SUITABLE BAMBOO STRIPS REINFORCEMENT RATIO FOR CONCRETE SLABS

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Abstract
Steel is a non renewable and environmentally unsustainable construction material. The search of renewable and environmentally sustainable material for flexural reinforcement of concrete had been the focus of many researchers. The use of Bamboo strip at flexural reinforcement for concrete slabs was considered in this paper. The effective performance of the Bamboos strips as tension reinforcement in concrete slab was assessed. The flexural capacities of Bamboo reinforced and plain concrete slabs were compared. The ultimate load of the slab reinforced with Bamboo strips was found to be almost seven times the ultimate load for the plain concrete slab. The ultimate flexural strength of the slab was achieved at 3% bamboo reinforcement. Therefore, Bamboo strips are suitable for use as tension reinforcement in concrete slab with reinforcement ratio not greater than 3%.

Keyword: *Bamboo, reinforcement ratio, reinforcement ratio, vegetable fibre, slabs*

1.0 INTRODUCTION

1.1 Background

Concrete is a widely used construction material for its numerous advantages among which are low cost, availability and fire resistance. Concrete cannot be used alone in flexural members such as slabs and beams. This is because of its low tensile strength. Steel is the convention tensile reinforcement material in concrete. It has a high tensile strength to take care of the low tensile strength of concrete, but its high cost due to costly manufacturing process lead to renewed interest in the search of alternative material (e.g. Urbanski, 2013). Apart from high cost, steel is not an environmentally sustainable material. Thus a more suitable substitute to steel is required. The required alternative material need to be cheaper, environmental friendly and with low required manufacturing energy (Rahman *et al*, 2011).

There many research efforts on the suitability of Bamboo as alternative tension reinforcement in concrete. It was clearly established in the literature that the tensile strength of bamboo is relatively high and can attain up to or more than 123 N/mm^2 (Harish et al., 2012; Ghavami, 2005). This made Bamboo, an attractive substitute to steel in tensile loading applications.

Some of the notable results on the performance of Bamboo reinforced concrete could be found in Adom-Asamoah et al. (2018); Archila, et al. (2018); Dange and Pataskar (2017); Maruthupandian, et al. (2016); Subramaniam and Venugopal, (2015); Bhonde, et al. (2014); Ajinkya, et al. (2013); Salau et'al. (2012); Wakchaure and Kute (2012); Atul and Damodar, 2011; Ghavami (2005). Most of work on Bamboo has focused on the comparison of the performance of Bamboo and steel reinforced concrete. There was little or no effort in the literature to establish the most suitable performance of Bamboo reinforcement in concrete. The aim of this paper is to determine the most suitable reinforcement

ratio of Bamboo as tension reinforcement in one way reinforced concrete slab.

2.0 MATERIALS AND METHODS

2.1 Materials

The materials used in this work include; bamboo strips, fine aggregate, coarse aggregate, Ordinary Portland cement and portable water.

2.1.1 Bamboo Selection and Preparation

The Bamboo, used for this study was obtained from Tanke Oke-odo Area of Ilorin, in Kwara state. The stem of the bamboo was cut to the required sizes and stacked for open air seasoning. Following the recommendations of various bamboo researchers (Salau *et'al*,2012), the selection of the bamboo was done thus:

i. Only Bamboos, showing a pronounced brown colour were used in order to ensure that the plant was mature and at least three years old.
ii. As far as possible, straight long bamboos without any deformations and cracks were selected.
iii. Bamboos used were free of any decay, fungus growth or holes due to white ants.
iv. The Bamboos were not cut under wet condition because the culms are generally weaker due to increased fiber moisture content.
v. All main reinforcements consist of bamboo splints with the nodes exposed upwards to increase bond; thus bamboo species with the greatest number of nodes were selected.

The selected bamboos were air seasoned for about 30 days and then cut into average strips sizes of 10 mm thick by 20 mm width by 1000 mm long. To determine the ultimate stress of the seasoned strip, 10x20 mm strip of 200 mm gauge length were axially loaded in tension on a 600 kN Avery Denison universal tensile testing machine. The specimens were tested to failure. The surface of the Bamboo strips was lightly scratched to induce roughness on the surface, in order to increase bond between it and concrete. To reduce water absorption as well as increase the bond with concrete matrix, the Bamboo strips were coated with bitumen and then sprinkled with fine sands in order to mimic the surface roughness of steel reinforcement. During the design phase of the experimental programme, 20-30 N/m^2 concrete compressive strength was chosen for the Bamboo Reinforced Concrete (BRC) one-way slabs. The cement content is 231 kg/m^3. The water/cement ratio is 0.65. While the aggregate maximum size of 15 mm.

2.1.2 Fine Aggregate

Sharp sand was used as the fine aggregate, having grains with a lower size limit of 70 or 60 μm and not larger than 4mm. The specific gravity and fineness modulus are 2.60 and 2.65 respectively. The sand was sieved with sieve size 4.75 mm to get rid of unwanted sizes. It was then washed and cleaned with water and spread out and left to dry in air before use.

2.1.3 Coarse Aggregate

Crushed stone of nominal size 15 mm was used as coarse aggregate, having specific gravity and fineness modulus as 2.68 and 3.58 respectively. The granite dust in the coarse aggregate was thoroughly sieved out, leaving no grains less than 9mm.

2.1.4 The Ordinary Portland Cement

Ordinary Portland cement of 43 grade was used throughout the study. The Normal consistency of the cement is 28%. The initial are final setting times are 124 min. and 185 min respectively. The compressive strength of the cement at 28 days is 25 N/mm^2. The

cement was stored in air tight sacs to avoid undue exposure to the atmosphere.

2.1.5 Mixing water

Portable water with no visible impurities was used for the concrete mixing and curing of all specimens.

2.2 Methods

The concrete mix proportion by weight adopted for this work was 1:2:4 (cement: sand: coarse aggregate) with water/cement ratio of 0.65 so as to have a true slump, workable and greater movement of concrete around the bamboo strips. Also 20-30 N/mm^2 compressive strength was used for the one-way bamboo reinforced concrete slabs.

The test specimens were one-way slab of 600 mm x 250 mm x 100 mm. The concrete slabs were reinforced with different amount of 10 mm x 20 mm bamboo strips resulting into varying percentages from 0% to 5%. The Bamboo reinforced concrete slabs were subjected to flexural tests with unreinforced plain concrete slabs serving as the control.

In the absence of any standard specifications for incorporating bamboo in concrete, reference was made to clauses 3.12.5 and 3.12.6 of the British Standard BS 8110 (1997), which stipulated a minimum of 0.4% and a maximum of 8% gross sectional area for reinforcement. Three-point bending test was adopted to assess cracking, deflection and flexural strength of the slabs at 28 days curing period. 30 concrete cubes of 150 mm size were cast from the slab mix to determine the compressive strength of the concrete. Crushing of the cubes was carried out at 28 days to determine the compressive strength.

2.2.1 Tensile test of the bamboo strips

Bamboo sticks of approximate cross sectional area of 200 mm^2 were tested for yield strength in universal testing machine and the average yield strength of bamboo stick was determined.

2.2.2 Casting of the Slab Specimens

Five number plain concrete slab panel of size 600 mm long by 250 mm wide 100 mm thick were cast considering 1:2:4 mix ratio and water cement ratio of 0.65. The mix of the materials prior to casting was implemented using laboratory based concrete mixer, and concrete was placed into prepared wooden mould in three layers. Every layer was tamped properly using tamping rod and then allowed to settle. The plain concrete specimens were then kept in wet place and demolded after 24 hours and then submerged in water in an open curing tank for 28 days curing period.

For the Bamboo, reinforced concrete slab, five reinforcement ratio of 1%, 2%, 3%, 4%, 5% were adopted for assessment as mentioned earlier. Five specimen were cast for each reinforcement ratio with the bamboo strips placed at the tension zones of the specimens. Plate 1 shows some of the prepared Bamboo reinforcement and plate 2 shows some of the slab specimens.

Plate 1: Some of the prepared Bamboo reinforcement

Plate 2: Casting of the slab specimens

2.2.3 Bending Tests

Each of the slab specimens (plain and the reinforced) was subjected to three-point bending tests and the failure loads were determined in accordance with BS EN 12390-5 (2000). The load was applied using a 600 kN capacity Avery Denison universal tensile machine. The distance between the specimen supports was 600 mm. the deflection of the specimens was measured at the mid-span using a dial gauge with precision of 0.01mm. The experiments were conducted at the concrete research laboratory of the Department of civil engineering, Ahmadu Bello University, Zaria. The test set up presented in Plate 3 and Figure 1.

Plate 3: Bending Test Set Up

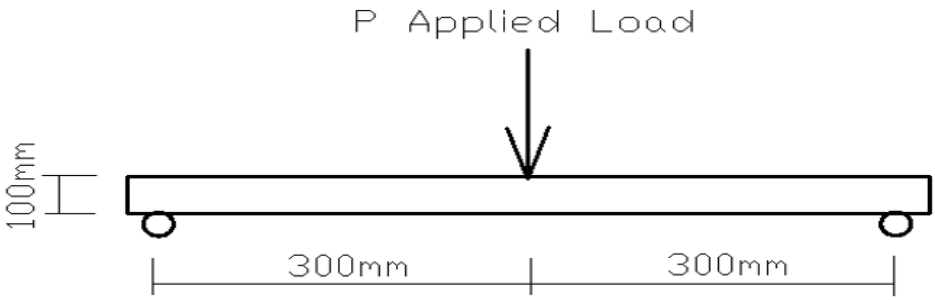

Figure 1: Test setup for slab specimens (Khan, 2014)

The result obtained from the bending test includes, ultimate load, maximum deflection and the flexural strength of the BRC slabs. The flexural strength was computed using equation (1.0) (Kurheka *et'al*, 2015).

$$f = \frac{3P_{max}l}{2bh^2}$$

(1.0)

Where, $\boldsymbol{P}_{max}$ = Maximum bending load (kN); L = length of sample (mm); b = width of sample (mm) and ; h = thickness of sample (mm)

3.0 RESULTS AND DISCUSSION

3.1 Properties of the Bamboo Strips

Natural Bamboo of pronounced brown colour were used in this study. Tensile tests were conducted on the Bamboo samples with nodes at gauge position. For most the specimen failed at the nodes. The result of tensile test of bamboo strip with ultimate load and modulus of elasticity are presented in Table 1.0.

Table 1: Result of tensile of the bamboo strips

Sample No.	Area (mm^2)	Ultimate load (kN)	Ultimate Tensile Stress (N/mm^2)
1	155.5	27.0	173.63
2	166.11	28.6	172.19
3	160.05	24.65	154.01
4	168.00	29.5	175.6
5	127.02	25.8	203.12
6	141.36	28.0	200.55

The average tensile strength of the Bamboo specimens used in this research is $180N/mm^2$.

3.1.2 Bending Tests Results

In the experimental program the concrete slabs reinforced with the Bamboo strips at the tension zone were tested in bending using three-point bending tests and the load-deflection curve were plotted. The results were compared with that of plain slabs of the same dimension. The bending test results are presented in Table 2.0. The results comprise of ultimate load at which the panel failed and ultimate deflection of the slab.

Table 2.0: Bending test results

S/No.	Slab Specimen	Weight of the slab (kg)	Ultimate load on slab (kN)	Ultimate deflection of slab (mm)
1	Plain Concrete	38.1	5.5	1.85
2	1 % Bamboo Reinforced	39.0	19.0	2.93
3	2 % Bamboo Reinforced	38.3	25.0	3.16
4	3 % Bamboo Reinforced	37.8	38.0	4.55
5	4 % Bamboo Reinforced	39.2	28.0	2.225
6	5 % Bamboo Reinforced	36.0	20.0	3.10

It was observed that the BRC slabs exhibit ductile failure under the application of loadings in flexure, while the plain concrete shows a brittle failure. At ultimate load, BRC slabs crushed under ultimate load then followed by the rupture of the bamboo strips. This might be due to the low structural property of bamboo (that is, young's modulus, yield strength, etc.) when compared to that of steel. The response of bamboo reinforced concrete slab to load shows similar trend with that of rattan cane reinforcement in the work of Akinyele and Olutoge (2011).

3.2 The Plain Concrete Slab (PCS)

The plain concrete slab control specimen failed suddenly without prior notice. Hence the failure mode of this specimen is brittle and the ultimate failure load is 5.5 kN.

3.3 The Bamboo Reinforced Concrete Slab (BRCS)

The reinforcement ratio of 1 to 5% was done by introducing the bamboo strips in the tension zone. While the BRC slab was under loading, cracks were seen to be growing in the vertical direction. The first crack occurred vertically from the point of load application which was flexure crack and the crack was widened. Then, crushing of concrete at the point load application was observed. The crack was rising very smoothly and slowly. The slab panels failed at a load of 19.0 kN, 25.0 kN, 38.0 kN, 28.0 kN, and 20.0 kN at 1%, 2%, 3%, 4%, and 5% of bamboo reinforcement ratio respectively. In singly reinforced bamboo panel, providing different percentages of bamboo strip ratios, that is, 1 to 5% in tension zone has enhanced the load carrying capacity of bamboo reinforced concrete slabs when compared to that of the controlled specimens.

From the results obtained, it can be seen that bamboo strip offers an increase in modulus of elasticity of the BRC slab compared to the plain ones. Also, it has been seen that using bamboo as reinforcement in concrete increases the load carrying capacity of slab to 38kN at 3% BRC and then dropped to 28 kN and 20 kN at 4 % and 5% respectively. The reason for the reduction in load carrying capacity of the slab might be attributed to large area of the bamboo strips had occupied in the concrete, thereby preventing adequate concrete to concrete bond. For singly bamboo reinforced concrete slab, the load carrying capacity increased to about 6 times, while maximum deflection of BRC slabs was 3times that of plain concrete. Rahman et al, (2011) also arrived at a similar result while evaluating the performance of bamboo reinforced beams.

3.4 Deflection- Load curves

Typical deflection-load curves for the singly BRC slabs are shown in Figure 2:

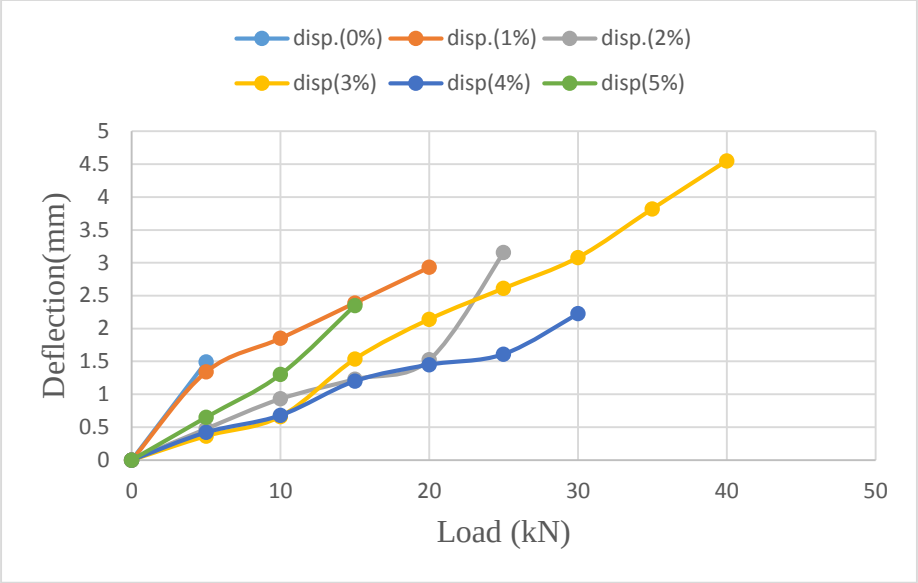

Figure 2 ; Relationship of load (kN) to deflection (mm) at reinforcement of 0 to 5%.

The central area undergoes some shear as well as maximum bending moment. Failures are generally due to a combination of the two failure modes. Usually bending failure cracks were the first to develop at the bottom surface of slab. This is because concrete is weak in tension. The first crack was initiated under the point load and propagated upward towards compression zone of concrete. As the load increased, additional cracks started to form throughout the slab that widened and propagated upward till the failure occurred.
Also, from the load- deflection curve, initial loading of the slabs showed approximately linear-elastic characteristics until the cracking load was exceeded, the first crack developed at the bottom of the slab at the middle where maximum bending occurred. After cracking, the gradient of the initial load–deflection curve reduced and continued to reduce gradually until the bamboo strip has yielded. A similar result was obtained from Asamoah and Kamkam (2009), while working on ‘‘Flexural behavior of one-way concrete slabs reinforced with steel bars milled from scrap metals’’. He suggested in his work that crack initiation was primarily due to pure bending action rather than shear. The modulus of rupture and corresponding deflection increases for BRC specimens as compared to those for plain concrete.

Table 3: Modulus of rupture and deflection for plain and bamboo reinforced concrete slabs

Sample	MOR(MPa)	Deflection (mm)
Plain Soncrete	1.98	1.85
1%BRC	6.84	2.931
2%BRC	9.0	3.155
3%BRC	13.68	4.55
4%BRC	10.08	2.225
5%BRC	7.2	3.10

However, it could be seen that the load carrying capacity of the bamboo reinforced slab with 3% reinforcement ratio was higher than other bamboo reinforced slabs reinforced with more than 3% reinforcement ratio. That of the plain concrete slabs has the lowest load carrying capacity. Also, from the test, it was observed that the modulus of rupture (MOR) increases to a maximum value of 13.68 at 3% reinforcement ratio, and it then reduced to 7.2 at 5% reinforcement ratio respectively. The 3% bamboo reinforcement ratio can be taken as the maximum reinforcement ratio for bamboo strips reinforced concrete slabs. For the situation were the strength requirement of the slab requires more than 3% bamboo strip, the additional strength requirement can be obtained through the use of conventional method by for example the use of steel reinforcement.

4.0 CONCLUSIONS

i. The experimental results show increase of flexural strength by about 590% for the Bamboo Reinforced Concrete (BRC) slabs compared with the plain concrete slabs. Also. the introduction of bamboo resulted to improvement in its ductile capacity, reducing the tendency of brittle mode of failure of the slab.

ii. There was substantial increase in flexural efficiency with bamboo as reinforcement in concrete. The plain slab failed at a load of 5.5 kN, while that of BRC at reinforcement ratio of 1%, 2%, 3%, 4,5% failed at a load of 19.0 kN, 25.0 kN, 33.0 kN, 28.0 kN and, 20.0 kN respectively.

iii. From the result obtained, the modulus of rupture of the bamboo reinforced concrete slab was found to be 3.45 N/mm^2, N/mm^2 5.0 N/mm^2, 6.91 N/mm^2, 5.09 N/mm^2, and 3.64 N/mm^2 times that of plain concrete slab for 1%, 2%, 3%, 4% and 5% bamboo reinforcement respectively.

iv. It was found that, the ultimate performance of the Bamboo strengthened slab was at 3% Bamboo strips reinforcement.

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