ISSN 2229-5518

Flexural Performance of Bamboo Reinforced Foamed Aerated Concrete Beams With and Without Compression Reinforcement

Efe Ikponmwosa, Funso Falade, Christopher Fapohunda, James Okosun

Abstract— The results of investigation conducted to evaluate the flexural performance of foamed aerated concrete beams with bamboo splints as tensile reinforcement, but with and without shear links are reported in this paper. The properties assessed are: density, compressive strength, crack pattern, deflection, and failure and moments. Foamed aerated concrete, having a cement-sand ratio of 1:3 was prepared. For foam generation, foaming agent and water in the ratio of 1:33 was prepared. A total of seventy two numbers of 225 x 225 x 2350 mm beam specimens with bamboo splints as reinforcement, with and without shear links and compression reinforcement were tested for flexural strength. For the shear links, 8mm diameter steel reinforcement at 150 mm centres was used. The specimens were tested at 7, 21, 28 and 45 days of curing. The results showed that beams specimens without compression and shear reinforcement exhibit shear failure while the beam specimens with compression and shear reinforcement displayed flexural failure. Larger deflection was recorded for beams without compression and shear reinforcement than for beam specimens with compression and shear reinforcement. Also beam specimens with compression and shear reinforcement developed higher moment than specimens without compression reinforcement. From the results of the investigations, it can be conclude that specimens with compression reinforcement in the compression zone displayed a better flexural performance than specimens without compression reinforcement in the compression zone.

Keywords— Aerated Concrete, Bamboo, Beams, Compression bar, and Flexural strength..

1 Introduction

Bamboo is a material that is presently being considered as a cheap substitute for steel as a reinforcing material in concrete production. The reasons for growing interest in bamboo, according to Rahman et al [1] include: availability, cheap, and its strength both in compression and tension , despite the fact that it has been used for construction of dwelling, and as props, framing, scaffolding for flooring, walls, roofs and trusses as observed by Adom-Asamoah and Afrifa [2]. The renewed interest in bamboo as a structural material has generated research activities. Maulik and Sanghvihave [3] presented a result of investigation that compared Bamboo-based construction with the modern construction practices. They concluded that the Bamboo housing system have sufficient strength for application for housing system. Siddhpura et al. [4] investigated the flexural performance of concrete beams with bamboo both as reinforcement and stirrups. Two types of coating, namely coal tar and epoxy resin, were used for the bamboo splints used as the reinforcement. Their results showed that beams specimens in which the bamboo splints were coated with coal tar exhibits higher flexural performance than specimens in which the bamboo splints were coated with epoxy resin.

Sevalia et al. [5] in their own investigation compared the structural performance of three types of beams: plain concrete beams, singly-reinforced beam with two numbers of bamboo splints at the tension zone, and doubly-reinforced beam with two bamboo splints both at the compression and tension zones. The beams had no stirrups. Their results showed that the doubly-reinforced beams performed better. The bond characteristics of surface conditions of bamboo splints with concrete were the object of investigation by Nithiplangsriskul [6]. Bamboo splints without surface coating, with coatings of asphalt, and with coatings of polydimethylsiloxane (PDMS) were used for the investigations. He discovered that beams reinforced with bamboo splints coated with asphalt exhibited greatest bond strength. Khare [7] carried out investigations to evaluate the feasibility of using bamboo as a structural material in reinforced concrete beams. Three types of beams: plain, bamboo-reinforced, and steel-reinforced, were used. He discovered that the use of bamboo increased the load-carrying capacity of plain concrete beams by as much as 250%, and developed 35% of load-carrying capacity of equivalent reinforced concrete beams. Sabbir et al. [8] evaluated the tensile properties of bamboo splints in reinforced concrete. The parameters evaluated were tensile strength, proof strength, and modulus of elasticity. They concluded that the tensile properties of bamboo-reinforced concrete beams are adequate for low-cost construction works. All these research efforts were conducted using the conventional concrete. Few research works are available on the applicability of bamboo splints as reinforcement in foamed aerated concrete, which is gradually being considered as solution to high cost of construction. There are fears however that using steel reinforcement in foamed aerated concrete will likely wipe out the comparative ad-

- *Efe Ikponmwosa is an Associate Professor at the Department of Civil and Environmental Engineering, University of Lagos. Email: efe_ewaen@yahoo.com*
- *Funso Falade is a Professor of Civil and Environmental Engineering, at the Department of Civil and Environmental Engineering, University of Lagos. Email: ffalde@hotmail.com*
- *Christopher Fapohunda is a Doctoral Student at the Department of Civil and Environmental Engineering, University of Lagos.* Email: fapohunda07@yahoo.com
- James Okosun is a Masters Student at *the Department of Civil and Environmental Engineering, University of Lagos.*

ISSN 2229-5518

vantage of foamed aerated concrete over the normal concrete in terms of reducing the cost of construction especially for low-cost buildings.

The aim of this work is to investigate the possibility of using bamboo splints as a structural material (reinforcement) in foamed aerated concrete production, by looking at the effects of shear links in bamboo-reinforced foamed aerated concrete beams. Shear links are usually provided to prevent cracking, and with compression reinforcement for proper anchorage of the links. The objective of this work is to investigate to what extent the absence or presence of shear link and compression reinforcement contributes to the structural performance of bamboo-reinforced foamed aerated concrete beams. The parameters investigated were: density, compressive strength, and flexural performance.

The definitions of some nomenclature in this work are: f_{bT} = ultimate stress of bamboo in tension = 95N/mm^2, f_{bC} = ultimate stress of bamboo in compression = 20N/mm^2, s = depth of compression zone in the aerated concrete section of the simplified stress block, f_{cua} = compressive stress of aerated concrete, A_b = area of tensile bamboo reinforcement, $A_{b'}$ = area of compressive bamboo reinforcement, b = with of the beam section, d = depth of tensile reinforcement, d' = depth of bamboo compressive reinforcement, M_u = ultimate moment of resistance

2.0 Experiment Details

2.1 Materials

Ordinary Portland Cement (OPC) whose production was in accordance with BS 12 [9] was used for this work. River sand obtained from river Ogun, Nigeria was used as fine aggregates. Particles passing through sieve size 3.35mm but retained on sieve size with 63μm was used for the production of foamed aerated concrete. The foam was generated using a lithofoam foaming agent, sourced from Germany. The characteristics of bamboo used for these works, based on the results of works done by Salau et al. [10] are: (i) bamboos that are three years old and showing a pronounced brown colour, (ii) bamboos without decay, fungus growth, or holes due to white ants, deformation with large diameter and straight long, (iii) bamboo having greater number of nodes. In addition, the selected bamboos were air dried for over 30 days (seasoning in air), and then sawn into strips size of 10 x 10 x 24000mm. In order to reduce water absorption and increase the bond with lightweight aerated concrete matrix, the bamboo strips were coated with bitumen. Wound around the bamboos is 1mm diameter coir rope at a pitch of about 25mm along the strip from end. 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 behaviour of the bamboo reinforced aerated concrete. Also, fine sands were sprinkled over the coats of bitumen with the aim of inducing roughness on its surface. Bamboo reinforcing bars completely coated and sand blasted are shown in Figure 1.

2.3 Experimental procedures

The mix proportion for the production of foamed aerated concrete used for this work are cement/sand ratio 1: 3, foaming agent/water ratio of 1: 33, and water/cement ratio of 0.7. The bamboo reinforcing bars are arranged with the 8mm diameter links spaced at 150mm centres. The bamboo strips were 10mm x 10mm in section. Thirty six foamed aerated concrete beams of 225 x 225mm cross-sectional area and 2350mm long reinforced with different percentages of the treated bamboo strips as tensile reinforcement were cast for the

Figure 1: Treated Bamboo Reinforcing bars

determination of the flexural strength. The thirty six beams with shear links, were divided into three groups I, II, and III as shown in Figure 2.

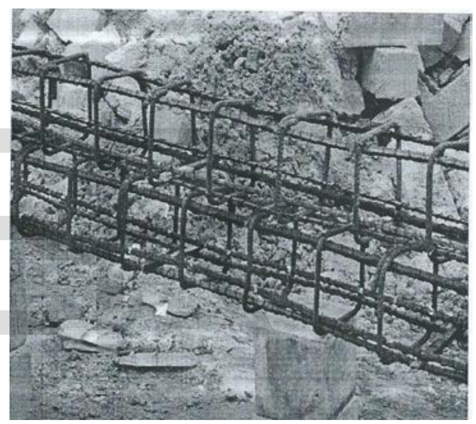


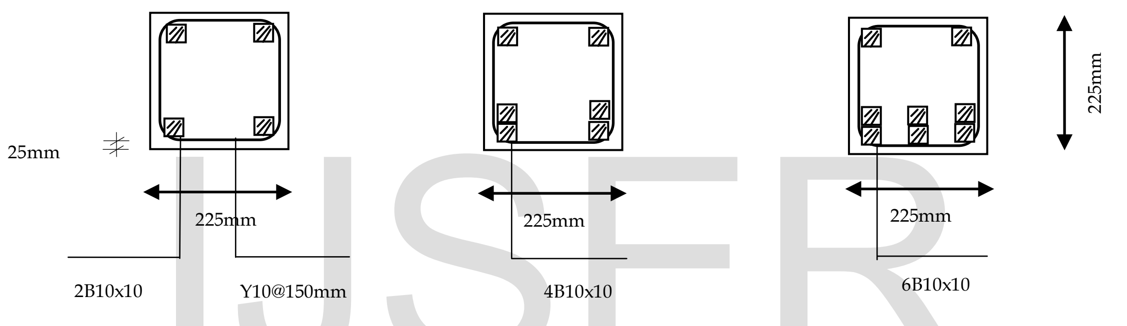
Figure 2: The arrangement of bamboo in the foamed aerated concrete beam with shear links

Group I consists of eight (12) beams with 2Nos of bamboo reinforcement bars at the tension face. Group II consists of eight (12) beams with 4Nos of bamboo reinforcement, while Group III has eight (12) beams which were reinforced with 6 Nos of bamboo reinforcement. Three beams in each of the group were tested tin flexure under third point loading at the curing age of 7, 21, 28 and 45 days. Another set of thirty six numbers of 225 x 225 x 2350 mm beams specimens without shear links, but with spacer bars were cast and labelled Groups IV, V, and VI. The spacer bars were at 150mm spacing. Figures 2 and 3 showed the arrangement of bars for the two sets of beams, while Figure 4 shows foamed concrete casting operation. The cross-sections are shown in Figures 5 and 6. The beams were tested under third point loading arrangement shown in Figure 7. Also twelve foamed aerated concrete cubes of 150 x 150mm in cross section were prepared for the determination of the compressive strength at different curing age of 7, 21, 28 and 45 days.

ISSN 2229-5518

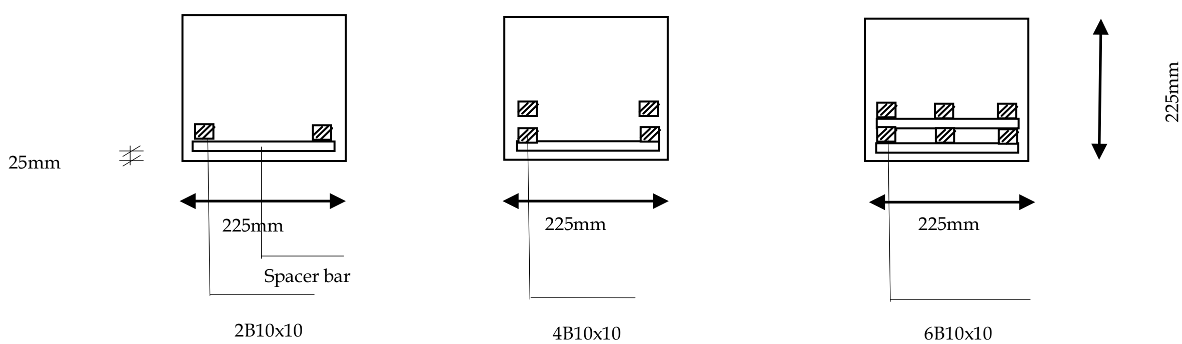
Figure 3: The arrangement of bamboo in the foamed aerated concrete beam without shear links

Figure 4: Foamed aerated concrete beams concreting operation



(a) Group I: 2 Tensile Bars (b) Group II: 4 Tensile (c) Group III: 6 Tensile

Figure 5: The cross sections of the three Groups of beams



(a) Group I: 2 Tensile Bars (b) Group II: 4 Tensile Bars (c) Group III: 6 Tensile Bars

Figure 6: The cross sections of the three Groups of beams without shear links

ISSN 2229-5518

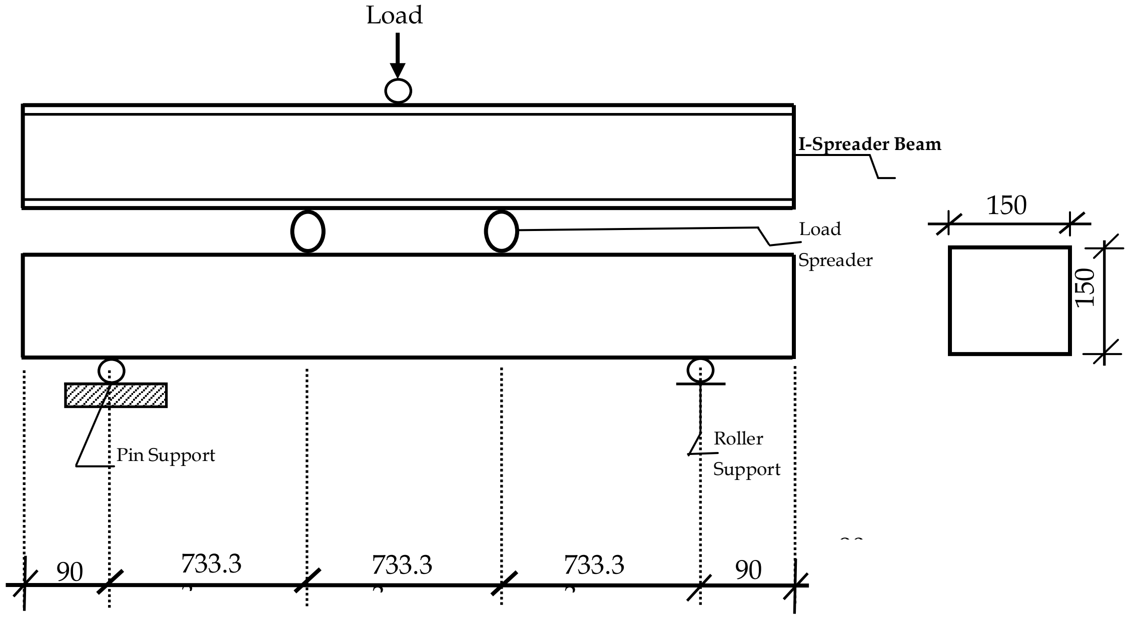
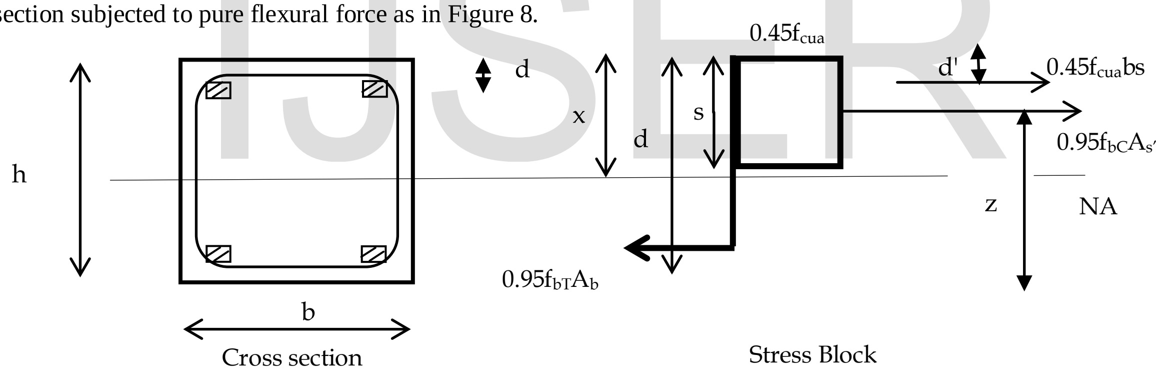


Figure 7: The Loading Arrangement for the Third Pont Loading Arrangement

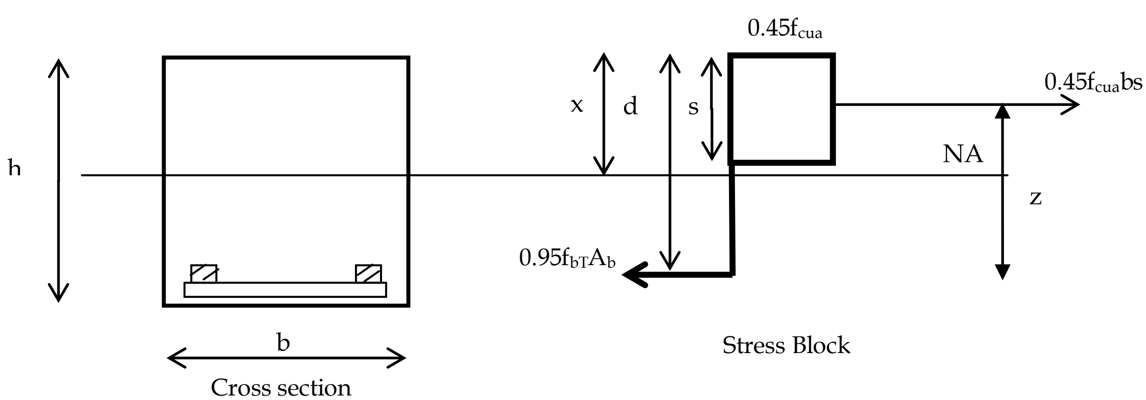
Theoretical Computation of Flexural Strength

The theoretical moment was calculated for each of the beam specimens using the simplified stress block at the ultimate limit state in accordance with the provision of BS 8110 [11] for the analysis of reinforced section subjected to pure flexural force as in Figure 8.

The factor of safety for aerated concrete and bamboo are assumed to be of concrete and steel as defined by BS 8110 [11] which are 1.5 and 1.05 respectively.



a. Beams with shear links



b. Beams without shear links

Figure 8: Simplified Stress block for Foamed aerated concrete beams section under Flexural Forces

From the simplified stress block, the ultimate moment of resistance ... ent at the centre of tensile bamboo

ISSN 2229-5518

reinforcement.

$$M_u = 0.45 f_{cua} \times bs \left(d - \frac{s}{2}\right) + 0.95 fbc \times Ab'(d - d') \quad (1)$$

The value of s in the equation can be determined from the stress block by considering equilibrium of forces in the section. The governing equation will be

Tensile force = Compressive force (2)

Therefore

$$0.95 fb_T \times Ab = 0.95 fb_c \times A_{b'} + 0.45 f_{cua} bs \quad (3)$$

$$s = 0.95(fb_T \times Ab - fb_c A_{b'}) / 0.45 f_{cua} b \quad (4)$$

Utilizing the equation 1 and 4 derived above, the calculations of the simplified depth of compression zone, s, as well as that of theoretical ultimate moment of resistance for the beams are presented as follows.

Beams with Shear Links

Group I: Beams (with two bamboo splints as tensile bars)

Taking the centre of tensile force to be the mid-depth of the double layers of the bamboo reinforcement,

d = h – c – diameter of link – (diameter of bar)/2

d = 225 – 25 - 10/2 = 185mm

from Equation (4).

s = 0.95(95 * 200 – 20 * 200)/ (0.45 * 9.333 * 225)

s = 15.08mm

Substituting s in Equation (1),

Mu = 0.45 * 9.333 * 225 * 15.08 (185 – 15.82/2) + 0.95 * 20 * 200 (185 x 30) x 10 $^{-6}$

Mu = 3.62KNm

Similarly, for

Group II Beams (with four bamboo splints as tensile bars), **Mu = 5.65KNm**

Group III Beams (with six bamboo splints as tensile bars), **Mu = 8.02KNm**

For the beams without shear link

The value of s in the equation can be determined from the stress block by considering equilibrium of forces in the section. The governing equation will be

Tensile force = Compressive force

Therefore

$$0.95 fb_T \times A_b = 0.45 f_{cua} bs \quad (5)$$

$$s = 0.95(fb_T \times A_b) / 0.45 f_{cua} b \quad (6)$$

By taking moment about the center of the reinforcement produces:

$$M_u = 0.45 f_{cua} \times bs \left(d - \frac{s}{2}\right) \quad (7)$$

Group IV: Beams (with two bamboo splints as tensile bars)

Taking the centre of tensile force to be the mid-depth of the double layers of the bamboo reinforcement,

d = h – c – (diameter of bar)/2

d = 225 – 25 - 10/2 = 195mm

from Equation (6).

s = 0.95(95 * 200)/ (0.45 * 9.333 * 225)

s = 19.10mm

Substituting s in Equation (7),

Mu = 0.45 * 9.333 * 225 * 19.1 (195 – 19.10/2) x 10 $^{-6}$

Mu = 3.347KNm

Similarly:

Group V Beams (with four bamboo splints as tensile bars), **Mu = 5.98KNm**

Group VI Beams (with six bamboo splints as tensile bars), **Mu = 8.46KNm**

3.0 Results and Discussions

3.1 Preliminary Tests on Aerated Cubes and Bamboo Strips

The average density of the foamed aerated concrete in this study is 1706.20kg/m^3. This value is within the range for lightweight concrete, for which this investigation is being conducted. The average 28day compressive strength of aerated concrete is 9.33N/m^2. The average tensile strength of bamboo splints was 95N/mm^2 which is about 38% of the mild steel. Also bamboo splints showed negligible elongation from the results obtained from all the specimens tested.

3.2 Failure Mode of Beams

3.2.1 Foamed Aerated Concrete Reinforced Beams without Compression Reinforcement

All the beam specimens without compression reinforcement (and the attendant links for proper anchorage) exhibited shear failure. The visual evidence of this type of failure is in the form of diagonal crack from the support to the direction of the point of load application, and this cracks widened in width until failure. Another feature displayed by beams with 6 bamboo splints at the tensile zone shown was also in form of many cracks inclined in the direction of the applied load, which resulted in the crushing of the concrete specimens.

3.2.2 Foamed Aerated Concrete Reinforced Beams with Compression reinforcement

All beams irrespective of the numbers of bamboo splints in the tension zone exhibited flexural tension failure of the bamboo reinforcement. This type of failure is shown to be one or two wide vertical cracks originating from concrete in the tension zone in addition to several smaller cracks. Beam specimens with 6 numbers of bamboo reinforcements in tension zone in addition to this exhibited flexural compression by crushing of concrete in compression. Increase in loads caused the portion of concrete section above the bamboo reinforcement bars in the compression to crush, and as a consequence, a shear plane developed through which a small upper portion in compression separated from the remaining part of the beam section. The separation of concrete in compression zone can either be a result of different compressive capability of the aerated concrete and bamboo reinforcement bars in the compression zone of the beam, or bond failure between aerated concrete and bamboo reinforcement, or both occurring simultaneously.

3.3 Deflection Characteristics of Beams

The pattern of 28-day deflection characteristics of foamed aerated concrete beam specimens with and without compression reinforcement for 2, 4 and 6 bamboo bars at the tension zone of the beams are respectively shown in Figures 9 to 11. From these Figures the followings are observed.

i) the average mid span deflection increased with loading for all numbers of bamboo in the tensile zone for all the beam specimens with and without compression reinforcement.

ii) the deflection for beam specimens without compression reinforcement are consistently larger than specimens with compression reinforcement. This means that specimens with compression reinforcement will perform better than specimens without compression reinforcement.

iii) all the beams specimens have non-linear load-deflection curve before initial crack. The exception was the beam specimens with four bamboo bar as reinforcement but with compression reinforcement which have a linear load-deflection curve.

ISSN 2229-5518

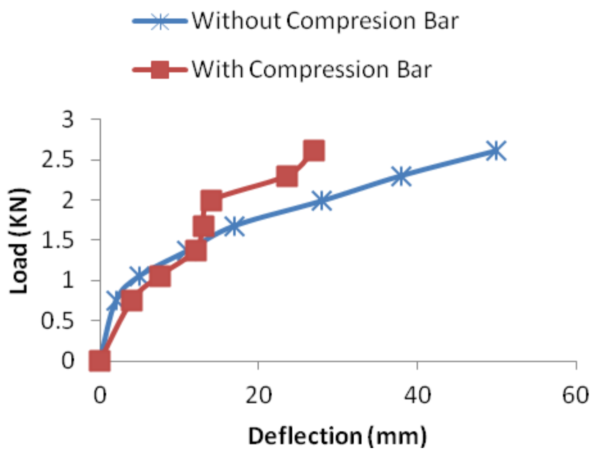


Figure 9: 28-day Load-deflection Characteristic for beams speci mens with and without compression bar having 2 bamboo bars as reinforcement at the tensile zone

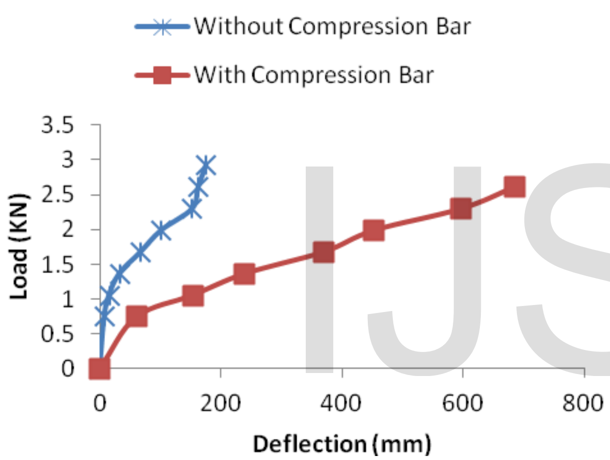


Figure 10: 28-day Load-deflection Characteristic for beams speci mens with and without compression bar having 4 bamboo bars as reinforcement at the tensile zone

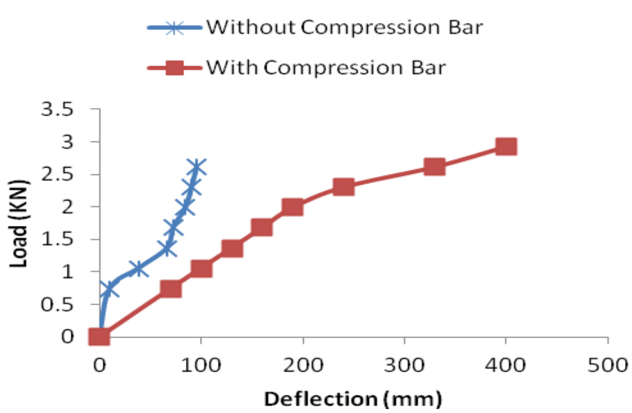


Figure 11: 28-day Load-deflection Characteristic for beams speci mens with and without compression bar having 6 bamboo bars as reinforcement at the tensile zone

The failure loads for the beam specimens are shown in Table (1). From Table (1), it can be seen that:

Table 1: Failure Loads for all the Beam Specimens at different curing age

No of Bars	Group	Details	7 days	21 days	28 days	45 days
2	I	With Compression Bar	2.765	4.315	5.095	5.902
	IV	Without Compression Bar	3.321	4.318	4.852	5.561
4	II	With Compression Bar	3.231	4.474	5.906	8.434
	V	Without Compression Bar	3.648	4.784	5.823	6.182
6	III	With Compression Bar	3.852	5.406	7.561	8.716
	VI	Without Compression Bar	3.542	4.784	6.861	6.888

i) the failure loads increased with curing ages irrespective of the number of reinforcement
in tension zone, and irrespective of whether there is compression reinforcement or not.
ii) the failure loads increased with increased in the number of compression reinforcement in the tensile zone. For example, at 28 days curing, the failure loads were: 5.095KN, 5.906KN, and 7.561KN for 2, 4, and 6 bamboo splints in the tension zone.
iii) the failure loads of specimens with compression reinforcement are higher than the specimens without compression reinforcement.

3.4 Flexural Behaviour

The experimental ultimate moments of resistance for all the curing ages for the beam specimens with and without compression reinforcement but with different numbers of bamboo bars as reinforcement in the tensile zone are presented in Table (2). It can be seen from the Table that ultimate moment of resistance increased with curing age for all the beam specimens. But the beams with compression reinforcement consistently gave a higher value of moment of resistance than specimens without compression reinforcement, at all the curing ages.
Table (3) compared the experimental and theoretical moments. From Table (3), it can be seen that both the experimental moments and the theoretical moments of the beam specimens increased with the number of bamboo splints in the tensile zone, with and without compression reinforcement, irrespective of the number of bamboo bars in the tensile zone.
For beams with two bamboo splints at the tensile zone, the experimental moments are larger than the theoretical moments. In all the remaining beam specimens, the theoretical moments are larger than the experimental moments.

Table 2: Experimental Ultimate Moments (KN.m) for all the Beam Speci

mens at Different curing age

No of Bars	Group	Details	7 days	21 days	28 days	45 days
2	I	With Compression Bar	2.17	3.38	3.99	4.62
	IV	Without Compression Bar	2.53	3.38	3.80	4.36
4	II	With Compression Bar	2.53	3.51	4.23	6.61
	V	Without Compression Bar	2.86	3.75	4.56	4.84
6	III	With Compression Bar	3.08	4.24	5.92	6.83
	VI	Without Compression Bar	2.78	3.75	5.38	5.35

Table 3: Comparison of Experimental and Theoretical Moments at 28-day Curing

No of Bars	Group	Details	Moments (KN.m)	
			Experimental	Theoretical
2	I	With Compression Bar	3.99	3.62
	IV	Without Compression Bar	3.80	3.35
4	II	With Compression Bar	4.23	5.65
	V	Without Compression Bar	4.56	5.99
6	III	With Compression Bar	5.92	8.02
	VI	Without Compression Bar	5.38	8.47

The relationship between the experimental and theoretical moments for beam specimens with compression reinforcement is represented by the scatter plot in Figure 12.
The correlation coefficient was 0.935, showing that a strong positive linear relationship existed. From the regression analysis, the relationship is expressed by:

$$y = 0.448x + 2.133 \quad (8)$$

where: y = experimental moment, x = theoretical moment
Also for beam specimens without compression reinforcement, the plot is shown in Figure (13). The correlation coefficient was 0.999, indicating a strong positive relationship.
The expression relating this relationship from regression analysis is:

$$y = 0.308x + 2.749 \quad (9)$$

where:
y = experimental moment, and x = theoretical moment

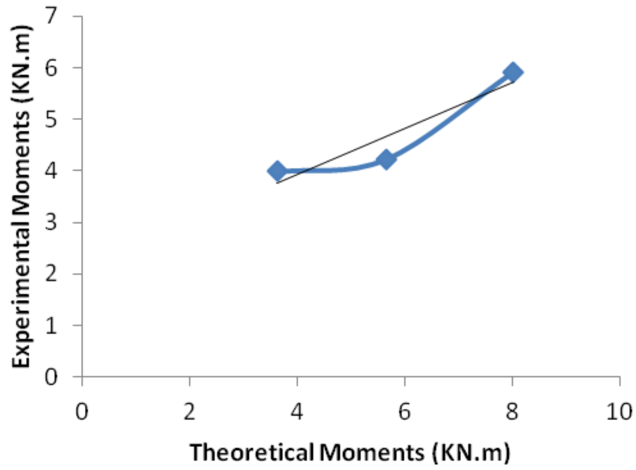


Figure 12: Relationship between the experimental and theoretical moments for beam specimens with bamboo splints in the tension zone and compression bars

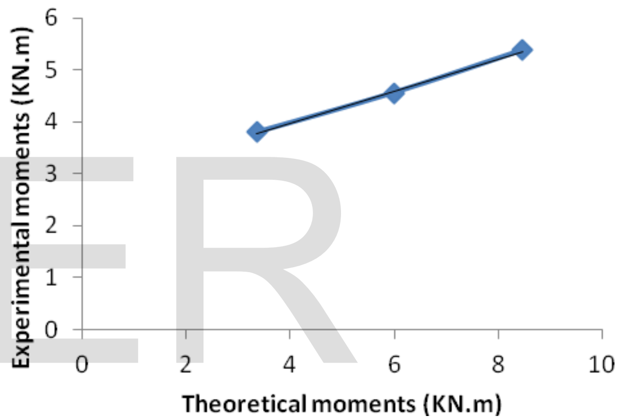


Figure 13: Relationship between the experimental and theoretical moments for beam specimens with bamboo splints in the tension zone without compression bars

4.0 Conclusions

From the results of this experimental work, the following conclusions are made:

i) Foamed aerated concrete beams specimens without compression and shear reinforcement exhibit shear failure while specimens with compression and shear reinforcement displayed flexural failure.

ii) Larger deflection was recorded for beams without compression and shear reinforcement than for beam specimens with compression and shear reinforcement.

iii) Beam specimens with compression and shear reinforcement developed higher moment of resistance than specimens without compression reinforcement.

iv) The foamed aerated concrete beams with compression reinforcement at the compression zone performs better that the beams without compression reinforcement, in terms of flexural parameters measured vis-a-vis: deflection, failure load, and moments of resistance.

References

[1] Rahman, M. M., Rashid, M. H., Hossain, M. A., Hassan, M. T.

ISSN 2229-5518
and Hasan, M. K. (2011). "Performance Evaluation of Bamboo Reinforced Concrete Beams". International Journal of Engineering & Technology, Vol. 11, No. 4, pp. 142 – 146.

[2] Adom-Asamoah, M. 1 , and Afrifa, O. R. (2011)" A Comparative Study of Bamboo-Reinforced Concrete Beams Using Different Stirrup Materials For Rural Construction". International Journal of Civil and Structural Engineering, Vol. 2, No. 1, pp. 407 – 423.

[3] Maulik D. K. and Sanghvi, C. S. (2011) , Comparative Study of Bamboo (Ikra) Housing System with Modern Construction Practices, National Conference on Recent Trends in Engineering & Technology, India.

[4] Siddhpura, N. B, Shaha, D. B., Kapadiaa, J V., Agrawala, C. S. and Sevaliaa, J. K. (2013). "Experimental Study on Flexural Element using Bamboo as Reinforcement". International Journal of Current Engineering and Technology, Vol. 3, No. 2, pp. 476 – 483.

[5] Sevalia, J. K., Siddhpura, N. B., Agrawal, C. S., Shah. D. B, and Kapadia, J. V. (2013). "Study on Bamboo as Reinforcement in Cement Concrete". International Journal of Engineering Research and Applications, Vol. 3, Issue 2, pp. 1181 – 1190.

[6] Nithiplangrusriskul, N. D. (2011). "Materials Characterization Of Bamboo And Analysis Of Bonding Strength And Internal Strength As A Structural Member In Reinforced Concrete". Materials Engineering Senior Project, California Polytechnic State University, Sans Luis Obispo.

[7] Khare, L. (2005). "Performance Evaluation of Bamboo Reinforced Concrete Beam". Masters' Thesis. The University of Texas at Arlington.

[8] Sabbir, M., Ashfaqul Hoq, S. M. and Fancy, S. F. (2011) "Determination of Tensile Property of Bamboo for Using as Potential Reinforcement in the Concrete". International Journal Of Civil & Environmental Engineering, Vol. 11 No. 5.

[9] BS 12 (1996) "Specifications for Portland Cement". British Standards Institution, London.

[10] Salau, M.A., Adegbite. I., and Ikponmwosa. E. (2012). "Characteristics Strength of Concrete Column Reinforced with Bamboo Strips". Journal of Sustainable Development, Vol. 5, No. 2, pp. 133 - 143.

[11] British Standard BS 8110. (1997) "Code of practice for Design and Construction". British Standards Institution, London.