specimens were taken individually on a digital weight machine and using a ruler respectively. All specimens were kept immersed in water at room temperature for 30 days in a curing water tank. The specimen were taken out from the water curing tank at consecutive intervals of 15 days and 30 days, their surface was wiped off properly using a dry cloth. The final saturate weigh and increase thickness of all the specimen were measured individually on a digital weight machine and a ruler respectively.
- Using the below mathematical expression the amount of water absorbed by both types of samples was calculated.
- $\text{Water absorbed(gm)} = \text{final saturated weight(gm)} - \text{Dry weight(gm)}$

  $\text{\% by weight of water absorbed} = \frac{\text{Water absorbed(gm)}}{\text{Final Saturated weight(gm)}} \times 100$

Type 3: Zero nodes present

Type 4: Type-A-2-One node present

Type 5: Two nodes present

Type 6: Zero nodes present

Type 7: One node present

Type 8: Two nodes present

COMPRESSION TEST

Specimen	Nodes	Dimensions			Cross-Sectional Area, A(mm^2)
		Gauge length, L(mm)	Outer diameter, D(mm)	Thickness t(mm)	$A=\frac{\pi}{4}\left(D^2-\left(D-2t\right)^2\right)$
A-1	0	145	47	6	772.832
A-2	0	142	43	8	879.646
A-3	0	117	44	10	1068.142
B-1	1	148	47	5	659.735
B-2	1	146	43	8	879.646
B-3	1	143	44	9	989.602

- The compression test was carried out on hollow bamboo culms to determine the compressive strength of bamboo .The compressive strength of bamboo is of utter importance to calculate the maximum allowable stresses in bamboo, when bamboo is being used as compressive reinforcement in the upper fiber of a doubly reinforced concrete beam.

- Total 6 bamboo splints were taken from different portions of bamboo culm for the test as shown in Fig.10.

- Type-A and Type-B kind of specimens were prepared. The ends were filed properly to ensure a smooth surface to achieve a uniform stress application over the entire cross-section. A compressive load was applied on the cross section of all specimens individually on a universal testing machine Fig. 11. The loading rate for all specimens was kept constant i.e. 0.05 kN/sec. The load and displacement readings were taken at regular intervals for each specimen, using a digital indicator Fig 12. The load at which the specimen failed was divided with the cross-sectional area to obtain the ultimate compressive strength of the specimen. Stress and strain values were calculated using the load and displacement values and a stress-vs.-strain graph was plotted for each of the specimen.

$$\text{Stress}(\sigma) = \frac{\text{Load}(\text{P})}{\text{crosssectioanl area}(\text{A})}$$

$$\text{Strain}(\in) = \frac{\text{Displacement}(\Delta)}{\text{Gauge Length}(\text{L})}$$

Figure 9: Samples for water absorption test. **Figure 10:** Samples for Compression test

Figure 11: Application of compressive load on samples, on a UTM.

Figure 12: Digital indicator of UTM, displaying the load and displacement readings.

TENSION TEST

- The tension test was carried out on bamboo splints to determine the ultimate tensile strength of bamboo. The ultimate tensile strength of bamboo is of utter importance to calculate the maximum allowable tensile stress in bamboo, when bamboo is being used as reinforcement in concrete elements to take the tensile loads. Using the data of tension test stress-vs.-strain curve was plotted for all specimens. The stress-vs.-strain curve is a characteristic property of a material and is used to study the properties of a material like modulus of elasticity, ductility, creep, relaxation, resilience, toughness etc.

- Total of 6 bamboo splints were taken from different portions of bamboo culm for the test as shown in Fig. 13.

Specimen No.	**Nodes**	**Dimensions**			**Cross-sectional area, A(mm^2)**
		Gauge Length, L(mm)	**Width, B(mm)**	**Thickness, T(mm)**	**A=T x B**
A-1	1	150	20	12	240
A-2	1	150	20	5	100
A-3	1	150	20	9	180
A-4	1	150	20	6	120
A-5	1	150	20	12	240
A-6	1	150	20	5	100

- Specimens A-1 to A-6 were prepared. A tensile load was applied on the cross section of all specimens individually on a universal testing machine Fig 14. The strain rate for all of the specimen was kept constant i.e. 0.06mm/min. The load and displacement readings were taken at regular intervals for each specimen, using a digital indicator Fig 15. The load at which the specimen failed was divided with the cross-sectional area to obtain the ultimate tensile strength of the specimen. Stress and strain values were calculated using the load and displacement values and a stress-vs.-strain graph was plotted for each of the specimen.

$$\text{Stress}(\sigma) = \frac{\text{Load}(\text{P})}{\text{crosssectioanl area}(\text{A})}$$

$$\text{Strain}(\epsilon) = \frac{\text{Displacement}(\Delta)}{\text{Gauge Length}(\text{L})}$$

Figure 13: Samples for Tension test

Figure 14: Application of tensile load on samples, on a UTM

Figure 15: Digital indicator of UTM, displaying the load and displacement readings.

RESULTS

DENSITY TEST

Specimen No.	Thickness (cm)	Oven dry mass (gm)	Volume of specimen (cm^3)	Mass density (gm/cm^3)
1	0.4	1.60	2.70	**0.593**
2	0.5	1.60	2.80	**0.571**
3	0.5	1.50	2.60	**0.577**
4	0.5	1.85	2.60	**0.712**
5	0.6	2.25	3.50	**0.643**
6	0.7	2.30	3.55	**0.648**
7	0.8	3.25	3.85	**0.844**
8	0.9	3.60	4.25	**0.847**
9	1.0	3.65	4.55	**0.802**
10	1.1	3.80	5.10	**0.745**
11	1.3	4.25	5.85	**0.726**
12	1.4	4.15	5.65	**0.734**

- The density of bamboo lies in the range of 0.571-0.874. The density of bamboo is very low which makes it a very light material hence it can be transported and worked easily, rendering the use of cranes and other big machines unnecessary.

INITIAL MOISTURE CONTENT TEST

Specimen No.	Nodes	Thickness, cm	Initial weight, gm	Oven dry weight, gm	Moisture content %
1	0	0.6	20.00	17.35	**13.25%**
2	0	0.7	20.00	17.30	**13.50%**
3	0	0.6	16.20	14.15	**12.65%**
4	0	0.6	16.90	15.00	**11.24%**
5	1	0.5	50.00	41.95	**16.10%**
6	1	0.5	40.00	39.75	**00.63%**
7	1	0.5	29.50	26.15	**11.35%**
8	1	0.6	30.25	26.85	**11.24%**
9	2	0.7	70.00	59.95	**14.36%**
10	2	0.6	60.00	55.75	**07.08%**
11	2	0.7	71.25	62.95	**11.65%**
12	2	0.5	55.50	48.95	**11.80%**

- The initial moisture content of bamboo specimens tested lies in the range of 00.63%-16.10%.
- The graph between “Average moisture content%-vs.-No. of Nodes” Fig 3.2.1comes out to be haphazard curve, hence no possible correlation can be drawn between the two from the obtained plot.The graph between “Average moisture content%-vs.-thickness”Fig. 16 can be approximated as a straight line, hence a linear relation seems to exist between the two. The thickness of a bamboo plant is not constant it varies along the height being maximum at the bottom and minimum at the top.Hence the specimen obtained from the bottom portion of bamboo has maximum initial water content and should be either avoided for use as reinforcing material in concrete or if used should be properly seasoned i.e. air dried.

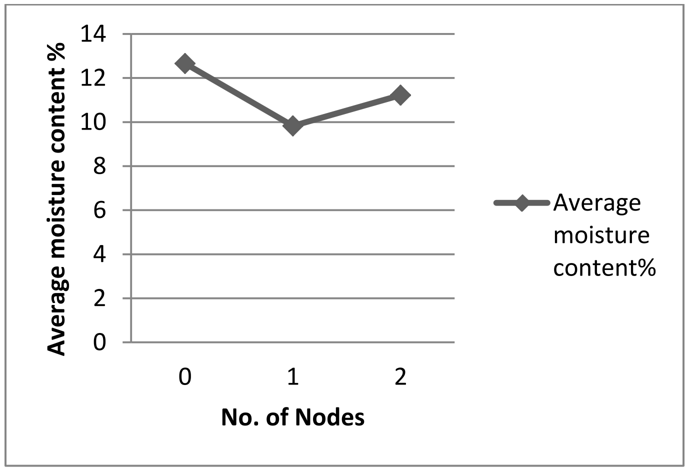

Figure 16: Average moisture content%-vs.-No. of Nodes

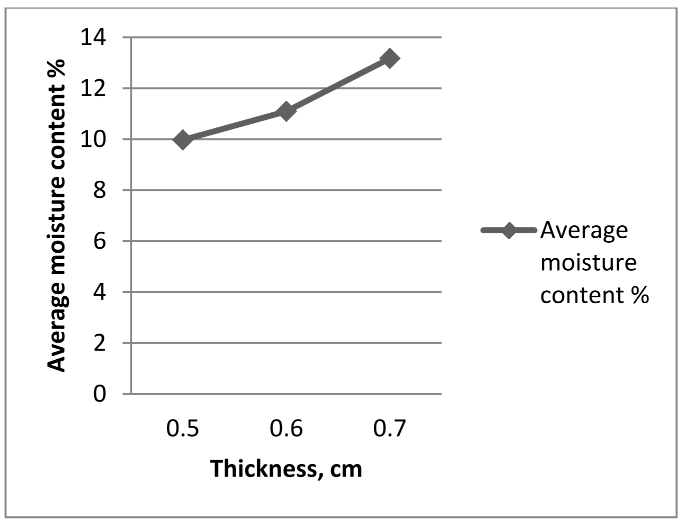

Figure 17: Average moisture content%-vs.-thickness

WATER ABSORPTION TEST

Type	Nodes	Water absorbed after 15 days,gm	Water absorbed after 30 days,gm
A-1	0	24.80	25.65
A-2	1	56.70	57.80
A-3	2	85.40	90.25
B-1	0	08.25	10.05
B-2	1	11.25	14.05
B-3	2	24.55	29.70

Type	% increase inthickness after 15 days	%increase in thickness after 30 days
A-1	00.00%	00.00%
A-2	16.67%	40.00%
A-3	16.67%	33.33%
B-1	00.00%	00.00%
B-2	00.00%	00.00%
B-3	00.00%	16.67%

- The graph between “amount of water absorbed-vs.-number of days of soaking” Fig 3.3.1, shows that water is absorbed by the bamboo specimen at a faster rate for the initial 15 days, thereafter it declines for all types of specimens. %increase in thickness after 30 days of soaking comes out to be as high as 40% in some of the non treated bamboo samples, which shows that there is a high possibility of swelling of the bamboo splints once they absorb water from the surrounding, eventually generating additional stresses in reinforced concrete elements if used as reinforcing material.
- The water absorption capacity of bamboo is as high as 60% by weight as seen after 30 days pf soaking. Which gets reduced to about 25% by weight on coating with a water proofing material i.e. bitumen.which necessitates the use of a water proofing compound.The graph between amount of water absorbed-vs.-number of nodes”Fig.3.3.2 can be approximated as a straight line hence water absorption capacity of bamboo increase with increse in the number of nodes, this is due to the presence of powder like grains at nodes.
- Though the water absorption capacity of bamboo get lowered to 25% from 60% on coating it with bitumen, but still there has been significant absorption of water in treated samples also which shows that bitumen is not a sucessful water coating material for bamboo because of its high viscosity and stripping property in presence of water.

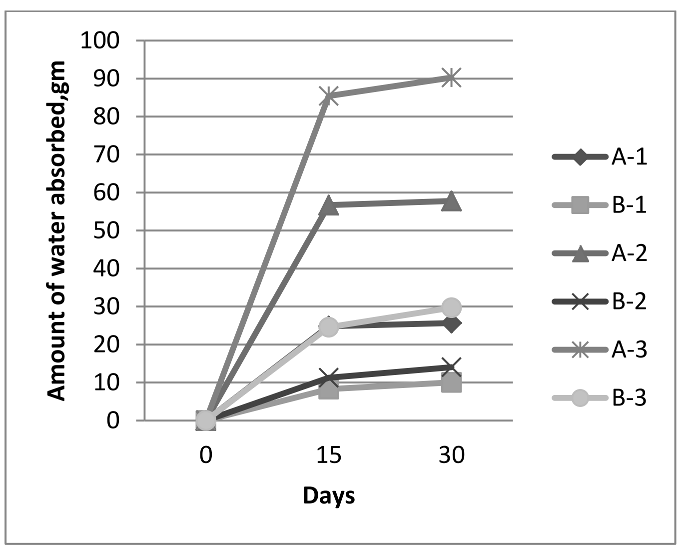

Figure 18:

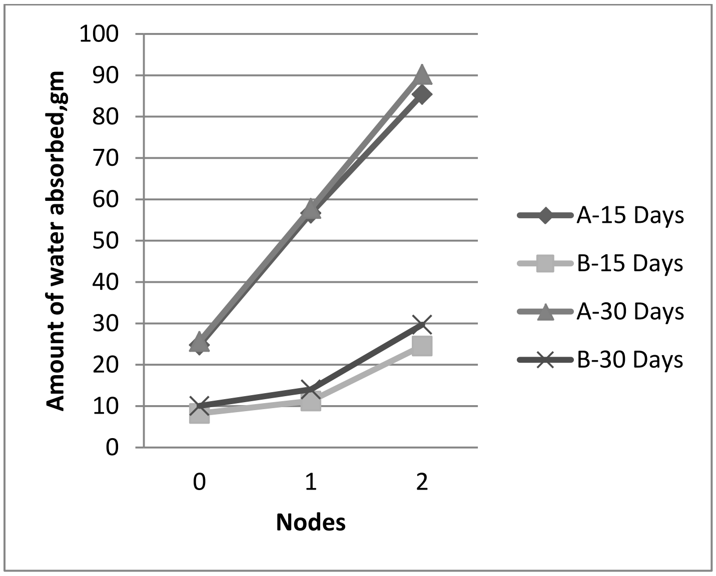

Figure 19:

COMPRESSION TEST

Sample	nodes	Thickness (mm)	Outer diameter (mm)	Ultimate Compressive strength (MPa)
A-1	0	6	47	**57.97**
A-2	0	8	43	**84.58**
A-3	0	10	44	**74.62**
B-1	1	5	47	**72.00**
B-2	1	8	43	**90.72**
B-3	1	9	44	**88.52**

- Bamboo in compression was seen to fail in two modes: Cracking of fibers Fig. 20 and crushing Fig. 21. Some of specimen failed as a combination of both the modes Fig 22.
- Bamboo shows a high value of compressive strength which is comparable to steel and concrete. The compressive strength of bamboo specimen with internode has been found to be greater than that of specimens without and internode this could be because of additional crossectional area at nodes (as walls are thicker on both sides of the node) and due to the dense mass present at nodes. Some of the specimen showed an ideal faliure by cracking longitudinally but most of them showed a mixed mode of faliure wherein the specimen cracked as well as got crushed.
- The stress-vs.-strain curve of specimens without an internode Fig. 23 seems to be fairly linear upto 40MPa. whereas the stress-vs.-strain curve of specimens with an internode Fig.24, seems to be fairly linear upto 102.9MPa.

Figure 20: cracking of fibers

Figure 21: Crushing of fibers

Figure 22: Cracking as well as crushing of fibers

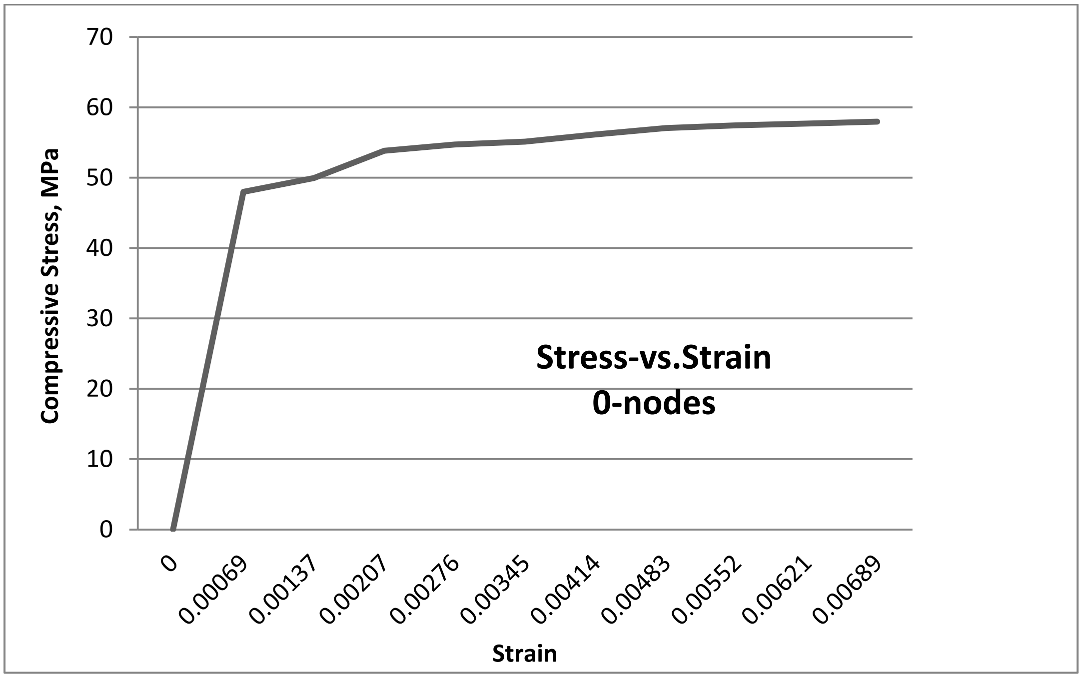

Figure 23: The stress-vs.-strain curve of specimens without a node

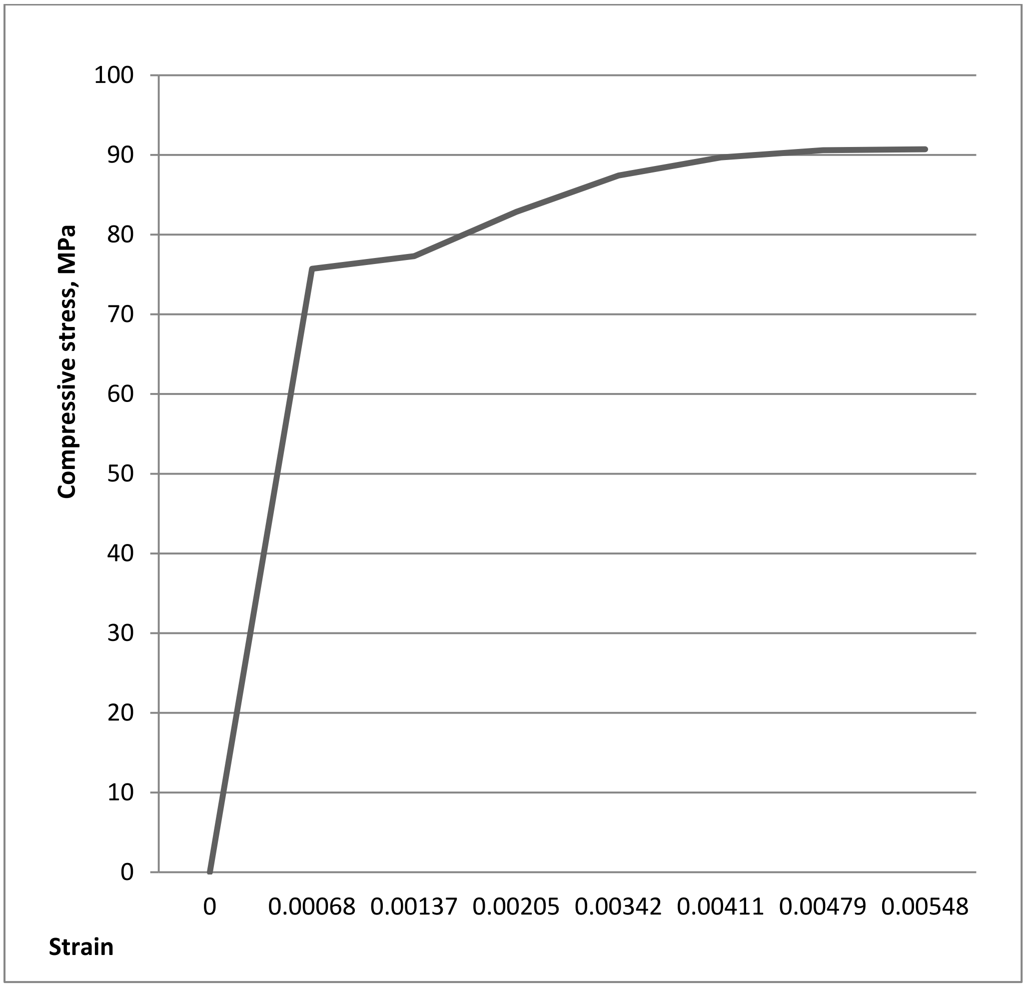

Figure 24: The stress-vs.-strain curve of specimens with one node

Sample	Nodes	Thickness (mm)	Width (mm)	Ultimate tensile strength (MPa)
A-1	1	12	20	**168.333**
A-2	1	5	20	**252.000**
A-3	1	9	20	**263.333**
A-4	1	6	20	**298.333**
A-5	1	12	20	**179.583**
A-6	1	5	20	**282.000**

- All the bamboo specimens have shown brittle failure at nodes (see Fig. 22), making node as the most critical section for failure under tensile stresses.
- The stress-vs.-strain curve of bamboo splint Fig. 23 shows that bamboo is a visco elastic material having both viscous and elastic properties and exhibits time dependent strain.
- The ultimate tensile strength of bamboo splints is as high as 282MPa which is comparable to the yield strength of structural steel i.e 250MPa. Hence bamboo can take sufficient tensile loads in a concrete flexure element.

Figure 25: Brittle Failure of bamboo splint at node under tensile load.

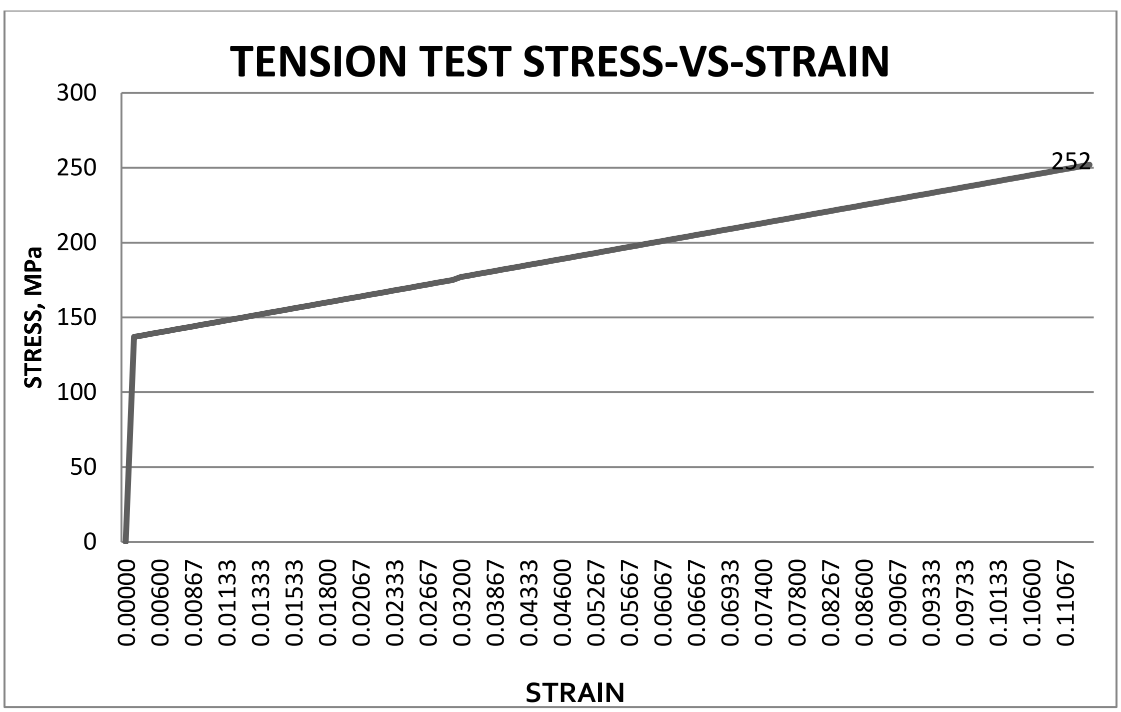

Figure 26: stress-vs.-strain curve of bamboo splint under tensile load.

CONCLUSIONS

1. The density of bamboo is very low lying in the range of 0.571-0.874 which makes it a very light material hence it can be transported and worked easily, rendering the use of cranes and other big machines unnecessary.

2. The initial moisture content decreases as we go along the height of bamboo culm from bottom to top. Hence the specimen obtained from the bottom portion of bamboo should either be avoided for use as reinforcing material in concrete or if used, should be properly seasoned.

3. The water absorption capacity of non-treated bamboo is as high as 60% by weight as seen after 30 days of soaking in water, which necessitates the use of a water proofing compound if bamboo has to be used as a reinforcing material in steel.

4. %increase in thickness after 30 days of soaking comes out to be as high as 40 in some of the non-treated bamboo samples which shows that there is a high possibility of swelling of the bamboo splints once they absorb water from the surroundings.

5. The water absorption capacity of bamboo increase with the increase in number of nodes hence the specimens containing large number of nodes should either be avoided for use as reinforcing material in concrete or if used, should be properly coated with an appropriate water proofing compound.

6. Bamboo in compression fails in two modes: Cracking of fiber and crushing. Most of specimens failed as a combination of both the modes.

7. Bamboo shows a high value of compressive strength (90.72MPa) which is comparable or even higher than steel and concrete. The compressive strength of bamboo specimen with internode has been found to be greater than that of specimens without and internode this could be because of additional cross-sectional area at nodes (as walls are thicker on both sides of the node) and due to the dense mass present at nodes.

8. The stress-vs.-strain curve of bamboo splint in tension shows that bamboo is a visco elastic material having both viscous and elastic properties and exhibits time dependent strain elasticity.

9. The ultimate tensile strength of bamboo splints is as high as 282MPa which is comparable to the yield strength of structural steel i.e 250MPa. Hence bamboo splints can resist sufficient tensile loads in a concrete flexure element.

10. All the bamboo specimens shown brittle failure at node, making node as the most critical section for failure under tensile stresses. The reason behind the brittle nature of nose is that at node Firstly, there is a change of boundary, hence higher stress concentrations, Secondly as compared to the internode part of bamboo where a very dense fibrous matrix is present along the length, there is no fibers present at nodes, there are only fine granules of wood present at the nodes ,on visual inspection it appears that nodes serves as the beginning and terminating point of fibers.

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