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In-Situ Tensile and Flexural Testing of Concrete Reinforcing Bars Made of Steel, Bamboo, and Rattan

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Abstract

The deformation properties and flexural performance of concrete elements reinforced with twisted steel rebars, rattan, and bamboo were compared in this research. Using a universal testing equipment, fifty specimens of each material were tested for yield strength (YS), ultimate tensile strength (UTS), and elonga-tion. Stirrups were primarily mild steel bars, and three beams with a concrete strength of 20 N/mm2 at 28 days were reinforced with bam-boo, rattan, and steel bars of the same proportion. In order to assess the flexural behavior, the beams were loaded center-point flexural according to BS 1881. Bamboo bars had a YS that was 13% of steel's and rattan bars had a YS that was 45% of steel, while the UTS of the two materials were 16% and 62% of steel, respectively. The elongation of rattan was 10%, that of bamboo was 7.42%, and that of steel was 14.7%. As a result, the natural rebars did not meet the BS 4449 minimum standard of 12%. Bamboo and steel RC beams exhibited quadratic load-deflection plots, but rattan RC beams exhibited a curved tendency. Rattan RC beams (RB) and bamboo RC beams (BB) were 32% and 13.5% stiffer than steel RC beams, respectively (SB). Both BB and SB had a residual flexural strength of 41% after the initial fracture, however RB only managed 25%. Additionally, BB and RB had moment capacities that were 51% and 21% of the capacity of steel RC beams, respectively. The low bonding at the bar-concrete interface and the high tensile strength of steel explain why natural rebars have much lower flexural capacities than steel. While rattan requires additional pre-strengthening treatment for increased interfacial bonding and load-carrying capability, bamboo bars are ideal for non-load bearing and lightweight RC flexural constructions.

Keywords

Reinforcing Bars, Bamboo, Rattan, Tensile Characteristics, Flexural Strength, Concrete, Load-Carrying Capacity

1. Introduction

Functionality, dependability, and longevity of a nation's built facilities significantly impact the nation's total sustainable economic development, productivity, and welfare. In addition to operational and environmental factors, the built environment is a known repository for component elements that contribute to structural deficiencies and functional obsolescence (Adewuyi et al. [1] [2], Adewuyi and Wu [3]). The adaptability of concrete to different shapes, its strength, its longevity, and its reaction to both the environment and the economy are all factors that contribute to its dominance over other building materials. References include Neville [4], Kosmatka et al. [5], Mehta and Monteiro [6], and Mosley et al. [7] about its tensile strength, which is approximately 10% of its compressive strength. Recent years have seen increased interest in the use of waste or natural resources to partially substitute cement and aggregate. Adewuyi and Ola [8] and Adewuyi and Adegoke [9] conducted previous research on using undesirable materials as partial replacements for cement and coarse aggregates, respectively, using waterworks sludge ash and periwinkle shells. The bulk of the world's built infrastructure is made of reinforced concrete (RC), and the characteristics of the reinforcing bars have a significant impact on how well these buildings perform. When concrete and reinforcement are well-bonded, the concrete may transmit its stress to the steel. The risks of profit maximization at the cost of quality have been highlighted in previous research on the chemical, physical, and strength properties of steel reinforcing materials. This poses a serious threat to the structural reliability and durability of buildings and civil infrastructure, as highlighted by Basu et al. [10], Olaniyi [11], and Kolade [12]. While both natural and synthetic non-ferrous reinforcing materials have been the subject of much research in recent decades, the latter is an ever-evolving area that needs further exploration. The development of synthetic fiber reinforced polymers (FRPs) has been extensively investigated and has shown promising results for a wide range of concrete structural applications. Papers by Nawy et al. [13], Nawy and Neuwerth [14], Yamasaki et al. [15], Faza and GangaRao [16], and Bakis et al. [17] detailed the first investigations into the development and behavior of concrete structures reinforced with various types of inorganic and organic FRP bars, including carbon, aramid, and glass fibers. On the other hand, these materials' high price tags prevent them from being widely used in public and private construction projects across the world.Andonian et al. [18], Manzur and Aziz [19], Kankam et al. [20], raffia palm [21], and palm stalk [22] are just a few of the natural reinforcing materials that have been the subject of several investigations. Natural fiber reinforcing materials such as bamboo (Bambusa vulgaris), rattan (Calamus deerratus), and others are gaining popularity as alternatives to traditional reinforcing steel in concrete, particularly for affordable homes in rural areas. Traditional thatching in rural Ghana involves tying the stems of babadua to the house structure and then daubing them with mud (Schreckenbach and Abenkwa [23]).Bamboo, composed of natural fibers derived from lignocellulosic sources, is a composite material that resembles perennial grass. It oc- curs in the natural vegetation of many parts of tropical, subtropical and mild temperature regions, with about 1250 species identified throughout the world (McClure [24], Austin and Ueda [25]). According to Falade and Akeju [26] [27], out of seven species of bamboo found in Nigeria, bambusa vulgaris makes about 80% of the species. The compressive strength of bamboo is two times that of concrete, and its strength-to-weight ratio is similar to that of steel when subjected to stress. Bamboo has been the subject of much investigation as a potential steel alternative in reinforced concrete. Reports of its use in water tank building have been made by Chembi and Nimityongskul [28] and Winarto [29]. Reinforcing lightweight concrete beams is something that Ghavami [30] mentioned. For low-income housing, Venkateshwarlu and Raj [31] and Raj [32] created ferrocement slab components based on bamboo for use as roofing and flooring. Its use in reinforced concrete slabs was investigated by Kankam et al. [33]. In contrast to the 204–250 N/mm2 discovered by Alade et al. [34], Falade and Akeju [26] [27] determined that the maximum tensile strength for bamboo was 133.54 N/mm2. A 28-day load-carrying capability of 134.65% was observed in the bamboo RC beams, compared to the unreinforced beams, according to further investigation. According to Akeju and Falade [35], the load capacity of mild steel RC beams was 1.5 times higher than that of its bamboo counterpart. Rattan is comparatively cheaper than wood and bamboo; and has tremendous a growth potential in rural areas. Alternatively, steel's mechanical characteristics and behavior have been extensively examined and recorded. Mahzuz et al. [36] determined ultimate tensile strength, yield strength, Young's modulus and bond strength (when embedded in concrete) of rattan samples cut from three years and older trees. Baba [37], Ghavami [30] [38], and Mahzuz et al. [39] reported comprehensive studies on the behaviour of bamboo, but only very few comprehensive data are available on tensile and flexural properties of rattan (Chowdhury [40]. Mahzuz et al. [41] determined the yield strength, ultimate strength and modulus of elasticity of a rattan (Calamus guruba) through experimental investigation. The performance of rattan RC beams was evaluated in flexure and shear. The result showed that bond stress was 42% lower position than the corresponding experimental shear stress. Lucas and Dahunsi [42] found that the interfacial bond strengths of rattan-concrete were in the range 0.082 - 0.598 N/mm2 depending on the species, concrete grade and other natural conditions. The experimental results of 0.34 - 0.38 N/mm2 obtained by Cox and Gyemayer [43] fall within the range. Moreover, Youssef [44] gave 0.56 - 0.68 N/mm2 for some bamboo species bonded with concrete. All the findings fall between 3.94 and 28.86% of steel-concrete bond strength of 2.07 N/mm2 of comparable concrete grade (Neville and Brook [45]). It was found that the moduli of elasticity for three species of Rattan were 3396, 516 and 11,106 N/mm2 for C. deerra- tus, E. macrocarpa and L. secundiflorum respectively (Lucas and Dahunsi [46]). The use of rattan reinforcement in lieu of conventional steel reinforcements requires better understanding under axial loading and performance conditions. Akinyele and Olutoge [47] investigated the flexural behavior of two-way slabs reinforced with rattan and conventional reinforcements under axial loading. Although extensive literature abound on natural rebars in reinforced concrete structures, no clear comparative investigations had been done on steel, bamboo and rattan under similar geometric and loading conditions to de- termine the relative capacities and thereby establishing the limits to the applicability of the natural rebars. Hence, this paper presents the experimental study to comparatively evaluate the flexural behaviour of concrete beams reinforced with steel, bamboo and rattan. The physical and tensile strength properties of steel, bamboo and rattan were first determined and the flexural capacities of concrete beams reinforced with the individual materials bars were evaluated. The limits of usage of bamboo and rattan bars as reinforcement were established with respect to the steel RC beams.

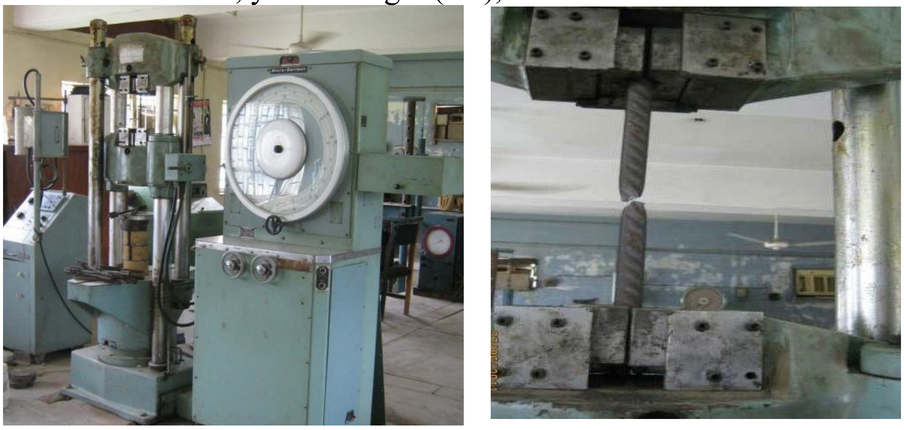
2. Experimental Investigations

Structural behaviour of concrete beams reinforced with bamboo, rattan and steel was comparatively evaluated experimentally in two folds. First, the tensile parameters of the reinforcing materials were determined in the laboratory. Second, the load-carrying capacities of RC concrete beams wherein bamboo, rattan and steel were separately employed as the longitudinal bars were investigated. Detailed experimental plan is described as follows.

2.1. Tensile Strength Properties of Steel, Bamboo and Rattan Bars

Figure 1 shows the results of an experiment utilizing a 600 kN capacity Avery-Denison servo-hydraulic universal testing machine (UTM) to measure the physical and tensile strength attributes of rattan, steel, and bamboo. We compared these results to those of BS 4449 and ensured they were in accordance with ASTM standards [48]. We purchased the twisted steel bars at random from big construction material suppliers in Lagos, Nigeria. Their diameters ranged from 10 to 12 mm and were of the same brand. The bamboo, which is greenish-brown and about three years old, was cut into bars that were ten to twelve millimeters thick. The bamboo came from several locations in Abeokuta, Nigeria, and had an average height of four to six meters. A typical tree's dimensions were an outside diameter of 85–105 mm, a thickness of 10–15 mm, and an internode spacing of 250–400 mm. For each of the three reinforcing materials that were studied, specimens that were 10 mm in size were taken into account. Also, mature Calamuc deerratus rattans were purchased in Ibadan, Nigeria, and then sliced into many lengths with a diameter ranging from 10 to 12 mm. Before cutting the rattan stems to conventional lengths, they should be air dried for one month.

For this tensile test, we used 50 individual samples of steel, bamboo, and rattan reinforcing bars with diameters ranging from 10 to 12 mm. A standard length of 600 mm and a gauge length of 200 mm were both used to cut the specimens. A material's ultimate tensile strength (UTS) is the greatest stress that it can endure before breaking under tension, whereas its yield strength (YS) is the stress at which further deformations cannot be repaired even after the load is removed. Ul-, yield strength (YS), and timate tensile strength (UTS), elastic modulus (EM), and elongation (E) of the three rebar types were determined experimentally in accordance with ASTM A370 [49]. The yield stress of the bar samples was determined by offset method. Offset of 0.2% proof strain was applied to steel, while 0.5% offsets applied to timber and rattan bars. The statistical distribution trend was determined and the characteristic yield strength below which not more than 5 percent will fall was determined for the three materials.



(a) (b)

Figure 1. Tensile strength test setup (a) Avery UTM and (b) steel specimen at fracture.

2.2. Flexural Strength Investigation of RC Beams

A 32.5 grit ordinary Portland cement was used. A water-cement ratio of 0.45 was used in line with BS 1881 [51] to mix the aggregates, which consist of river sand and crushed granite with a maximum nominal size of 15 mm that conforms to BS 882 [50]. In Table 1 we can see the aggregate proportions broken down by density. On the seventh day, the compressive strength of a 150 mm concrete cube was 13.68 N/mm2, and on the 28th day, it was 20.05 N/mm2. The density on the 28th day was 2404 kg/m3. A total of 18 concrete beam specimens measuring 150 × 150 × 900 mm were made and divided into three sets. All the beams, which correspond to 4Φ10 mm bars (two bars at the tension and compression zones each), were reinforced at a ratio of 0.35 percent of the concrete surface. There were steel bars with a diameter of 10æ8 mm that were positioned 100 mm apart and had a nominal cover of 20 mm. Steel reinforcing bars were used to strengthen the first set of six beams, while bamboo and rattan were used to strengthen the second and third sets, respectively. Figure 2 shows the experimental setup, whereas Figure 3 shows the geometry and reinforcing features of the RC beams used for flexural testing. In increments of 0.1 kN, a hydraulic actuator was used to exert a center concentrated load on the RC beam. To measure the vertical displacements at the mid-span under the applied load, a linear variable differential transformer (LVDT) was employed for each specimen. The experimental measurements were recorded using a data collecting system, and a load cell was used to track the applied stress.At 28 and 168 days of age, the flexural behavior of concrete beams reinforced with steel, bamboo, and rattan was compared in the research. There was no discernible variation in the flexural behavior of the three groups at 28 and 168 days old, according to the experimental examination. Concrete beams reinforced with steel, bamboo, and rattan were experimentally tested at first cracking and ultimate failure loads to establish their stiffness and flexural capacities.

3. Experimental Results

3.1. Tensile Parameters and Statistical Distributions of Reinforcing Materials

Yield stress (YS) and ultimate tensile stress (UTS) were extracted from the stress-strain curve with the proof strain taken as offset parallel to the linear part of the stress-strain relation. The elongation was measured in percentage of the original length. The YS of rattan, bamboo and steel were 58.46, 201.14 and 442.73 N/mm^2 respectively, while the UTS were 85.35, 335.23 and 540.13 N/mm^2 in the same order. It is obvious that the results summary in **Table 2** that all the three reinforcing bar types met the requirements for the minimum stress ratio of

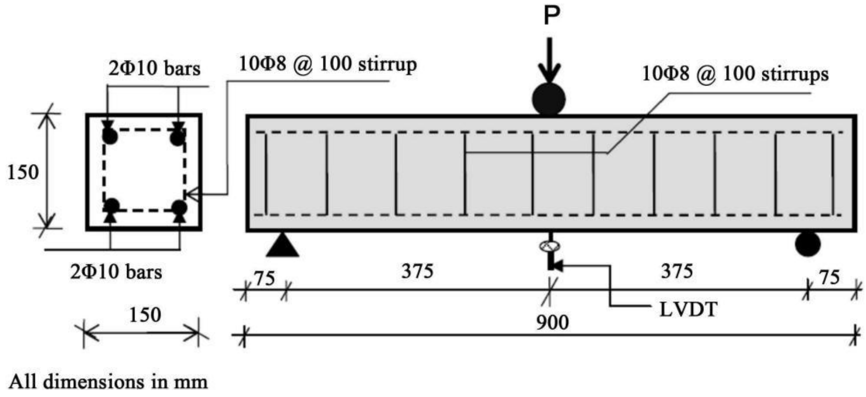


Figure 2. Flexural test setup of RC beams indicating geometric and reinforcement details.

Table 1. Mix proportioning of constituents of concrete.

	Water	Cement	Fine aggregates	Coarse aggregates
Mass (kg)	110	245	761	1288
Ratio	0.45	1.00	3.10	5.26

Table 2. General statistical tensile parameters of rattan, bamboo and steel bars.

Material	Parameters	Yield strength (YS)	UTS (N/mm^2)	Stress ratio, $\frac{UTS}{YS}$	Elongation (%)
Rattan	Mean, μ (N/mm^2)	58.46	85.35	1.46	10.00
	SD, σ (N/mm^2)	5.71	7.28	0.15	2.29
	COV (%)	9.76	8.53	10.09	22.90
	$\mu + 1.64\sigma$ (N/mm^2)	67.82			
	$\mu - 1.64\sigma$ (N/mm^2)	49.10			
	Range	46 - 75			8 - 14
Bamboo	Mean, μ (N/mm^2)	201.14	335.23	1.67	7.42
	SD, σ (N/mm^2)	6.06	15.05	0.07	2.11
	COV (%)	3.01	4.49	5.58	28.44
	$\mu + 1.64\sigma$ (N/mm^2)	211.09			
	$\mu - 1.64\sigma$ (N/mm^2)	191.20			
	Range	188 - 218			4 - 10
Steel	Mean, μ (N/mm^2)	442.73	540.13	1.22	14.7
	SD, σ (N/mm^2)	33.23	51.91	0.11	2.06
	COV (%)	7.50	9.61	9.16	14.01
	$\mu + 1.64\sigma$ (N/mm^2)	497.22			
	$\mu - 1.64\sigma$ (N/mm^2)	388.24			
	Range	354 - 541			12 - 23

Figure 3. Experimental setup of concrete beams RB, BB and SB.

1.08 specified by BS 4449 [48] with bamboo having the highest value of 1.67, followed by rattan (1.46), and finally steel (1.22). Moreover, it is noteworthy that bamboo did not meet the minimum elongation requirement of 12% specification. However, steel fully satisfied the specifications for reinforcing bars, but rattan marginally fulfilled this requirement. The Normal (Gaussian) random variable is almost certainly the most important distribution in structural reliability. For every sample yield strength x, mean strength value $\bar{x}$ and standard deviation σ, the Normal distribution function $f(x)$ of the yield stress values of the fifty experimental results expressed in Equation (1) was plotted against the individual yield stress.

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\bar{x}}{\sigma}\right)^2\right] \quad (1)$$

In addition, further examination of the tensile strength characteristics showed that rattan, bamboo, and steel all exhibit regularly distributed, or Gaussian, tensile qualities. See Figure 4 for the three reinforcing materials' yield stress distribution curves.

Concepts from statistics and the application of statistical approaches to real-world variations form the basis of limits state design. According to BS 4449 [48] and BS 8110 [52], the characteristic yield strength fyk of the reinforcing materials was defined as the value of the yield stress below which no more than 5% of the test material is anticipated to fall. Therefore, the typical strengths of the different kinds of reinforcing bars were calculated by taking the mean strength value, x, and dividing it by 1.64 times the standard deviation, σ.Hence, rattan bars had a typical yield strength of 49.10 N/mm2, bamboo bars of 191.20 N/mm2, and steel bars of 388.24 N/mm2. These results were consistent with those of Akinyele and Olutoge [47], Obilade and Olutoge [53], Mahzuz et al. [41], Mahzuz et al. [36], Mahzuz et al. [39], and Mahzuz et al. [41]. Alade et al. [34] and Falade and Akeju [26] [27] disagree with the tensile characteristics of bamboo. Also, the coefficient of variation revealed that none of the parameters were more than 30%, which means that the tensile characteristics are statistically trustworthy according to the allowable deviations from the mean values, which is supported by the data.

3.2. Flexural Behaviour of Concrete Beams Reinforced with Steel, Bamboo and Rattan Bars

Nine 150 × 150 × 900 mm RC beams symmetrically placed between simple supports spaced at 750 mm effective span. Three replicas of the beam specimens were reinforced with bamboo, rattan and steel longitudinal bars and denoted as bamboo RC beams (BB), rattan RC beams (RB) and steel RC beams (SB). The longitudinal bars of diameter 10 mm were sliced from rattan and bamboo, while reinforcing steel bars were also of 10 mm size. Mild steel of 8 mm diameter were employed as stirrups to resists shear for the three RC beam types.

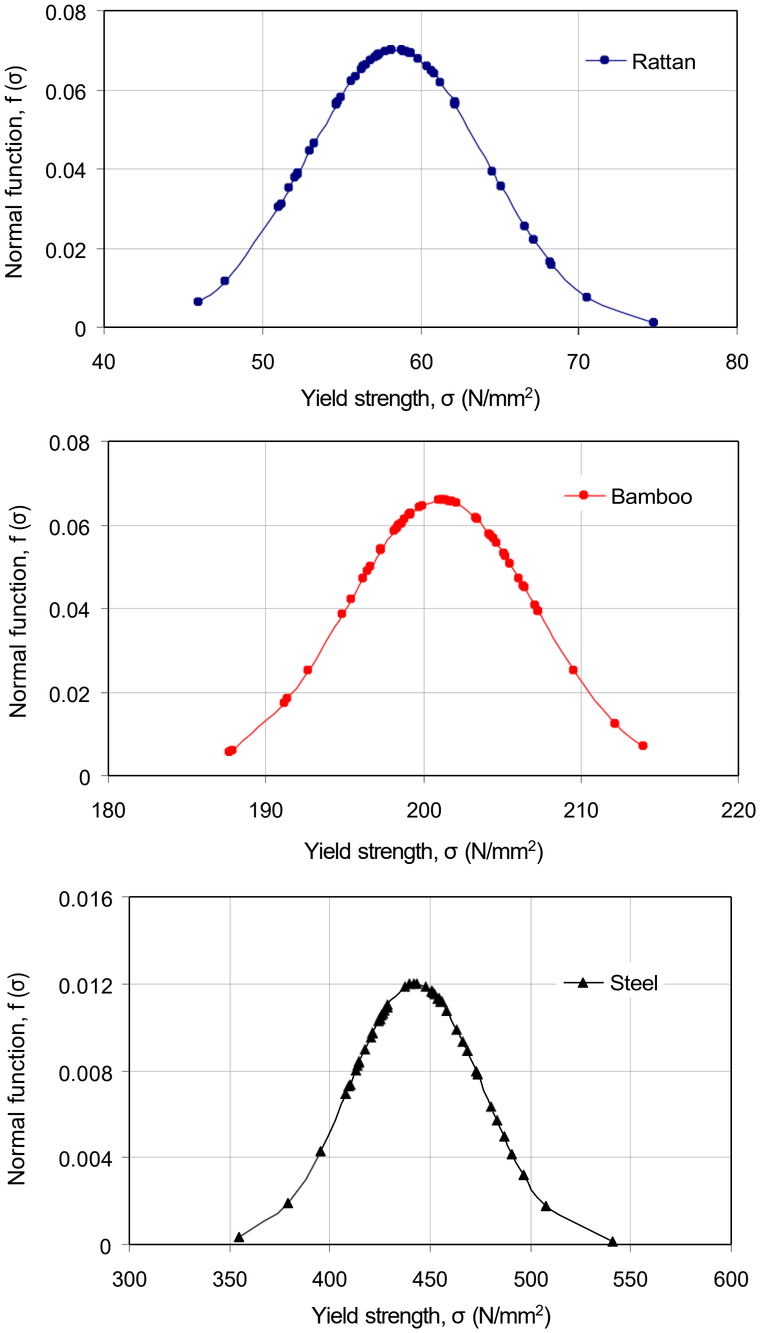


Figure 4. Normal distribution curve for yield strength of rattan, bamboo and steel bars.

For clear comparative evaluation of the flexural behavior of BB, RB and SB, the mean load-deflection (P-δ) curves of beam samples reinforced with each of the reinforcing materials are shown in Figure 5. The curves steel RC beams had the highest stiffness, while rattan RC beams had the least. Although, the three curves are quadratic, the P-δ plots of rattan RC beams can still be regarded as being linear until the beam ruptured. The load-deflection curve of the bamboo RC beams (BB) can be expressed as $P = -0.0794\delta^2 + 2.6021\delta - 1.2808$ ($R^2 = 0.968$), rattan RC beams (RB) is related by $P = 0.0064\delta^2 + 0.7364\delta - 0.1738$ ($R^2 = 0.984$) and steel RC beams (SB) can be represented by $P = -0.4766\delta^2 + 8.5301\delta - 0.6182$ ($R^2 = 0.997$). The average stiffness val-

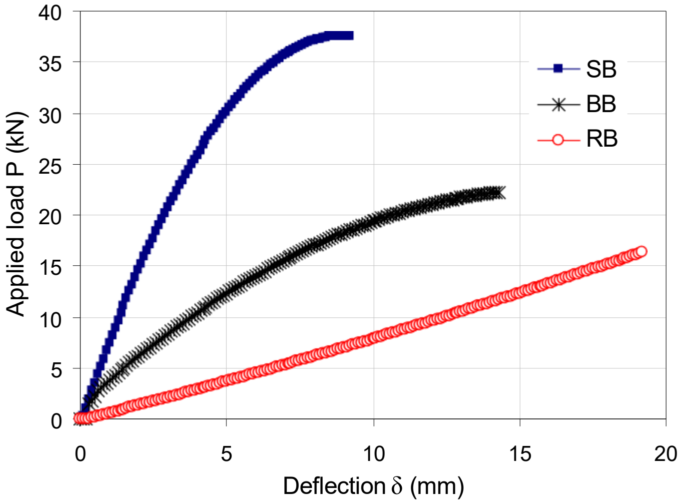


Figure 5. Load-deflection curved for bamboo, rattan and steel RC beams.

BB had a value of 1.97 N/mm (or 1970 kN/m), RB had a value of 0.83 N/mm (or 830 kN/m), and SB had a value of 6.147 N/mm (or 6147 kN/m). It follows that RC beams made of bamboo have a flexural stiffness of about 32% and RC beams made of rattan around 14% of the flexural stiffness of RC beams made of traditional steel bars. Table 3 summarizes the flexural behavior of BB, RB, and SB with respect to the ultimate failure load (Fu), flexural strength (also called the modulus of rupture), and first crack load (Fc). In terms of The experimental ultimate failure load, c, Fu, as well as the first cracking loads was 59% for rattan, 55% for bamboo, and 59% overall. as well as RC beams made of steel bars. Accordingly, RC beams made of bamboo and steel had residual load bearing capabilities of 41% of the final values after the initial break, but RC beams made of rattan had capacities of only 25%. It is reasonable to assume that rattan had already used up a significant portion of its load-carrying capacity at first fracture, unless it had been processed to increase its strength. Compared to traditional steel RC beams, the first breaking loads of rattan RC beams were 30% and 55%, respectively.

From these results, we may infer that rattan had the lowest resilience after the initial break, while SB exhibited the most. Essentially, this means that even after the first fracture, steel RC beams maintained a residual load-carrying capability of 40%. Bamboo RC beams exhibited similar pattern as it also had about 40% of the load-carrying capac- ity after the first crack, while rattan RC beam had only 25% left after the occurrence of the first crack. Based on the initial fracture, it seems that RB had about used all its capacity. This is evident in the almost linear load- deflection curve with barely any provision for second stiffness. Furthermore, compared to traditional steel RC beams, the experimental ultimate failure loads of rattan RC beams were 24% lower and 55% lower, respectively. This indicates that the carrying capacity of bamboo RC beams is about one-half of the conventional steel RC beams, while rattan RC beams were barely one-quarter of the steel RC beams capacities. The flexural strengths of RC beams made of bamboo (6.22 N/mm2), rattan (2.56 N/mm2), and steel (12.22 N/mm2) were measured. The indication of this is that the flexural strengths of bamboo and rattan RC beams were 51% and 21% respectively of the conventional steel RC beams. Table 4 provides a summary of the RC beams' failure mechanism, fracture pattern, and crack width. The mode of failure for bamboo and steel RC beams was shear, indicated by diagonal cracks, because of the relatively higher tensile strength of steel rebars than the rattan RC beams which failed by flexure (vertical cracks). At the midspan, the reinforcement was sufficient for BB and SB to withstand the moment. However, shear was at its maxi- mum at the support which coincided with the location of the maximum crack widths. On the other hand for rat- tan RC beam with low yield strength, the flexural mode of failure preceded the shear mode of failure as indi- cated by the vertical cracks neat the middle of the span. In addition, the experimental maximum crack width for bamboo, rattan and steel RC beams were 9.3, 6.7 and 7.0 mm. The rattan RC beams had the minimum crack widths because of the flexural mode of failure under rela- tively smaller ultimate failure load. On the contrary, bamboo and steel RC beams failed under a comparatively higher load due to shear. The knife-edge condition informed the pattern and size of crack propagation.

Table 3. First crack and failure loads for beams.

Beam No.	First crack load, F (kN)	Ultimate failure load, F (kN)	$\frac{F_c}{u}$	Flexural strength (N/mm^2)
Bamboo RC-BB	11	18.67	0.59	6.22
Rattan RC-RB	6	8	0.75	2.56
Steel RC-SB	20	34	0.59	12.22

Table 4. Failure mode and crack characteristics.

Beam No.	Mode of failure	Type of crack at failure	Experimental maximum crack width (mm)
Bamboo RC-BB	Shear	Diagonal	9.3
Rattan RC-RB	Flexural	Vertical	6.7
Steel RC-SB	Shear	Diagonal	7.0

4. Conclusions

The following salient conclusions can be drawn from the study.

The stress ratios of the three reinforcing materials met the minimum required value of 1.08, and their tensile characteristics followed a normal distribution. Rattan has thirteen times the strength of steel reinforcing bars and bamboo forty-five times that strength. 2) Steel rebars completely fulfilled the ductility criteria, although rattan only partially fulfilled them, and bamboo's elongation fell short at 12%.3) Lightweight RC constructions are the only ones that can be constructed using bamboo and rattan. Compared to RC beams made from traditional steel bars, bamboo and rat-tan RC beams have flexural stiffness levels about 32% and 13.5%, respectively. Traditional steel RC beams had initial breaking loads that were 55% of bamboo's and 30% of rattan's. Bamboo RC beams had ultimate failure loads 51% higher than normal steel RC beams, whereas rattan RC beams had loads 21% higher. 4) After the first fracture, the residual capacity of bamboo and steel RC beams was 40%, whereas the load-carrying capability of rattan RC beams was 75%. 5) The mode of failure for bamboo and steel RC beams was shear, indicated by diagonal cracks because of the short-span specimen adopted and the relatively higher tensile strength than the rattan RC beams which failed by flexure (vertical cracks). 6) Epoxy-bonded galvanized iron or fiber thread wound spirally around the bars of bamboo or rattan RC beams might increase their flexural and bonding strengths.

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