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Assessment of Performance of Bamboo as Reinforcement in Structural Concrete Members

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Abstract
The use of steel, one of the essential materials for structural reinforcement in the construction industry, is plagued by rise in cost, degradation of non–renewable materials, pollution due to industrial production and sharp practices on quality. In the light of this, bamboo, being a common plant growing all over the world, strong, dense, flexible and elastic in nature, is being considered as an alternative reinforcement material in concrete structures. This work assessed the structural performance of bamboo relative to its ability to structurally support concrete in compression. Matured and seasoned bamboo culms of over 40 and 10 mm in diameter and thickness, respectively, were used. Bamboo splints of various width sizes of 12, 16, 20 and 25mm were cut, prepared and used. These were compared with 12mm high yield (HY) steel reinforcement and in terms of its tensile strength, compression strength and bending stresses. Bamboo width seizes were also adopted as concrete reinforcement and the reinforced concrete beam tested for flexural strength at 7, 28 and 56 days. Ultimate tensile strengths result of 12, 16, 20 and 25mm bamboo rods were 60, 44, 33 and 29% of the strength of 12mm HY diameter steel bar of 583.48 N/mm². 150 mm high culms gave average of 62 N/mm² in compression strength. Average flexural resistance of 500mm span bamboo was 8.5N/mm². Flexural strength investigation performance at 28 days for reinforced concrete beam containing 6 nos 12 mm bamboo rods were 50% of the value of singly reinforced concrete beam containing 12mm HY reinforced bar. Corresponding values for beams reinforced with 8nos 16mm bamboo width size, 2 nos 20mm width size, and 4 nos 25mm width size were 55.2%, 50.9% and 52.4%, respectively, these being the highest performances observed. The study revealed that bamboo splints of the stated width sizes and above can be used for lightweight structural construction due to their strength characteristics.

Key words: *steel, bamboo, compression stress, flexure and tensile strength*

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I. Introduction

In recent times, there are a number of problems encountered with the commonly used construction materials like steel. These include rise in cost, degradation of the non-renewable material, and the pollution of the environment due to the industrial process of steel production. Added to these are the sharp practices of cutting down on the quality of reinforcing steel products which are inimical to the structural integrity of buildings. Bamboo one of the oldest traditional building materials used by mankind, the bamboo culm, or stem, has been made into different products ranging from domestic household products to industrial goods (Nayak*et al*, 2013).

Bamboo is a natural perennial grass-like composite and contains ligno-cellulosic-based natural fibers (Adewuyi*et al*, 2015; Nayak*et al*, 2013). It occurs in the natural vegetation of many parts of tropical, subtropical and mild temperature regions, with about 1250 species identified throughout the world (Austin & Ueda, 1972). There are seven species of bamboo in Nigeria among which the specie bambusa vulgaris constitutes 80% (Falade&Akeju, 2002).

Bamboo reaches its full growth in just a few months and reaches its maximum mechanical strength in just few years. Its abundance in tropical and subtropical regions makes it an economically advantageous material. Some of the positive aspects such as a lightweight design, better flexibility, toughness (due to its thin walls and discretely distributed nodes) and its great strength make it a good construction material (Khare, 2005).

The strengths of bamboo have also been reported, according to (Adewuyi*et al* 2015) and (Nayak*et al* 2013), some species of bamboo have ultimate tensile strength that is the same as that of mild steel at yield point. This ranges between 140 and 280N/mm^2. Other authors have also corroborated this. Yu *et al*. (2008) reported tensile strength for bamboo as varying between 115 and 309 N/mm^2. Agarwal&Maity (2011) observed a tensile strength of 370N/mm^2 in their own investigations. Thus, it is obvious that bamboo's tensile strength can be in the range of that for mild steel and can be adopted as reinforcement in concrete structures.

1.1 Bamboo as a Construction Material

Through research, it has been found that some species of bamboo have ultimate tensile strength as that of mild steel at yield point. Experimentally, Aladе*et al* (2004) found that the ultimate tensile strength of some species of bamboo is comparable to that of mild steel ranging from 200 to 250N/mm^2. However, Adewuyi*et al* (2015) &Nayak*et al* (2013) reported values ranging from 140N/mm^2 to 280N/mm^2. Specifically, Falade&Akeju (2002) reported maximum tensile strength of 133.54 N/mm^2 for bamboo.In many overly populated regions of the tropics, certain bamboos serve as a cheap material for permanent or makeshift buildings (Nayak*et al*, 2013).

Bamboo is an extremely strong fiber with twice the compressive strength of concrete and roughly the same strength-to-weight ratio of steel in tension. Many researchers have tried to use bamboo in construction works. Chembi&Nimityongskul (1989) and Winarto (1989) have reported its use in construction of water tanks. Venkateshwarlu& Raj (1989) and Raj (1990) developed bamboo-based ferrocement slab elements for roofing/flooring purpose in low cost housing. It has been established that in seismic zones the failure of bamboo is very less as the maximum absorption of the energy is at the nodes (Nayak et al, 2013). In nature when bamboo is covered with heavy snow, it will bend until it touches the ground without breaking. This implies that bamboo has greater flexibility than wood (Khare, 2005). Bamboo is a versatile material because of its high strength-to-weight ratio, easy workability and availability. It can be used as bamboo trusses, bamboo roofs skeleton, bamboo walling/ceiling, bamboo doors and windows, bamboo flooring, reed boards, and scaffolding.

However, one major problem with bamboo is that it attracts living organism such as fungi and insects. Bamboo is prone to insects than other trees and grasses because it has a high content of nutrients (Khare, 2005). In order to combat this problem, it becomes necessary to treat bamboo to protect it from environmental attack. Though steel does not have the problem peculiar to bamboo, it also needs to be coated in order to protect it from rusting. This is a major weakness that should be addressed if the potential of bamboo will be effectively harnessed.

The study assessed the performance of bamboo as reinforcement in structural concrete as replacement for steel in structural members as it uses are in infancy and results obtained so far are widely varied. Thus, this work will stand to answer questions on the suitability of bamboo in replacing reinforcing steel especially in low strength structural membersviz a viz, tensile, compression and flexural strength. Therefore, it becomes important to report the use of bamboo samples produced from the Nigerian locality as a reinforcing material.This may likely be accrued to differences in locations where bamboos grow, giving the bamboo from different locations their peculiar strength and traits. Therefore, it behooves research effort to investigate the possibility of exploring the potentials of bamboo in replacing steel as reinforcement material in reinforced concrete structural members. This is the crux of this work.

II. Materials and Methodology

2.1 Sample Preparation

The bamboo reinforcing materials were sourced and prepared in various sizes and shapes. Seasoned brown bamboo culms/stems of uniform diameter ranging between 50mm and 60mm were prepared. From the seasoned brown culms of bigger diameters, splints of various sizes (width); 12 mm, 16 mm, 20mm and 25 mm were prepared. As much as possible, the internodal distances were ensured as uniform. Besides, the prepared bamboos were air-dried for four weeks to further season them and further coated with expoxy materials plate 1.

2.2 Steel reinforcement

The 12mm high yield steel rods were obtained from reputable sales outlets in the city of Abeokuta and cut to sizes

2.3 Cement

Portland cement of the Elephant brandwas obtained from reputable sales outlets in the city of Abeokuta.

2.4 Aggregates

The sand used was washed river sand, with particle size ranging from 2mm down while granite used, size 19mm down, was sourced from quarries in the city of Abeokuta. The details of the experimental works are further discussed.

III. Testing of samples

3.1 Tensile Strength of Steel and Bamboo

The tensile strength of these two materials was determined experimentally in line with ASTM specifications. The yield strength, ultimate tensile strength and young modulus of the materials were experimentally determined in accordance with ASTM A370.


Plate 1: Coating the Bamboo with Epoxy Plate 2: Tensile strength of 12mm dia. Steel

For emphasis, two categories of rods were tested. These are 12mm, 16mm, 20mm and 25 mm width bamboo splits, and 12mm high yield steel.For each of these rods, 4 numbers of 600mm long rods were prepared and tested using a 300kN capacity universal testing machine (UTM). It was ensured that bamboo nodes are located close to the ends of the bamboo rods while the ends were roughened to enhance grip with the machine. The ultimate tensile strength (UTS) was determined as the maximum stress that the rods can withstand while being stretched or pulled before failing or breaking. Plates 2 and 3 show the steel and bamboo being tested, respectively.


Plate 3: Tensile strength of splint bambooPlate4: Weighing Bamboo for Compression

The yield stress is also determined as the stress at which deformation is not recoverable after load removal. From the stress-strain relationship, the modulus of elasticity, E is also determined as:
E = stress at yield point/corresponding strain …1

3.2 Compression Strength of Bamboo Stalk

The test involved 4 numbers of 150mm long dried bamboo stem cut in between the culms. These are tested for compression on the UTM. The compression failure loads were determined while areas were calculated from the measured inner and outer diameters. With these, the compressive strengths were determined for the four samples and averages were determined.
Plates 4 and 5 show the process of weighing and crushing the bamboo for the compression strength determination.

3.3 Bending (Flexural) Stresses of Bamboos

Four test samples of bamboo, cut into lengths of 600mm were also tested to determine their bending stress. The test comprised of the specimens subjected to lateral loading with three point loading contact. The samples were placed on two supporting chucks at each ends and a downward force applied at the center point of the specimen (Plate 6).

3.4 Compressive Strengths of the Concrete

Concrete cubes of 150 mm were prepared using concrete moulds. The mix ratio was the common 1:2:4 while the water cement ratio of 0.5 used. Twelve concrete cubes were cast and cured; three each for 7, 28 and 56 days respectively. The concrete cubes were demoulded after 24 hours of casting and placed in water for curing. At the stipulated days, the compressive strengths were determined using the UTM. The compressive strengths are the failure load per unit area. Averages of each of the three cubes are taken and recorded.

3.5 Bending (Flexural) Strength of the Reinforced Concrete Beams

To test for structural strengths, cement concrete beams of size 150mm by 150mm by 600mm with bamboo splint reinforcements were used. Bamboo of sizes 12, 16, 20 and 25 mm in width were adopted with the numbers of splints ranging between 2 to 8 in each beam. Moreover, singly reinforced beams with 12mm diameter high yield reinforcement were also tested.


Plate 5: Crushing the Bamboo on UTMPlate 6: Flexure Strength Test of Bamboo

The test arrangements were presented in Figure 1 and Plate 7. For each of these, 12 beams are cast, making a total of 48 beams. For each form of structural elements, three beams each are tested for flexure at 7, 28 and 56 days of curing using the UTM.

The reinforcement rods were 560 mm length, leaving out 20 mm cover at both ends of the beam. In order to prevent the swelling of the bamboo, waterproofing of the bamboo was done by coating with epoxy materials (Plate 1).

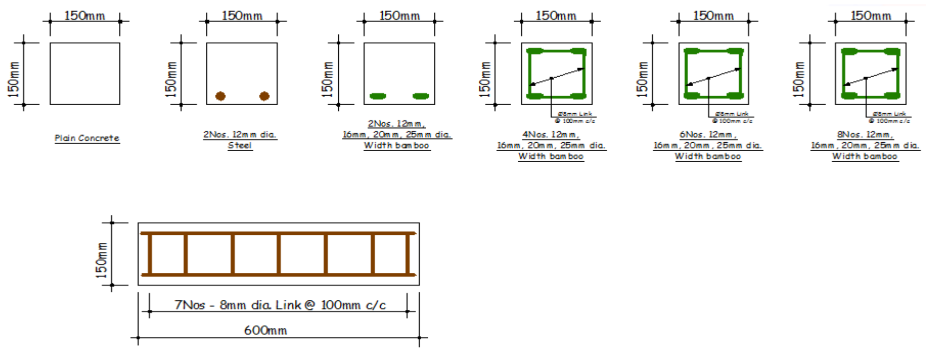

Fig. 1 Section Through Reinforced Concrete Beam (Plain, Steel and Bamboos)

Plate 7: Arrangement of ReinforcementPlate 8: Flexural strength test of concrete beam

Steel stirrups were at 100mm centers to hold reinforcement. This was to ensure a fairly uniform cross section of the bamboo. In order to increase the bond, the bamboo splits are wound round with 1mm diameter coir rope at a pitch of about 25mm along the splints from one end to the other. The coir rope was also coated in hot bitumen after being wound round the bamboo strip. This gave a surface similar to a ribbed steel surface. The ribbed surface was expected to improve the bond considerably and the structural behavior of the bamboo reinforced concrete. The flexure test on a sample was presented in Plate 8.

IV. Analysis and Discussion of Results

4.1 The Ultimate Tensile Strength

The ultimate tensile strength of the 12 mm HY diameter steel was 583.48 N/mm^2 compared to 354, 254, 193 and 168 N/mm^{2}for 12, 16, 20, and 25 mm width bamboo, respectively. It shows that bamboo only possessed 60, 44, 33 and 29% of steel strength as the width increases, respectively(Tables 1 to 5 and fig. 2).

Table 1: Tensile Strength of 12 mm dia. High yield bar;Steel area = 113.10 mm^2

Sample nos	Failure load (kN)	Ultimate tensile strength N/mm^2	Lower Yield strength N/mm^2	Upper Yield strength N/mm^2	Strain (ε) $= l - l_0/ l_0$	Young modulus (E) N/mm^2	Stress ratio Ys/Uts
S1	67.07	593.30	423.59	428.25	0.138	59.10	
S2	65.62	580.21	420.79	425.81	0.145	61.74	
S3	65.25	576.92	413.18	417.01	0.190	79.23	
Average		583.48	419.18	423.69	0.158	66.94	0.73

Table 2: Tensile Strength of 12 mm width bamboo area = 72 mm^2

Sample nos	Failure load (kN)	Ulitmate tensile strength N/mm^2	Lower yield Strength N/mm^2	Upper Yield strength N/mm^2	Strain (ε) $= l - l_0/ l_0$	Young modulus (E) N/mm^2	Stress ratio = Ys/Uts
A1	22.82	316.93	170.15	170.15	0.053	9.02	
A2	23.74	329.75	228.23	228.23	0.035	7.99	
A3	25.88	359.49	217.52	217.87	0.048	10.45	
A4	27.53	382.32	225.38	225.38	0.035	7.89	
A5	27.53	382.32	225.01	225.38	0.035	7.89	
Average		354.16	213.15	213.4	0.041	8.65	0.61

Table 3: Tensile Strength of 16 mm width bamboo area = 96 mm^2

Sample nos	Failure load (kN)	Ultimate tensile strength N/mm^2	Lower yield strength N/mm^2	Upper Yield strength N/mm^2	Strain (ε) $= l - l_0/ l_0$	Young modulus N/mm^2	Stress ratio =Ys/Uts
B1	28.02	291.88	159.69	159.77	0.018	2.88	
B2	28.07	292.43	160.99	161.28	0.037	5.97	
B3	22.94	238.97	159.81	160.22	0.041	6.57	
B4	18.79	195.77	108.79	108.79	-	-	

B5	23.94	249.43	159.48	159.53	0.035	5.58	
Average		253.7	149.6	149.92	0.033	5.25	0.59

Table4: Tensile Strength of 20 mm width bamboo area = 120 mm^2

Sample nos	Failure load (kN)	Ultimate tensile strength N/mm^2	Lower yield strength N/mm^2	Upper Yield strength N/mm^2	Strain (?) = l – l$_0$/ l$_0$	Young modulus	Stress ratio= Ys/Uts
C1	27.45	228.71	128.67	128.90	0.026	3.35	
C2	25.90	215.79	128.18	128.18	0.072	9.23	
C3	24.05	200.43	125.90	125.90	0.022	2.76	
C4	24.62	205.16	121.75	121.75	0.010	1.22	
C5	13.93	116.06	63.38	63.52	0.009	0.57	
Average		193.23	113.57	113.65	0.028	3.42	0.59

Table 5: Tensile Strength of 25 mm width bamboo area = 150 mm^2

Sample nos	Failure load (kN)	Ultimate tensile strength N/mm^2	Lower yield strength N/mm^2	Upper Yield strength N/mm^2	Strain (?) = l – l$_0$/ l$_0$	Young modulus	Stress ratio =Ys/Uts
D1	23.12	154.12	90.70	90.70	0.015	1.37	
D2	16.02	106.77	65.99	65.99	0.061	4.03	
D3	25.22	168.10	99.43	99.43	0.008	0.79	
D4	39.37	262.49	-	-	0.039	-	
D5	22.93	152.88	-	-	0.067	-	
Average		168.87	85.37	85.37	0.030	2.06	0.51

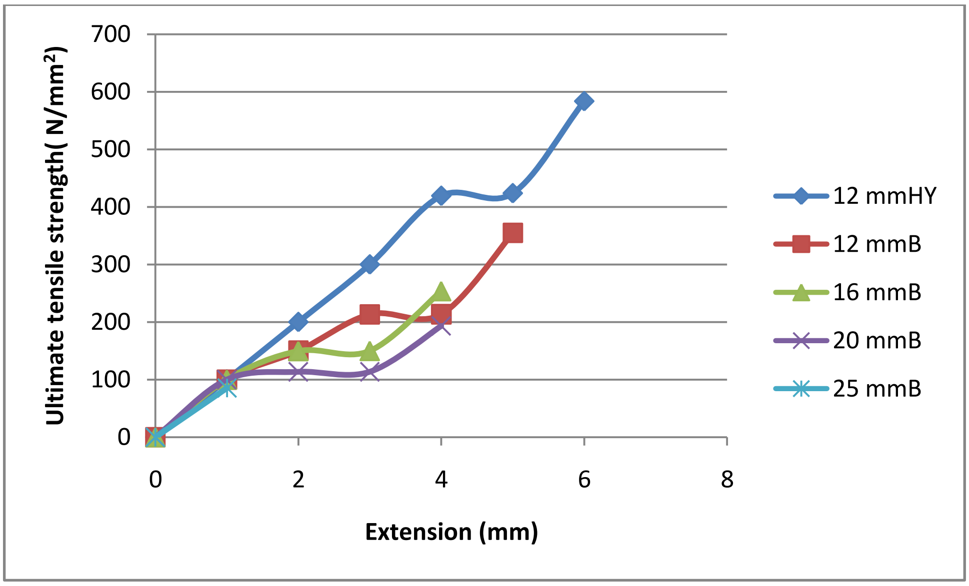

Fig. 2: Ultimate tensile strength vs Extension curve of Steel and bamboo rods

4.2 Compressive Strength of 150 mm Long Bamboo

The bamboo culm is 150 mm high with inner and outer diameters of 44.5 and 67.25 mm, respectively with culm thickness of 10.38 mm. The average compressive strength of 62.4 N/mm^{2}was achieved (Table 6).

Table 6: Compression strength test of 150 mmdeep bamboo

Sample nos.	Thickness (mm)	Outer dia.(mm)	Inner dia. (mm)	Wt. of sample (kg)	Area (mm^2) $\pi/4[D^2 - (D-2t)^2]$	Failure load (kN)	Compression Strength (N/mm^2)
A1 Top Bot	10 12	67 68	45 40	222.8		126.42	
A2 Top Bot	10 10	65 66	45 45	205.5		103.05	
A3 Top Bot	11 09	70 66	49 48	206		109.79	
A4 Top Bot	12 11	70 66	41 43	221		132.47	
Average	10.38	67.25	44.5	213.8	1889.86	117.9	62.4

4.3 Bending Stress of 500 mm Long Bamboo

A span of 500 mm length of bamboo stalk was tested for bending or flexure.The average bending stress result was 8.5 N/mm^2 with average inner and outer diameter of 43 and 68.63 mm and thickness of 12.88 mm, according to Table 7.

Table 7: Bending/Flexure Strength of 500 mm length bamboo

Sample nos.	Thickness (mm)	Outer dia. (mm)	Inner dia. (mm)	Wt.of sample (kg)	Failure load (kN)	Area (mm^2)	Bending stress σ = P/A N/mm^2
A1 top Bot	16 16	68 69	37 37	930.5	30.17		
A2 top Bot	09 09	68 68	51 47	690.3	19.21		
A3 top Bot	18 17	70 69	35 37	-	28.68		
A4 top Bot	08 10	67 70	50 50	716	20.41		
Average	12.88	68.63	43	778.9	24.62	2256.2	8.57

4.4 Compressive Strength of Concrete

Cube strength of 19 N/mm^2 at 28 days was also used in testing for flexure of a singly steel reinforced beam and doubly reinforced concrete bamboo beam (Table 8).

Table 8: Test for Compressive strength of concrete ratio 1: 2: 4

Curing Days	Specimen	Weight (kg)	Ultimate Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
7days	1	8.2	207.7	9.2	8.5
	2	8.2	190.2	8.5	
	3	8.1	175.6	7.8	
28days	1	8.4	382.3	17.6	19
	2	8.4	395.7	17.6	
	3	8.5	504.3	22.4	
56days	1	8.6	579.3	25.7	28
	2	8.6	597.7	26.5	
	3	8.7	719.7	32	

4.5 Flexural Strength Investigation of Reinforced Concrete Beams

This measures the ability of a beam to resist failure in bending. Acentre point loading UTM machine was used. The compressive strength of concrete cube at 28 days strength was 19 N/mm^2(Table 8) and this was used in designing a light weight concrete and used for proportioning the materials for flexure strength.Flexural strength measures the modulus of rupture (MR) of the beam.The result in Tables9 to 12 gave the MR values of the bamboo-reinforced concrete beams with 2 to 8nos bamboo compared to singly steel-reinforced concrete beam as shown in the table.At 28 days strength when concrete could have achieved 75% of its strength, the beam reinforced with 2-nos 12 mm width bamboo had 41.6% of the strength of the singly steel-reinforced concrete beam. Corresponding values for 4-nos, 12 mm, 6-nos, 12 mm and 8-nos 12 mm are 42.7%, 50% and 63%, respectively. For16 mm width bamboo-reinforced concrete, the corresponding values were 28%, 35.9%, 43% and 55.2%, respectively. For 20 mm width, there were 50.9, 51 3, 55.7 and 68.3% and finally, the values for 25 mm width bamboo were 36.9, 52.4, 60.2 and 72%, respectively(figs. 3 – 6).

Table 9: Flexural Strength of 12 mm width bamboo-reinforced concrete beam

Specimen	7 days		28 days		56 days	
	Average load (kN)	Flexural strength (N/mm^2)	Average load (kN)	Flexural strength (N/mm^2)	Average load (kN)	Flexural strength (MPa)
Control (S)	36.07	6.41	84.82	15.08	86.21	15.32
2nos (B)	24.85	4.42	35.33	6.28	32.94	5.85
4nos (B)	26.47	4.70	36.27	6.45	40.69	7.23
6nos (B)	27.73	4.92	42.46	7.55	46.59	8.28
8nos (B)	29.69	5.29	54.18	9.63	56.95	10.12

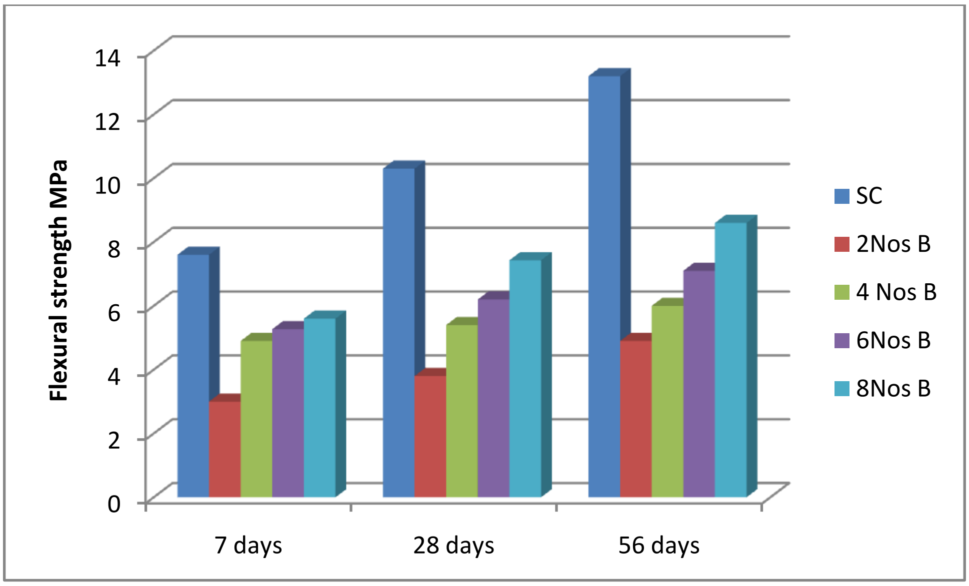

Fig. 3: Flexural strength of 12 mm width bamboo-reinforced concrete

Table 10: Flexural strength of 16 mm width bamboo-reinforced concrete beam

Specimen	7 days		28 days		56 days	
	Average load (kN)	Flexural strength (N/mm^2)	Average load (kN)	Flexural strength (N/mm^2)	Average load (kN)	Flexural strength (MPa)
Control (S)	40.50	7.20	52.76	9.38	70.87	12.60
2nos (B)	13.72	2.44	15.26	2.71	16.33	2.90
4nos (B)	17.53	3.12	18.94	3.37	20.56	3.66
6nos (B)	22.73	4.04	23.07	4.09	25.11	4.46
8nos (B)	26.31	4.68	29.15	5.18	32.4	5.76

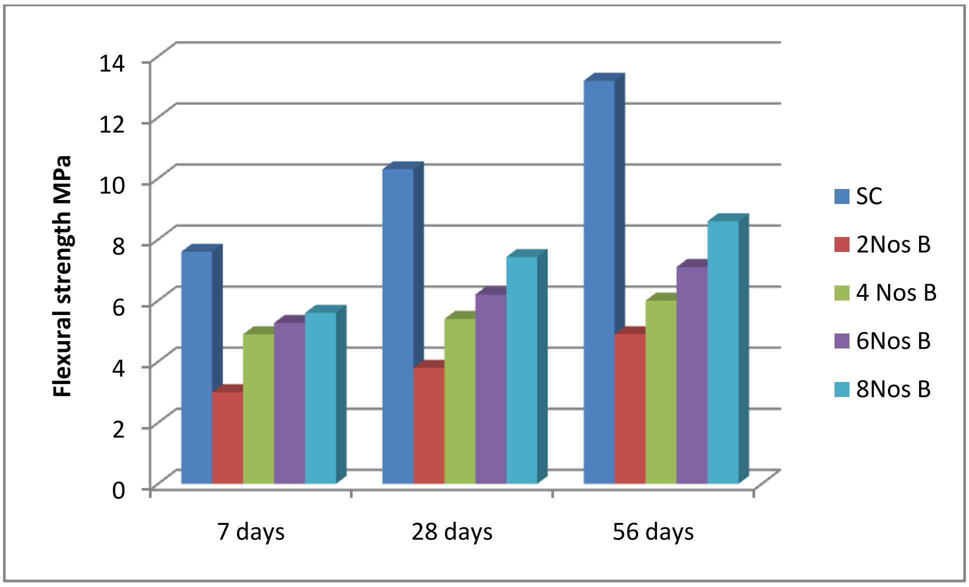

Fig. 4: Flexural strength of 16 mm width bamboo

Table 11: Flexural Strength of 20 mm width bamboo-reinforced concrete beam

Specimen	7 days		28 days		56 days	
	Average load (kN)	Flexural strength (N/mm^2)	Average load (kN)	Flexural strength (N/mm^2)	Average load (kN)	Flexural strength (MPa)
Control(S)	33.15	5.89	69.01	12.42	75.01	13.50
2nos (B)	25.74	4.58	35.03	6.33	42.03	7.57
4nos (B)	26.01	4.62	35.77	6.37	42.36	7.62
6nos (B)	26.36	4.69	38.47	6.92	46.51	8.37

8nos (B)	28.8	5.12	47.11	8.48	51.14	9.21

Table 12: Flexural strength of 25 mm width bamboo-reinforced concrete beam

Specimen	7 days		28 days		56 days	
	Average load (kN)	Flexural strength (N/mm^2)	Average load(kN)	Flexural strength (N/mm^2)	Average load (kN)	Flexural strength (MPa)
Control (S)	42.5	7.6	58.0	10.3	74.35	13.2
2nos (B)	16.63	3.0	21.59	3.8	27.5	4.9
4nos (B)	27.8	4.9	30.2	5.4	34.0	6.0
6nos (B)	29.65	5.27	34.6	6.2	39.8	7.1
8nos (B)	31.4	5.6	41.8	7.43	48.4	8.6

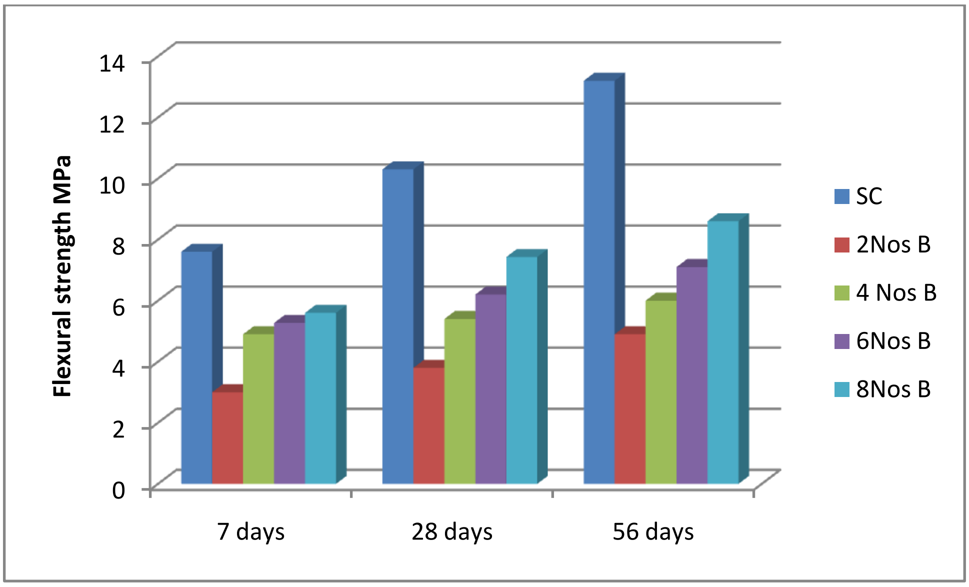

Fig.6: Flexural strength of 25 mm width bamboo

V. Conclusion and recommendation

5.1 Conclusion

The following were the conclusions made in this work:

- The average ultimate tensile strength of steel was 583 N/mm^2 while the bamboo in their various sizes had 60, 44, 33, and 29% respectively of steel strength.
- It was further assessed that the average bamboo culms height of 150 mm gave the value of 62.4 N/mm^2 in compression with the inn and outer diameter of 43 and 67 mm respectively.
- Average bending stress of 500 mm span bamboo tested for flexure resulted in 8.5 N/mm^2, thickness 13 mm, with inn and outer diameter of 43 and 68 mm.
- Flexure investigation of reinforced bamboo concrete beam tested at 28 days strength resulted:
- 12 mm width size - 2 nos 41.6%, 4 nos 42.7%, 6 nos 50% and 8 nos 63%.
- 16 mm width size - 2 nos 28.8%, 4 nos 35.9%, 6 nos 43% and 8 nos 55.2%.
- 20 mm width size – 2 nos 50.9%, 4 nos 51%, 6 nos 55.7% and 8 nos 68%.
- 25 mm width size – 2 nos 36.9%, 4 nos 52.4%, 6 nos 60% and 8 nos 72%.

5.2 Recommendations

Bamboo splints could be used as reinforcements in concrete, the strength possession depends on width sizes and generally for lightweight construction.

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