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FLEXURAL STRENGTH OF BAMBOO AND STEEL REINFORCED CONCRETE BEAM

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ABSTRACT

There is no doubt that construction and building industries are the main energy and materials consumers of any country. In sustainable development, both the immediate and imminent needs are adequately taken into consideration. Sequel to the fact that concrete is weak in tension, reinforcement is inevitable to compensate for the deficiency. This paper purposes to comparing the flexural properties of concrete beams reinforced with bamboo strips and steel bars. Bamboo strips were found to be a close replacement to steel for light-weight constructions. This research consists of 100 x 100 x 450mm reinforced concrete beams with varying percentages of steel served as reference. Three beams were cast for each bamboo/Steel reinforcement ratio for each curing age making a total of Ninety-Six beams for flexural properties test. Three cubes were prepaid for every curing age summing up to Twenty-Four cubes for compressive test. The area of Bamboo reinforcement equivalent to steel was calculated via the equivalence of the force that could withstand the bending stresses which was also resisted by corresponding bamboo area. Steel stirrups were used to carter for shear in the beams. Flexural and compressive strengths at 7-, 14-, 21- and 28-days have been taken into consideration for comparison purpose. The graphs from the results were plotted and the suitability of bamboo reinforced beam was discoursed regarding the failure types. Results from the research reveal that bamboo can be used in low-cost constructions.

Keywords: Bamboo, Building, Concrete Beam, Construction, Equivalence, Industries, Steel, Reinforcement Area

INTRODUCTION

Concrete is widely used in construction industries based on the several indispensable advantages which include low cost, accessibility and less prone to fire. Its use is not without reinforcement since it has low tensile strength. In a nutshell, reinforcement bars are inevitable in concrete. Though steel and fibre reinforced plastic (FRP) have excessive tensile strength when compared with concrete, and reimburses for the deficiency by providing high tensile strength, ductility and flexural strength, it should be reserved for heavy-load constructions due to the cost and high source of energy consumption expended during processing (Saandeepani & Krishna, 2013; Qaiser *et al*., 2020).

Sustainable materials are the main areas of interest trending in several fields now (Gómez *et al*., 2019; Yang *et al*., 2020; Zhang *et al*., 2019; Shi *et al*., 2020); examples include natural fibres and sandwich hybrid composite (Khan *et al*., 2018; Salman *et al*., 2016).

Bamboo is being considered as a solution for the construction of enormous low-cost housing problems faced by several developing countries because of the numerous benefits, for example rapid growth, ability to survive, ecofriendly, low tendency to expand on absorption of water, and high strength along the fiber direction (Yang *et al*., 2020). A grate quantity of construction projects is constructed using steel and concrete which also has skyrocketed presently. The ecosystem has been greatly upset by the manufacture of these construction materials, through the emission of Carbon (IV) Oxide since their discovery. About 1.83 tonne of Carbon (IV) Oxide is emitted per tonne of steel produced which is a serious problem with the production of cement and steel (Mali & Datta, 2020).

The functionality, reliability, and durability of construction technologies are the basis for the economic growth, productivity, and the well-being of any nation. In view of the ravaging global economic recession, high cost and deficiency in production of steel and FRP bar, people are prompted to seek alternative to the increasing demands of steel in building industry. The current research intends to estimate the flexural strength performance of bamboo and steel reinforced concrete beams, to ascertain the adequacy of bamboo reinforced concrete beam.

MATERIALS AND METHODS

Materials

For the purpose of this study, all necessary materials were carefully selected to ensure that they met the required standards and sourced from local markets.

Bamboo selection

The selection of the bamboo was done sequel to the recommendations of Salau *et al*., (2012).

Steel bars

The research incorporated T10 and R6 as longitudinal and shear reinforcements respectively.

Fine Aggregate

Sharp river sand used was within the size range of 150 μm and 4. 76mm according to (BS 812-2: 1995).

Coarse Aggregate

Aggregate within 9mm to 20 mm was used as coarse aggregate without impurities according to (BS 812-2, 1995).

Cement

Specifically, the Portland Limestone Cement used was of grade 42.5R as recommended by (BS EN 196-1 – 6, 2018)

Water

Portable water in compliance with BS EN 1008 was used

Methods

Test on Bamboo and Steel Reinforcement

i. Mechanical properties of bamboo and steel reinforcement bars - (ASTM).

Test on Cement

i. Consistency test for cement - (BS EN 196-3, 2018).
ii. Initial and Final Setting Time for Cement - (BS EN 196-3, 2018).
iii. Soundness Test - (BS EN 196-3, 2018)

Test on Aggregate

i. Sieve Analysis Test for Fine and Coarse Aggregate - (BS EN 933-2, 2020)
ii. Aggregate crushing value - (BS EN 1097-2, 2020)
iii. Aggregate impact value - (BS EN 1097-2, 2020)
iv. Specific Gravity (BS 812-2, 1995)
v. Toughness - (BS 812-2, 1995).

Test on Fresh Concrete

i. Workability Test - BS (EN 12350-2, 2019)

Test on Hardened Concrete

i. Compressive Strength - BS 8500 (2019)
ii. Flexural Strength Test - ASTM C496-96 (2017).

Concrete mix design

Concrete mix used was designed following the recommendations of Marsh, (1997) as approved by BS 12 (1996), BS 4027 (1996) for concrete mix designs that meet workability, compressive strength and durability requirements using Portland cements, and BS 882, (1992) for concrete using natural aggregates.

Experimental procedures

The experiment consists of 100 x 100 x 450mm reinforced concrete beams with varying percentages of bamboo and steel reinforcement with steel serving as reference. The constituents of the beam specimens are shown in table 1. Concrete grades 25MPa was used for the flexural properties and compressive test. Three beams were cast for each bamboo/Steel reinforcement ratio for each curing age making a total of Ninety-Six beams for flexural properties test. Three cubes were prepaid for every curing age summing up to Twenty-Four cubes for compressive test. To incorporate bamboo reinforcement in concrete, the equivalent area of bamboo was calculated from the same bending moment in the steel bars. The flexural and compressive tests were carried out at 7-, 14-, 21- and 28-days curing.

Table 1: Reinforcement Bars Arrangement

Age (day)							
7	**14**	**21**	**28**	**7**	**14**	**21**	**28**
Area of Bamboo				**Area of Steel**			
145	145	145	145	50.2	50.2	50.2	50.2
290	290	290	290	100.6	100.6	100.6	100.6
435	435	435	435	150.9	150.9	150.9	150.9
580	580	580	580	201.2	201.2	201.2	201.2

Load analysis

Totally or partly replacing of steel with bamboo in reinforced concrete beams is made possible through the same design procedures outlined in relevant concrete design codes. These formulars are got from the fundamental law of materials in view of the inner equilibrium efforts. For equilibrium, the ultimate design moment, M, must be equal to the tensile force F_{st} in the reinforcing bar and the concrete compressive force F_{cc} that passes via the midpoint of the actual area of concrete in compression, at a distance of (z). Figure 1 illustrations the balanced state of a section of singly reinforced concrete beam (Tokuda *et al*., 2020; Mosley *et al*., 2012; BS 8110, 1997).

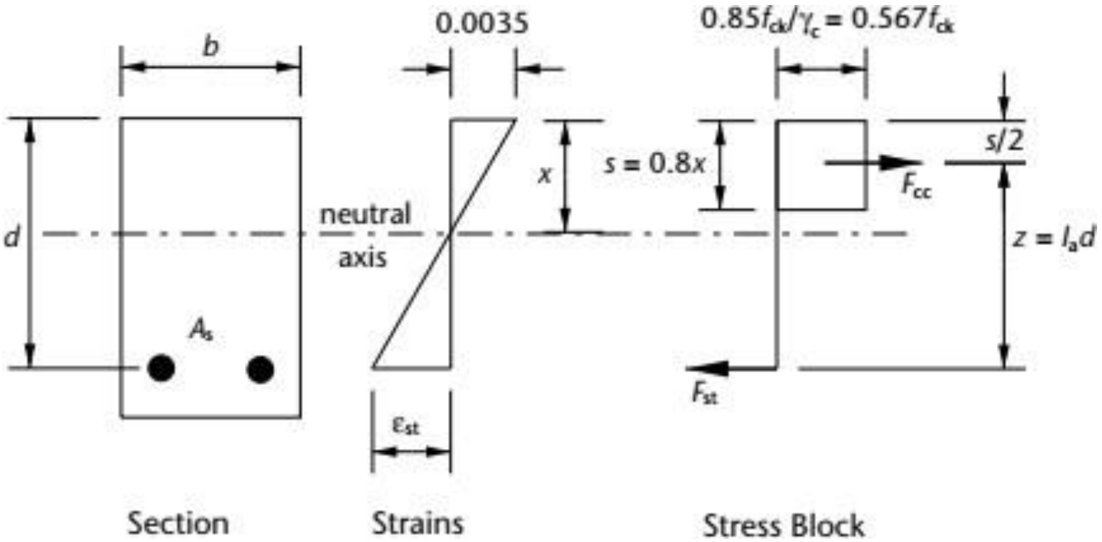

Figure 1: Equilibrium Conditions Singly Reinforced Concrete Beam (Mosley *et al*., 2012; BS 8110, 1997; Eurocode 2, 2008)

Neutral axis (NA): The is calculated from Equation (1)

$$x = 1.25d\left(1 - \sqrt{\left(0.5 - \frac{1.76M}{bd^2 f_{ck}}\right)}\right) \quad (1)$$

Concrete compressive force: The resultant compressive force in concrete F_{cc} is given in Equation (2)

$$F_{cc} = 0.8 f_{ck} bx \quad (2)$$

Tensile force in steel: The resultant tensile force in steel F_{st} is given in Equation (3).

$$F_{st} = A_s x f_{yk} \quad (3)$$

Bending moment: The bending moment of the beam is given in equation (4)

$$M = 0.8 f_{ck} bx(d - 0.4x) \quad (4)$$

Service bending moment: The bending moment M is given in Equation (5)

$$M_k = \frac{M}{\gamma_f} \quad (5)$$

Imposed load: The imposed load P is given in Equation (6) and is linked with bending moment M_k and the element's weight q

$$M_k = Pa + \frac{ql^2}{8} \quad (6)$$

Steel reinforcement area (A_s): No safety coefficients is needed in the expression given in Equation (7)

$$A_s = \frac{M_k}{f_{yk}(d - 0.4x)} \quad (7)$$

Bamboo reinforcement area: The area of Bamboo reinforcement equivalent to steel was calculated based on bending moment in the steel reinforcement as shown in Equation (8).

$$A_{bamboo} = \frac{\sigma_{steel}\, x\, A_{steel}}{\sigma_{bamboo}} \quad (8)$$

Deflection: The vertical displacement D_{max} determined is given in Equation (9)

$$D_{max} = \frac{l}{250} \quad (9)$$

where:
M = bending moment (MPa); f_{ck} = Concrete compressive strength (N/mm^2); b_w = breadth of concrete beam (mm); x = distance from beam's top to neutral axis (mm); d = effective dept (mm); F_{cc} = compressive force in concrete (KN); f_{yk} = characteristic yield stress (N/mm^2); F_{st} = resultant tensile force in concrete; M_k = service bending moment (MPa); M = bending moment (MPa); P = imposed load (KN); a = distance between load P and support (mm); q = beam's distributed load (KN/mm); l = element length (mm); A_s = area of steel reinforcement (mm^2); σ_{steel} = steel tensile stress (N/mm^2); F = load on the bamboo/steel reinforcement (KN); σ_{bamboo} = bamboo tensile stress (N/mm^2); A_b = equivalent bamboo area (mm^2); D_{max} = deflection (mm); (Tokuda et al., 2020; Mosley et al., 2012).

Characteristic material strengths

According to Mosley *et al*., (2012), the design of any element is founded on strengths below which results are not likely to fall (characteristic' strengths). In any given material it is expected that the probability Distribution Function (PDF) of the strength is normal to give a frequency distribution curve in Figure 2. Thus, characteristic strength is calculated from Equation (10).

$$f_k = f_m - 1{:}64s \quad (10)$$

where $f_k =$ characteristic strength, $f_m =$ mean strength and $s =$ standard deviation.

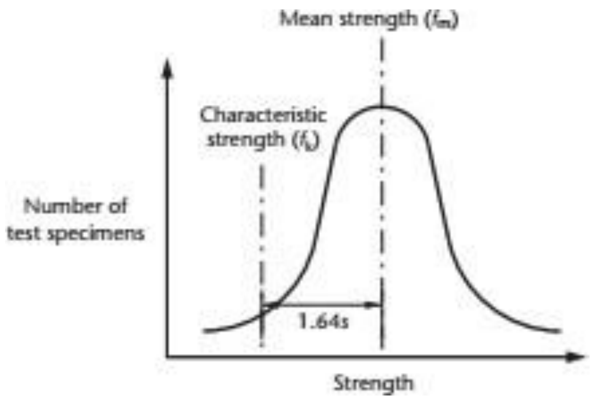

Figure 2 Normal frequency distribution of strengths (Mosley et al., 2012)

RESULTS AND DISCUSSION

Index Properties for fine aggregate

It's important to ascertain the index properties of fine aggregate used in this research and evaluate whether it falls within the acceptable limit specified by the BS 882 1992. Figure 3 illustration the fine aggregate particle size distribution curve used in this study. As can be seen from the envelop, the fine aggregate falls within the overall limit and additional limits (Zones C and M) given in the gradation limits of BS 882: 1992.

Properties for coarse aggregate

The result of the index properties of coarse aggregate for this study is presented below in Figure 4. From the grading curve, it can be seen that the coarse aggregate has most of its particles about the same size. This shows that the aggregate is a uniformly graded and predominantly nominal size of 20mm.

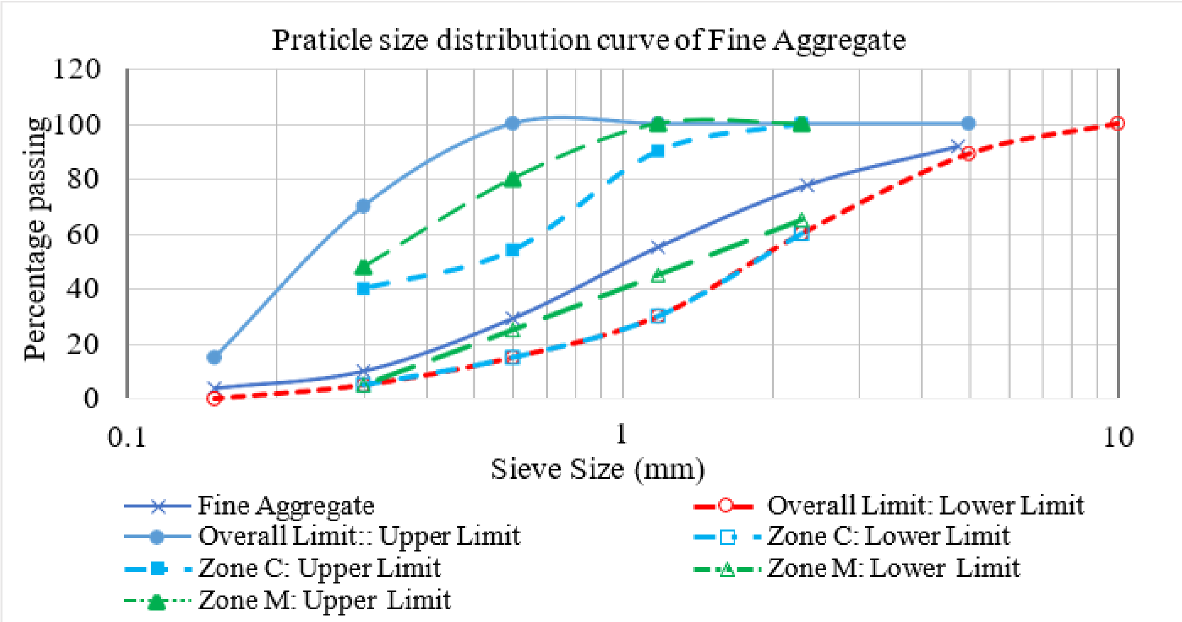

Figure 3: Fine Aggregate Distribution Curve

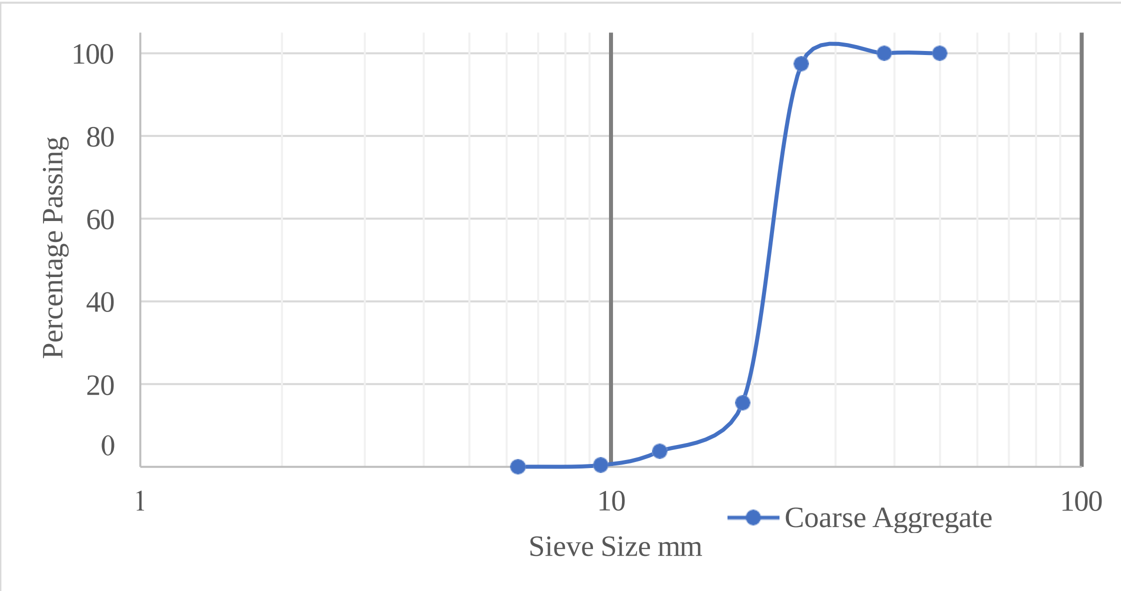

Figure 4: Particle Size Distribution Curve of Coarse Aggregate

Characteristic strengths descriptive statistics for bamboo and steel bar

Tables 2 illustrates the result of longitudinal steel and bamboo reinforcements subjected to tensile loading. The characteristics tensile and strengths of bamboo and steel bars are 130 MPa and 377 MPa respectively. From these table, it is glaring that the yield strength of the steel bars is below the standard value of 460N/mm^2 endorsed by BS4449, nevertheless its ultimate tensile strength to yield strength ratios are above 1.15 stipulated by BS4449 which makes it acceptable for use in reinforced concrete structures. The tables expresses that the yield strength of steel reinforcement is about three times the yield strength of bamboo reinforcement.

Table 2: Characteristic strengths descriptive statistics for steel and bamboo reinforcements

Statistic	Steel	Bamboo
	Yield Strength	**Yield Strength**
Sample Size	9	9.0
Range	36	5.5
Mean	398.33	132.6
Variance	150.75	3.1
Std. Deviation	12.278	1.8
characteristic strength	377	130

Compressive and tensile strength test of concrete
To determine the slump value, the instructions outlined in BS 8110 were followed. The results of the slump test obtained from the experiment are 49-, 50-, 48- and 47-mm. These values fall within the acceptable range of relevant codes, which is an indication of good workability. compressive and tensile strength tests are tabulated in table 2. The observed concrete strengths are higher than the characteristics strength but lower than the target mean strength that was intended in the design stage. The tensile strength results observed from the experiment also shows high values which indicates that concrete made with these mix designs will produce high flexural strength properties.

Table 3: Compressive and Tensile Strength Test Result

Age (Days)	Cube ID	Mean Compressive Strength (MPa)	Cylinder ID	Mean Tensile Strength (MPa)
		25 MPa concrete mix design		
7	25C1	15	25T1	1.45
14	25C2	21.25	25T2	1.83
21	25C3	22.5	25T3	1.90
28	25C4	23.75	25T4	1.97
		33 MPa concrete mix design		
7	33C1	19.8	33T1	1.75
14	33C2	28.05	33T2	2.20
21	33C3	29.7	33T3	2.29
28	33C4	31.35	33T4	2.37

Bamboo and Steel reinforced concrete beams flexural test results
These results are summarized in Figure 4 to figure 6.
Failure load versus Deflection curve
Figure 5 and 6 show the failure load - deflection curve of bamboo and steel reinforced concrete beams at constant age and reinforcement areas for concrete grades 25- and 33-MPa respectively. The constitutive equation for bamboo reinforced concrete beams plays a good role in enhancing the flexural properties of bamboo reinforced concrete beam.

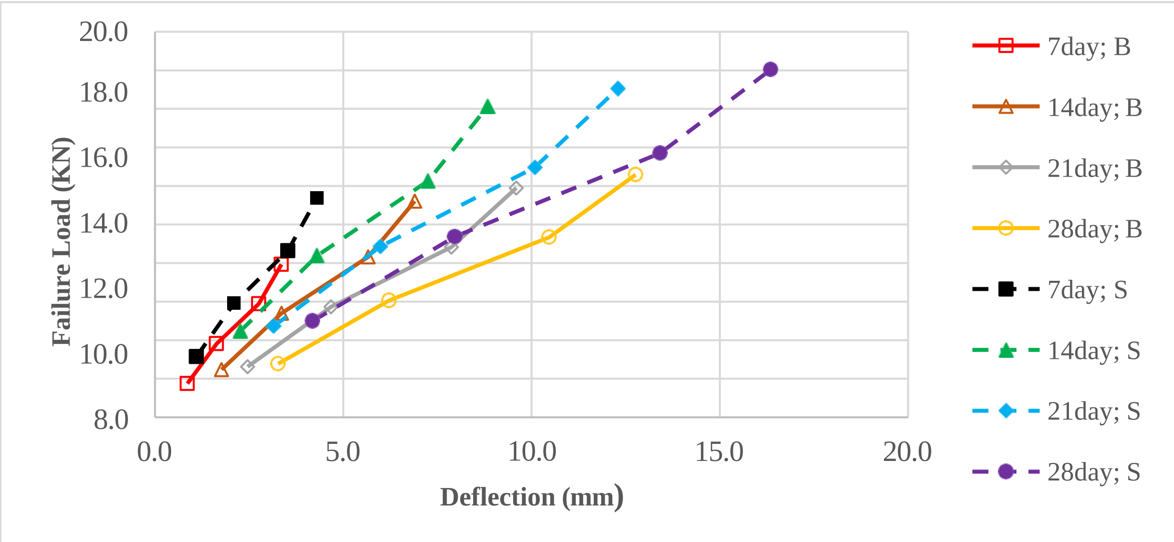

Figure 5: Failure Load - Deflection Curve for Singly Reinforced Concrete Beams at 25MPa concrete grade

Notwithstanding, the performance of steel reinforced concrete beam was higher than that of bamboo reinforced concrete beam with little margins. The percentage loss (difference) in failure load between steel and bamboo reinforced concrete beams decreases with increase in both areas of steel and bamboo reinforcements. For steel and bamboo areas of 50.3mm2 and 145mm2; 100.6mm2 and 290mm2; 150.9mm2 and 435mm2; and 201.2mm2 and 580mm2, the corresponding percentage loss in failure load are 26.7%, 14.7%, 10.1% and 7.9% respectively. However, it was observed that higher concrete grades significantly improve the flexural properties of bamboo and steel reinforced concrete beams as the maximum deflection attained by bamboo and steel reinforced concrete beams at 25MPa are lower than that at 33MPa.

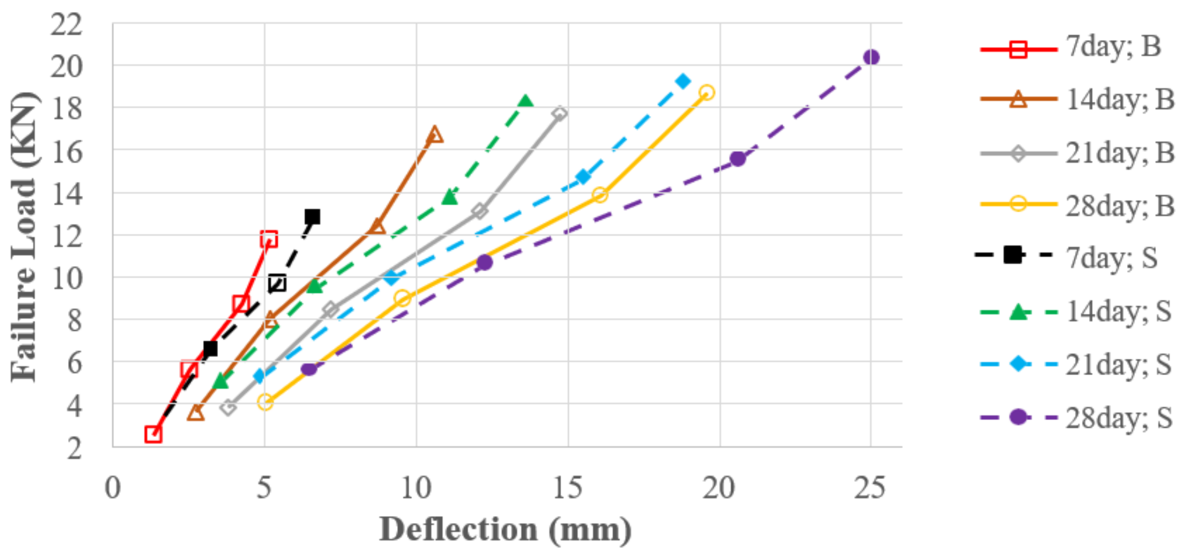

Figure 6: Failure Load vs Deflection Curve for Singly Reinforced Concrete Beams at 33MPa concrete grade

Deflection versus area of reinforcement

Deflection - Area of reinforcement curves for bamboo and steel reinforced concrete are indicated in Figure 7 and 8 respectively. The effect of the area of reinforcement on the structural performance of two concrete beams are similar. At this point, deflection is dependent on the yield strength of the reinforcement, area of bars and the depth of the members. It is observed that even at the equivalent areas of reinforcement, the deflection values for steel reinforced beams are higher than that of bamboo reinforced concrete beam. It was observed that the average percentage loss (difference) in deflection value for bamboo and steel reinforced concrete beams is 21.7%. This is attributed to the high brittle nature of bamboo reinforcement concrete and the bond between bamboo and concrete. This shows that stiffness in steel and bamboo reinforced concrete beams are proportional to the area of reinforcement vie constitutive equation. Nevertheless, it was observed that higher areas of reinforcement bars meaningfully improve the deflection capacity of bamboo and steel reinforced concrete beams as the maximum deflections achieved by bamboo and steel reinforced concrete beams at 33MPa are higher that of 25MPa.

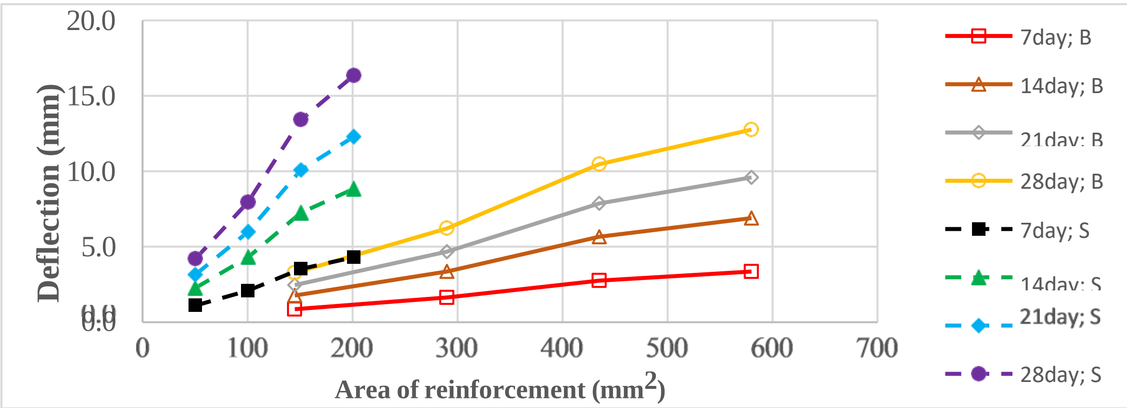

Figure 7: Deflection vs area of reinforcement curve for Singly Reinforced Concrete Beams at 25MPa concrete grade

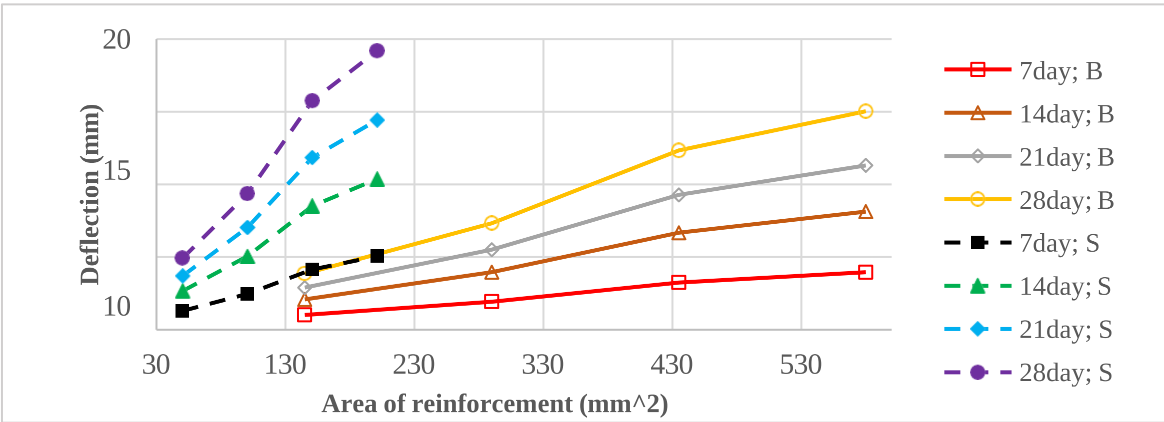

Figure 8: Deflection vs area of reinforcement curve for Singly Reinforced Concrete Beams at 33MPa concrete grade

Failure load versus area of reinforcement

The failure load - area of reinforcement curves for concrete grades 25- and 33- MPa are shown in figures 9 and 10 respectively. The plots show direct relationship between the load capacity of bamboo and steel reinforced concrete beams with the reinforcement area. This in turn shows that the structural behaviuor of bamboo reinforced concrete beam to load is very much similar to that of steel reinforced concrete beams. This was possible based on the equivalent area of reinforcement. which determines the stiffness of the member. A close look at figures 9 and 10, showed that higher areas of reinforcement bars, meaningfully improve the load carrying capacity of bamboo and steel reinforced concrete beams as the maximum failure load achieved by bamboo and steel reinforced concrete beams at 33MPa were higher than that of 25MPa. It can be seen from these graph that the percentage of bamboo reinforcement area required to achieve the same stiffness with a certain steel area is enormous. However, this is a major setback as the percentage area of bamboo is not within the upper and lower limits of some relevant codes. A special code calibration is needed to harness the grate potentials in bamboo. As indicated in these graphs, bamboo reinforcements should be limited to low-cost construction and light loaded members.

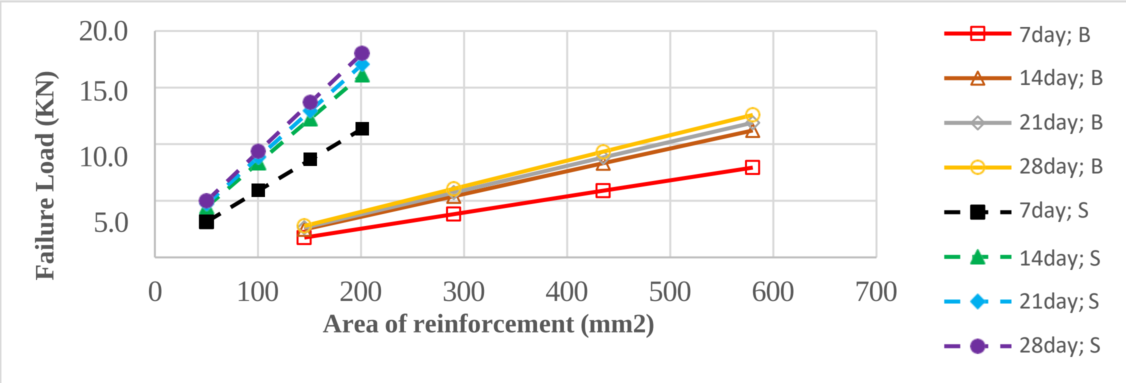

Figure 9: Failure load vs area of reinforcement curve for Singly Reinforced Concrete Beams at 25MPa concrete grade

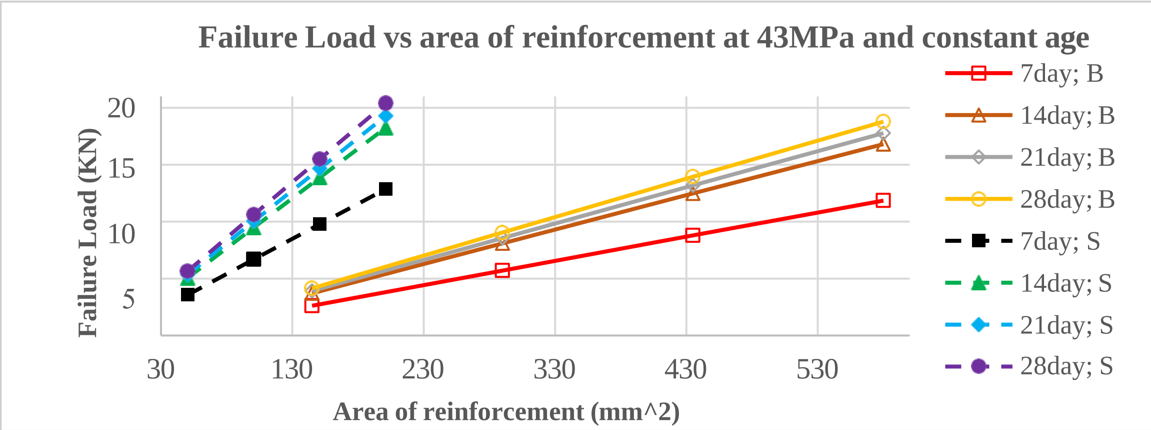

Figure 10: Failure load vs area of reinforcement curve for Singly Reinforced Concrete Beams at 33MPa concrete grade

CONCLUSION

The area of the bamboo bars obtained from constitutive equation significantly improved the flexural properties of bamboo reinforced concrete beam under bending. At high concrete grades and areas of reinforcement bars, significant improvement in the flexural properties of bamboo and steel reinforced concrete beams were recorded as the maximum deflection and load carrying capacity attained at 25MPa were lower than that at 33MPa. The area of reinforcement required in bamboo reinforced concrete beam is enormous, hence, does meet the relevant codes' specifications for minimum and maximum percentage areas of reinforcement. The flexural properties of steel reinforced concrete beam were achieved with small areas of steel bars in conformity with the relevant codes' requirements. Thus, steel bars are the perfect reinforcement for concrete beams sequel to the magnitude of the load sustained. The flexural strengths of bamboo reinforced concrete beam can be predicted via the equivalence of the force required in the steel reinforced concrete beam to withstand the bending moment. Results showed that steel reinforced concrete beams performed better than bamboo reinforced concrete beam with regard to flexural properties. Therefore, bamboo reinforcement cannot completely replace steel reinforcement in heavy-load constructions, but it can be used in lightweight and low-cost construction.

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