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BEHAVIOUR AND PERFORMANCE OF BAMBOO AS A REINFORCEMENT FOR CONCRETE BEAMS

BY

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Abstract. A growing attention to climate change has led to search for alternative and sustainable materials in construction. One promising material is bamboo because of its desirable mechanical properties. A research was conducted to assess the suitability of the bamboo as reinforcement material in concrete beams. Laboratory experiments were conducted on bamboo reinforced beams and using steel reinforced beams as control. Silt test, compaction factor test and slump test were carried out to ensure the suitability of concrete constituents used in the experiment. Flexural test was carried out on the beam to measure the flexural resistance of the beam reinforced with bamboo strips. Findings showed bamboo reinforced beams having 20-28% of the flexural strength of steel reinforced beams. Sizes of bamboo strips should be varied in order to get a more favourable flexural strength.

Keywords: aggregates; bending strength; experiments; bamboo reinforcement; water-cement ratio.

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1. Introduction

Bamboo is used as Bamboo Trusses, Bamboo Roofs Skeleton, Bamboo walling/ceiling, Bamboo Doors and Windows, Bamboo Flooring, Reed Boards, Scaffolding (Nayak *et al*., 2013). Bamboo possesses desirable properties, and hence can be used as reinforcement in concrete structures (Adom-Asamoah and Afrifa Owusu, 2010). The tensile strength of bamboo can be comparable to that of mild steel (Agarwal *et al*., 2014). Ashwin (2015) conducted an experimental investigation on deformations of bamboo reinforced concrete columns. The result showed that the bamboo reinforced column did not increase the strength but it enhanced the ductility of the section which makes it is suitable for low rise building. Pratima *et al*. (2013) evaluated the performance of bamboo as reinforcement in design of structural element. Three years old brown coloured bamboo plants were selected and each sample of 1m was chosen for the experiment. Moroz *et al.* (2014) assessed the performance of bamboo reinforced shear walls for use in low-cost houses.

This study is aimed at assessing the suitability of bamboo as reinforcement material in concrete beams with steel and bamboo stirrups.

2. Bamboo Reinforcement for Concrete Beams

Several investigations were conducted by Mahzuz (2011) on composite samples of bamboo where mortar was poured in its hole, with the mixture of sand, cement and stone chips poured in its hole, bamboo reinforced column sample where bamboos sticks were used as alternative of steel. Bhowmik *et al.* (2017) studied the splint of Bambusa Balcooa species used as reinforcing material in the brick aggregate concrete for making concrete beam using different percentage of bamboo reinforcement. The average tensile strength of bamboo was found to be 287.69 MPa. Khan (2014) conducted an experimental investigation on bamboo reinforced concrete beams. In his study he compared the beams reinforced with steel and bamboo sticks of square, triangular and circular cross section. Based on the experimental results obtained, load carrying capacity, deflection, flexural and shear strength of bamboo reinforced beam with square cross section was higher when compared to bamboo reinforced beam with triangular and rectangular cross section.

Nayak *et al.* (2013) studied the cost-wise comparison of steel reinforcement to bamboo reinforcement. He designed on the basis of shearing and bending. He conducted test on one-way slab of size 3000 x 7000 sq-mm with providing beam of 7000 mm length and 250 x 250sq-mm bamboo and finally found out that bamboo reinforcement is cheaper than that of Steel reinforcement. Terai and Minami (2012) investigated the mechanical properties of bamboo reinforced concrete structure and compared the result of bamboo reinforced concrete members with reinforced concrete members.

Ogunbiyi (2015) studied tensile strength-behaviour with different size of steel and compared it with bamboo reinforcement. The study concluded that due to the minimal breaking force of bamboo, it cannot be employed as a main structural member in building and other engineering works but can be used as partition wall, ceiling, roof and other areas of engineering construction that is not heavy load-bearing. Sevalia *et al*. (2013) conducted a study on bamboo reinforced cement concrete. In his study, several tests were carried out: tensile test on bamboo stirrups, compression test on cement concrete cubes and flexural test on bamboo reinforced concrete beams to evaluate the performance of bamboo. It was concluded that modulus of elasticity and load carrying capacity was greater in double reinforced beam than singly reinforced beam. Kariuki *et al*. (2014) conducted an experiment on flexural strength of laminated bamboo beams and concluded that bamboo laminated beam has better load carrying capacity than cypress beam.

3. Methodology

This section presents the laboratory test approach adopted for the study.

3.1. Materials

Fine aggregate/sand containing more than 85% sand-sized particles (by mass). Coarse aggregate/Stones with 6-20mm size, according to BS 812-2:1995.

Steel with a tensile strength to the reinforced concrete, according to BS 8110 part 1:1997. Cement/ Binder (Ordinary Portland cement conforming to BS12.2:1971). Dangote cement brand of class 42.5 R was used in the experiment.

Bamboo with brownish skin was used in the experiment (Pratima *et al*., 2013). A width of 12mm and seasoned with pesticide for 15 days (Kariuki *et al*., 2014).

Clean pipe borne water was used for mixing which conformed to the requirement of BS 1348(1980).

3.2. Methods

Mixing - A concrete mix-1:2:4 of concrete grade C25. By weight with water cement ratio 0.5 was used to produce concrete for the study. Casting and curing - Eighteen (18) reinforced concrete beam samples of 150×150 ×750 mm was done. Care was taken to properly cure the beams to achieve best strength. The samples were kept in moulds for 24 hours. The samples were air dried for 14 and 28 days respectively (BS 1881-108:1983, BS EN 12390-2:2009). Three beams each were provided at a water/cement ratio of 0.5 and 14- and 28-days curing for flexural strength testing.

Flexural tests were conducted on the beam samples with bamboo and steel reinforcement respectively Khan (2014). A mix ratio of 1:2:4 (C25) was used for casting of the bamboo reinforced beam and the bamboo reinforced concrete beam, Self-Compacting Concrete (SCC). Twelve bamboo reinforced concrete beams were subjected to a bending test, total of six bamboo reinforced concretes beams with steel stirrup, six bamboo reinforced concretes with bamboo stirrup and six reinforced steel concretes was cast and cured for fourteen (14) and twenty-eight (28) days (BS 1881-108:1983, BS EN 12390-2:2009). Laboratory test was carried out on both fresh and hardened concrete. The six reinforced steel concrete beams were cast to serve as a control sample.

All tests were carried out in the Civil Engineering Laboratory of Cape Coast Technical University, Ghana.

Silt test - Test was carried out according to the BS 812 to determine the amount of silt, clay, or other fine dust that may be present in the fine aggregates (sand sample).

Sieve analysis - Sieve analysis of coarse aggregates was done as prescribed in the BS 812: part 103: (1989).

Percentage of silt depth to sand thickness, Eq. (1):

$$\frac{\text{silt depth}}{\text{sand thickness}} \times 100\% \tag{1}$$

Workability of fresh Concrete - A slump test and a compaction factor test were conducted to access the workability of the fresh concrete. A slump test was conducted according to BS 1881-102 and a compaction factor test was conducted according to BS 1881-103.

Slump test - was performed according to BS 1881-102. Reduction in slump in time was measured and also concrete require monitoring by means of test to ensure the subsequent mixes were of the same consistency. The test was done to measure the degree of compaction resulting from the application of standard amount of work.

The compaction factor test was computed from the formula, $\text{C.F.} = \frac{\text{Mp}}{\text{Mf}}$.

$$\text{Therefore C.F} = \frac{11445}{13375} = 0.86 \tag{2}$$

Flexural test - was conducted to determine the bending strength or modulus of rupture of the specimen. The flexural strength of the beam was measured according to BS 12390-5:2000 using the flexural testing machine. The test measured the bending strength of the beam resulting from the application of load. The testing was done at the ages of 14 and 28 days after curing.

The Flexural strength was calculated using Eq. (3):

$$F_{cf} = \frac{FL}{d_1 \times d_2^2} \quad (3)$$

according to BS EN 123950-5:2000, Flexural Strength of Test Specimens where: Fcf – flexural strength, in MPa (N/mm²); F – maximum load in (N); L – distance between the supporting rollers (mm); d_1 and d_2 are the lateral dimensions of the specimens (mm) *i.e*. breadth (b) and depth (d).

The bond between bamboo and concrete was improved by providing a coal tar plus sand coating on the bamboo surface. Coal tar reduces the water absorption which diminishes the swelling and shrinkage effect of bamboo reinforcement.

Control test - A steel reinforced concrete beam of 12 mm diameter rod with metal stirrups was used as control. The results are presented in tables and scattered line graphs.

4. Findings

Tables 1 and 2 show the silt test results of the sieve analysis of coarse aggregates and fine aggregates, respectively.

Table 1
Sieve Analysis of Coarse Aggregates

BS sieve sizes (mm)	Mass of gravel retained (g)	Percentage Retained (%)	Percentage Passing (%)
20	273	12.55	87.45
14	629	28.93	58.52
10	766	35.23	23.29
6	477	21.94	1.35
Pan	29	1.33	0.02
TOTAL	2174	100%	-

The Universal soil classification system table shows that if $C_c = \frac{D_{30}^2}{D_{60} \times D_{10}}$ is between 1 and 3, the soil is classified as poorly graded aggregate. Considering D_{10} = 7.9 mm; D_{30} = 11.0 mm; D_{60} = 14.10 mm, it follows:

$$C_u = \frac{D_{60}}{D_{10}} = \frac{14.1}{7.9} = 1.78 \quad (4)$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{11^2}{14.1 \times 7.9} = 1.08 \quad (5)$$

Per ASTM classification, gravels are classified to be sizes of 60 mm to 2 mm. Within the gravel classification we have coarse gravel, medium gravel and fine gravel which are 60 mm to 20 mm, 20 mm to 6 mm and 6mm to 2 mm respectively. With respect to the ASTM classification it is observed that the aggregate used were medium gravel, as shown in Table 1 because it ranges from 20 mm to 6 mm and then pan. Since medium coarse was attained, its size improves the strength, workability of the concrete. There its uniformity with the distribution curve is as shown in Fig. 1.

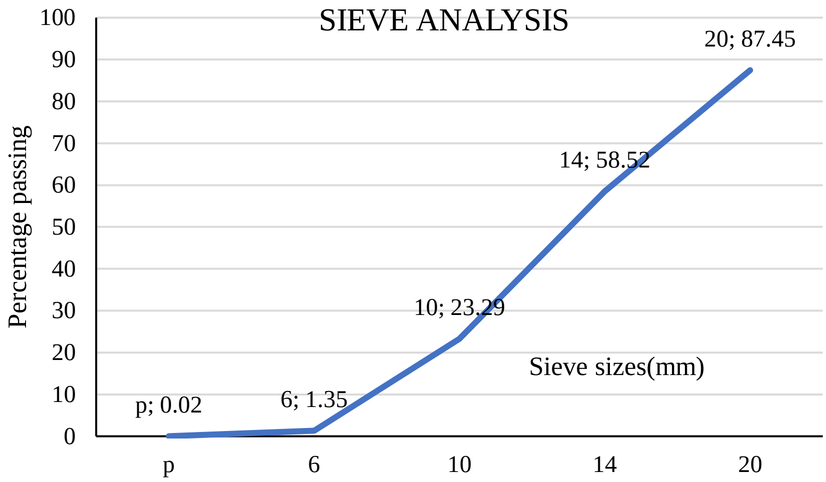

Fig. 1 − Particle size distribution curve of coarse aggregates.

Table 2

Sieve Analysis of Fine Aggregates

BS sieve sizes (mm)	Mass of gravel retained (g)	Percentage Retained (%)	Percentage Passing (%)
9.50	3	0.21	99.79
6.30	15	1.03	98.77
5.00	6	0.41	98.35
4.75	2	0.14	98.22
2.36	165	11.32	86.90
2.00	94	6.45	80.45
1.18	343	23.53	56.93
0.60	356	24.42	32.51
0.425	269	18.45	14.06
0.30	0	0	14.06
0.15	145	9.95	4.12
Pan	60	4.12	0
TOTAL	1458	100	-

The Universal soil classification system table shows that if $C_c = \frac{D_{30}^2}{D_{60} \times D_{10}}$ is between 1 and 3, the soil is classified as poorly graded aggregate. Considering D_{10} = 0.2 mm; D_{30} = 0.58 mm; D_{60} = 1.18 mm, it follows:

$$C_u = \frac{D_{60}}{D_{10}} = \frac{1.18}{0.2} = 5.9 \quad (6)$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{0.58^2}{1.18 \times 0.2} = 1.43 \quad (7)$$

Per the ASTM classification, sand is of size 2 mm to 0.0 6 mm. Table 2 indicates that there is some amount of gravel in the sand which is sieve 9.50 mm to 2. 36 mm. It gives the indication that the sand needs be to sieved before use for the concrete work. The sand exhibits uniformity per the distribution curve in Fig. 2. There is absence of silt in the sand at the end of the experiment.

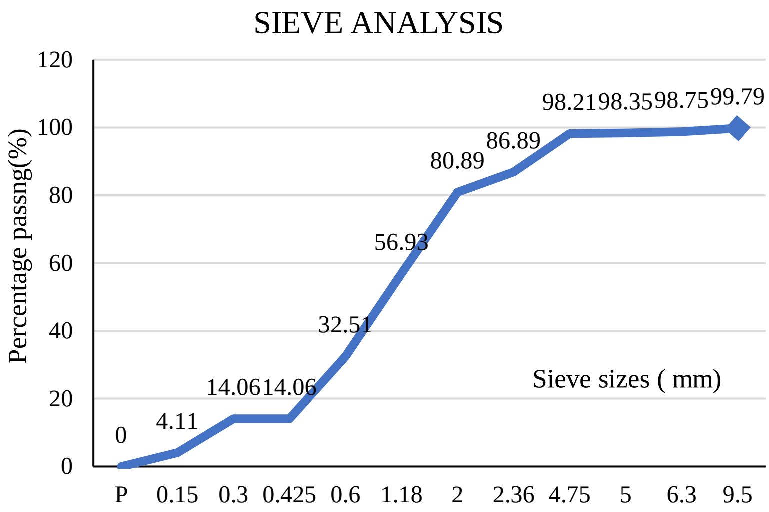

Fig. 2 − Particle size distribution curve of fine aggregates.

Table 3 presents the values obtained for the fresh properties of concrete, namely the compaction factor and the slump. The water to cement ratio was 0.5.

Table 3
Compaction Factor and Slump Values

Water / cement ratio	Compaction factor	Slump (mm)
0.5	0.86	10

Tables 4 and 5 show the properties of the steel and bamboo reinforcement bars respectively, as used in the experiment. The sample conformed to the requirement of steel grade B 500 and to the ductility class C and it can be classified as mild steel.

Table 4
Steel Reinforcement Bars

Description	Unit	Value
Diameter	mm	12
Cross-sectional area	mm^2	113.1
Mass per meter length	Kg/m	0.888
Elongation	%	15
Yield strength	N/mm^2	336
Ultimate tensile strength	N/mm^2	486

Table 5
Bamboo Reinforcement Bars

Description	Unit	Value
Diameter	mm	12
Cross-sectional area	mm^2	126.7

Table 6 shows the three samples (denoted by S.1, S.2 and S.3) for each curing age which differ from each other in terms of their maximum force and stress. It shows that the curing age also has an influence on the strength of the RC beam.

Table 6
Bending Strength and Ultimate Loads for the RC Beams

Days	Bending stress (N/mm^2)			Ultimate load (kN)		
14	S1	S2	S3	S1	S2	S3
	18.3	19.8	16.9	135.3	148	125.2
Average	18.33			136.17		
28	S1	S2	S3	S1	S2	S3
	16.9	19.6	20	125	145.5	150
Average	18.83			140.43		

Tables 7 and 8 show the bending strength bamboo RC beam with bamboo stirrup and bamboo RC beam with steel stirrup, respectively. It shows that bamboo with steel stirrup has high average bending stress than that with bamboo with stirrup. This indicates that the presence of steel stirrup in bamboo RC beam has an influence on the strength of the RC beam. Although stirrup was introduced in the RC beams to check for shear occurring in the beam.

Table 7
Bending Strength and Ultimate Loads for the RC Beams with Bamboo Longitudinal Reinforcement and Stirrups

Days	Bending stress (N/mm^2)			Ultimate load (kN)		
14	S1	S2	S3	S1	S2	S3
	3.9	3.4	3.6	29.9	25.1	25.4
Average	3.63			26.8		
28	S1	S2	S3	S1	S2	S3
	5.1	4.4	4.8	38.5	33.0	35.6
Average	4.77			35.7		

Table 8
Bending Strength and Ultimate Loads for the RC Beams with Bamboo Longitudinal Reinforcement and Steel Stirrups

Days	Bending stress (N/mm^2)			Ultimate load (kN)		
14	S1	S2	S3	S1	S2	S3
	4.1	4.0	4.5	27	26.5	30.1
Average	4.2			27.87		
28	S1	S2	S3	S1	S2	S3
	4.7	5.7	5.0	35.5	43.0	37.5
Average	5.13			38.67		

Table 9 and Fig. 3 show that as the curing age increases, the strength also increases and this denotes the effect of curing with respect to its age to the RC beam, because 28 days age recorded higher strength than that of 14 days age.

Different stirrup in bamboo RC beams has given the knowledge on the effect of steel stirrup and bamboo stirrup to the beams. The bamboo RC beam with steel stirrup attained higher strength than that with bamboo stirrup.

Table 9
Flexural Strength

Days	Flexural Strength (N/mm^2)		
	Steel RC Beams	Bamboo RC Beam	Bamboo reinforcement with steel stirrups RC Beam
14	18.16	3.57	3.72
28	18.72	4.76	5.16

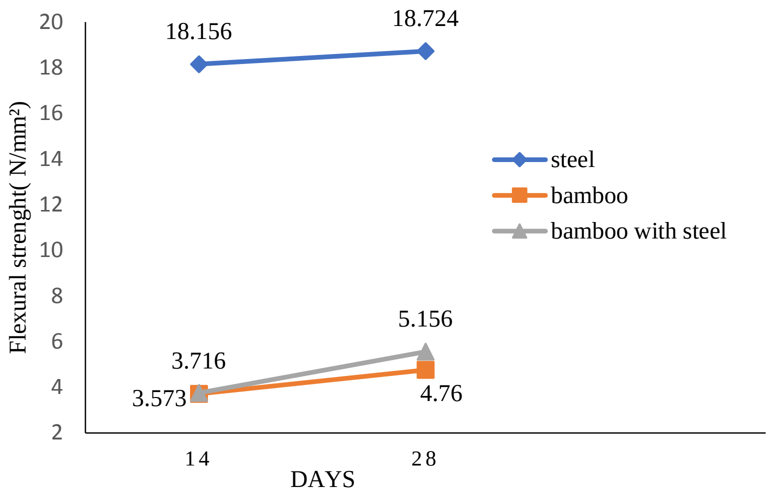

Fig. 3 − Flexural Strength of RC Beams Reference.

Table 10 shows that bamboo RC beams with bamboo stirrups attained 20% and 25% flexural strength of steel RC beam at the age of 14 and 28 days of curing respectively. Bamboo RC beams with steel stirrups attained 20% and 28% flexural strength of steel RC beam at the age of 14 and 28 days of curing respectively.

Table 10

Percentage Variation of Flexural Strength of Bamboo RC Beams to that of Steel RC Beams

Days	Bamboo RC Beam	Bamboo reinforcement with steel stirrups RC Beam
14	20%	20%
28	25%	28%

5. Summary of Findings

The percentage variation of flexural strength of bamboo RC beam to that of steel is 20-28%. Flexural strength of steel reinforced beams recorded 18.156 MPa and 18.724 MPa at age 14 and 28 days respectively. Flexural strength of bamboo RC beam with steel stirrup was 3.716 MPa and 5.156MPa at age 14 and 28 days respectively. Flexural strength of bamboo RC beam with bamboo stirrup recorded 3.573 MPa and 4.76 MPa at age 14 and 28 days respectively. Bamboo is essentially an elastic brittle material, whereas steel exhibits considerable ductility. This limits the ‘allowable’ stress that may be utilized with bamboo based on the margin of safety desired.

6. Conclusions and Recommendations

This study is aimed at assessing the suitability of bamboo as reinforcement material in concrete beams with steel and bamboo stirrups. Bamboo RC beams with steel stirrups were found to have higher flexural resistance than that with bamboo stirrups. Therefore, bamboo should be used for lightly reinforced structures.

Further research should be conducted with a different mix ratios and water cement ratio and varying sizes of bamboo strips in order to get a more favourable flexural strength.

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COMPORTAMENTUL ŞI EFICIENŢA BAMBUSULUI CA ARMĂTURĂ ÎN GRINZILE DIN BETON

(Rezumat)

Atenţia crescută de care se bucură schimbările climatice a dus la identificarea unor materiale alternative, sustenabile pentru domeniul construcţiilor. Una din soluţiile identificate este bambusul datorită proprietăţilor sale mecanice. Lucrarea prezintă rezultatele muncii de cercetare privind eficienţa bambusului ca armătură în grinzile din beton. Materialele componente care alcătuiesc betonul au fost testate cu privire la utilizarea adecvată a acestora. Încercările de laborator s-au efectuat pe grinzi din beton armat folosind ca material de armare bambusul dar şi oţelul traditional în epruvetele martor. Rezultatele testelor la încovoiere au arătat că epruvetele armate cu bambus au dezvoltat o rezistenţă la încovoiere cuprinsă între 20% şi 28% comparativ cu epruvetele în care s-a folosit armătura tradiţională din oţel. Ca direcţie viitoare de cercetare se propune modificarea diametrului armăturii din bambus pentru a creşte capacitatea portantă la încovoiere a grinzilor din beton.