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Strength Properties of Steel and Bamboo Reinforced Concrete Containing Quarry Dust, Rice Husk Ash and Guinea Corn Husk Ash

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ABSTRACT

The rising cost of concrete production due to the global recession in world economy caused by the COVID-19 pandemic and the greenhouse gases emitted in the production of cement has necessitated the need for alternative materials for cement. In this study, bamboo strips and steel rebars were used as reinforcements in a ternary blended concrete to determine their strength properties. In alignment with standard requirements for testing, concrete specimens were tested at curing ages of 7, 14 and 28 days for compressive, splitting tensile and flexural strengths. The morphological and bond characteristics of the bamboo were determined through the Scanning Electron Microscopy (SEM) and Fourier Transform Infra-Red Spectroscopy (FTIR), respectively; while its tensile strength was determined and compared with that of steel reinforcement. These results showed that bamboo is ductile and has stretching vibrational spectrum. The combinations of quarry dust, river sand, Rice Husk Ash (RHA) and Guinea Corn Husk Ash (GCHA) yielded compressive and split tensile strengths of 20.4 N/mm^2 and 2.18 N/mm^2, respectively. Concrete with 50 % river sand and 50 % quarry dust performed better in flexure for both Bamboo Reinforced Concrete (BRC) and Steel Reinforced Concrete (SRC) at 28 days with strengths of 12.75 N/mm^2 and 22.49 N/mm^2, respectively. Therefore, bamboo, quarry dust, rice husk and guinea corn husk ash can be used for reinforced concrete production.

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NOMENCLATURE

M_c	Control mix	M_3	Mix combination 3
M_2	Mix combination 2	M_4	Mix combination 4

INTRODUCTION

The global recession has resulted in the rising cost of cement which is the major constituent in the production of concrete. In the same vein, conventional construction materials became very expensive [1]. This has led to a compromise in quality in building construction as a result of the reduction of the use of cement in concrete mix to manage cost; thus, leading to incessant building collapse [2, 3]. As a result of these challenges, numerous alternative materials are being proposed for concrete production. Concrete is a composite material formed by bonding together of aggregates and fluid cement which hardens overtime [4].

Cement, being one of the fundamental constituents in concrete production, causes a grave hazard by emitting carbon dioxide, and other greenhouse gases into the environment at an alarming rate, which are largely responsible for global warming. It was estimated that about 0.9 tons of carbon dioxide is released into the environment when producing a ton of cement [5, 6]. Over the years, researchers have suggested different industrial by-products and agricultural residues as alternative binders in the production of durable and sustainable

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concrete [7, 8]. Amongst are ground granulated blast furnace slag (GGBS) [1], fly ash, silica fume, metakaolin and GGBS [5], sorghum husk ash [9], guinea corn husk [10, 11] and so on as an admixture or a partial replacement for cement because they possess pozzolanic properties. They have all proven to be suitable alternatives in improving the strength characteristics in blended cement. Rice Husk Ash (RHA) has a distinct pozzolanic property, which means it provides reactive SiO_2 to react with water and $Ca(OH)_2$, which is formed during the hydration of calcium silicates in cement, to yield calcium silicate hydrate, which is responsible for the strength of cement-based materials [12]. Also, both sharp sand and granite being the conventional fine and coarse aggregates have been replaced with materials such ceramics, polyvinyl wastes [13], glass [14–16] and quarry dust [17–19]. All these have been used to improve the quality of concrete.

Steel reinforcements are the most widely and generally used reinforcements in concrete for load bearing structures. Due to the high cost of steel, bamboo is being considered as a possible alternative due to its low cost and some of its identical physical strengths to steel. Bamboo can be utilized as rebar in concrete for light weight structures under particular conditions and with careful preparation [20, 21]. It is a member of the grass family and is exceptionally resistant to tensile stress, making it one of nature's most adaptable products. Bamboo's flexible mobility necessitates the development of an extremely light yet tension-resistant fibre in the bamboo culm that can bend in extreme directions without breaking. When used as concrete reinforcement; however, the natural form of bamboo offers a number of issues. Bamboo can expand with water and decay if left untreated. One of the disadvantages of employing natural bamboo in structural concrete is shrinkage and long-term durability, which causes concrete matrix segregation [22]. Because bamboos are stronger in tension than in compression, their usage in concrete is critical, as concrete is strong in compression but weak in tension. As a result, when utilized as reinforcement, bamboo can compensate for concrete's poor tensile strength [20]. It can play a significant role in decreasing global carbon emissions due to its unrivalled ability to collect carbon.

Varma [23] and Karthik et al. [1] worked on treated bamboo and incorporated them in concrete that was made with Ground Granulated Blast Furnace Slag and fly ash as partial replacement of cement while they partially replaced river sand with manufactured sand (m-sand) [24]. Their findings reveal that treated bamboo can be utilized as reinforcements in concrete. Also, Raut and Deo [24–26] replaced cement and sand with fly ash and considered the inclusion of fiber on the durabibility of concrete. They reported an improvement in compressive strength, electrical resistivity, ultrasonic pulse velocity and decrease the shrinkage in the concrete samples tested.

However, from the literatures reviewed, there is no record on BRC composite made with admixtures such as RHA and Guinea Corn Husk Ash (GCHA). Therefore, in this study, the possibility of using quarry dust as fine aggregate, RHA and GCHA as admixtures or partial replacement for cement alongside bamboo and steel as the reinforcement for the improvised concrete was examined and compared with the conventional reinforced concrete. The parameters investigated in this study are compressive strength, flexural strength, crack development and propagation patterns, and the ultimate bending moments.

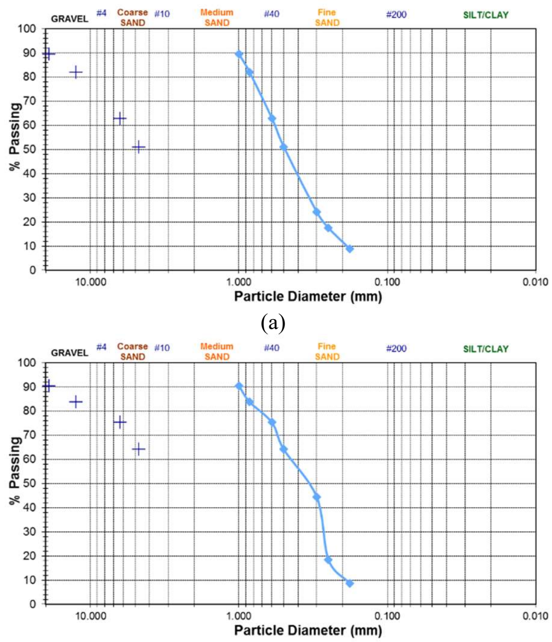
MATERIAL AND METHODS

The materials used for this research include Portland Limestone Cement (PLC) of grade 42.5R conforming to BS EN 196-3 [27], RHA, GCHA, river sand, quarry dust, granite, portable water, steel reinforcement and bamboo. The aggregates were prepared in conformity to BS 8500-1 [28] and BS EN 206:2013+A1:2016 [29]. The properties of both the fine and coarse aggregates are summarized in Table 1. The particle size distribution curve for the fine and coarse aggregates are presented in Figures 1 and 2, respectively. The river sand, quarry dust and granite have a coefficient of uniformity of 2.78, 1.94 and 2.50, respectively. This shows that all the aggregates used in the study are uniformly graded. Rice Husk from Lafiagi passing through 90µm sieve was burnt at 650 ℃ for 2 hours in conformity to the method adopted by Thiedeitz [30]. Guinea Corn Husk collected from a milling store in Ijagbo, Kwara state, Nigeria, was burnt at 650 ℃ for 4 hours following the method adopted by Bello et al. [31]. The guinea corn husk ash was ground with a milling machine and allowed to pass through 90µm sieve size as stipulated by Odeyemi et al. [10]. The materials were tested for their specific gravity, water absorption, fineness modulus, and normal consistency as stated in Table 1. Portable and clean water of 7.5 pH value was used for the concrete mix.

Bamboo, of the *Bambusa Valgaris* stock, obtained from Opo Maalu in Kwara state was processed into typical 10 mm reinforcement bar size. Preliminary treatment of the bamboo followed the procedure adopted by Karthik et al. [1] which entails subjecting the bamboo

Table 1. Physical properties of aggregates used

S/N	Aggregates	Specific gravity	Water absorption (%)	Fineness modulus	Normal consistency (%)
1	River sand	2.66	2.6	3.64	-
2	Quarry dust	2.49	3.2	3.79	-
3	Granite	-	0.3	6.6	-
4	Cement	2.67	-	0.79	29



(a)

(b)

Figure 1. Particle size distribution (a) river sand (b) quarry dust

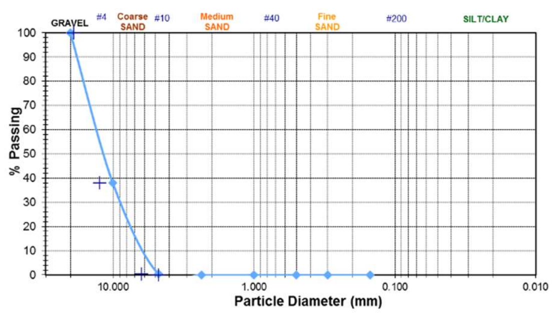


Figure 2. Particle size distribution of granite

to soaking under room temperature of 27 ℃ for 48 hours and afterwards, they were sundried for 30 days, thereby reducing the moisture content to the barest minimum. Precautions were taken before picking the bamboo to ensure that they show no traces of decay and flaws. It was then stripped into typical 10 x 10 x 480 mm size at a sawmill. Prior to its use or casting the beams samples, all the bamboo strips were greased thoroughly to ensure adhesion to the concrete and to reduce absorption of water. 10 mm high yield steel reinforcement and bamboo strip were used. The flexural strength of the high yield steel and bamboo is shown in Table 2.

Mix design

Four main categories of mixes were considered based on the aggregate combinations (Table 3) and to follow the

Table 2. Steel and bamboo reinforcement tensile force and strength

Reinforcement type	Maximum tensile force	Maximum tensile strength
Steel rebar	50kN	637N/mm^2
Bamboo strip	3.5kN	35N/mm^2

trend used by Karthik et al. [1]. The control mix was designated as M_C. It contains the basic components of concrete viz cement, sand, and granite in ratio 1:2:4 and water-cement ratio of 0.5. M_2 contains cement as binder, 50% quarry dust, 50% of river sand as the fine aggregate and granite; M_3 contains 5% of GCHA, 15% of RHA and 80% cement as binder, 100% quarry dust as fine aggregate and granite. Lastly, M_4 contains 5% of GCHA, 15% of RHA, 80% cement as binder, 50% of river sand, 50% of quarry dust as fine aggregate and granite as coarse aggregate.

Sample preparation

In triplicates, a total of 36 concrete cube samples of 100×100×100 mm dimensions and 36 concrete cylindrical samples of 150 mm diameter by 300 mm height were cast and tested (Table 4). However, for beams, four sets of beams were constructed for each category, with two examples strengthened with 10mm steel bars and the other two with bamboo strips. Binding wires were used to secure the bamboo strips with stirrups. In total, 42 beams measuring 100×100×500 mm were made and cured in water for 28 days. For all the samples, a 20 mm concrete layer was maintained with a water-to-cement ratio of 0.5.

Experimental investigation

The compressive, split-tensile, and flexural strengths were determined using a Universal Testing Machine (UTM) at a constant loading rate of 120 kN/min while the crack development (failure) pattern was visually monitored. The cured concrete samples were tested at 7, 14 and 28 days. The systematic loading arrangement of a point load flexural testing was adopted. The beam sample was positioned with simple supports at 50 mm from both ends. Figure 3 shows the schematic loading arrangement and the section of the beam.

RESULTS AND DISCUSSION

Characterization of bamboo

The characterization of bamboo was done through the SEM and FTIR analyses. The SEM image of the bamboo represented in Figure 4 shows the morphology of the bamboo at magnification of 1000. The micrograph revealed rough texture with desert-like topography. The presence of pores all over the flat surface terrain indicates

Table 3. Summary of mix design

S/N	Mix description	Water-Cement ratio (litres)	Binder (kg)			Fine aggregate (kg)		Coarse aggregate Granite (kg)
			Cement	GCHA	RHA	River sand	Quarry dust	
1	M_c	17.75	35.5	0	0	71	0	142
2	M_2	17.75	35.5	0	0	35.5	35.5	142
3	M_3	17.75	28.4	1.775	5.325	0	71	142
4	M_4	17.75	28.4	1.775	5.325	35.5	35.5	142

Table 4. Summary of sample preparation

Curing days	Samples	Mix				Total number of samples
		M_c	M_2	M_3	M_4	
7	Cubes	3	3	3	3	12
	Cylinders	3	3	3	3	12
	Beams	2SRC & 2BRC	2SRC & 2BRC	2SRC & 2BRC	2SRC & 2BRC	16
14	Cubes	3	3	3	3	12
	Cylinders	3	3	3	3	12
	Beams	2SRC & 2BRC	2SRC & 2BRC	2SRC & 2BRC	2SRC & 2BRC	16
28	Cubes	3	3	3	3	12
	Cylinders	3	3	3	3	12
	Beams	2SRC & 2BRC	2SRC & 2BRC	2SRC & 2BRC	2SRC & 2BRC	16

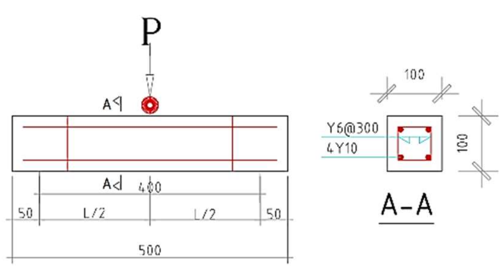


Figure 3. Schematic load setup for flexural test and beam section

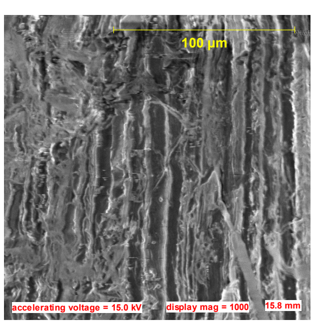


Figure 4. SEM for bamboo

the weak cohesion within itself with the possibility of a strong adhesion to other materials due to its hydrophilic nature.

Figure 5 shows the transmittance of bamboo gotten from its absorbance result. Its peak transmittance intensity is shown at 1037.01 cm^{-1}. This signifies that the bamboo powder comprises of a single bond molecule and stretching vibrational spectrum. It consists of a functional group of C=C stretching vibrational spectral between the bamboo particles. Consequently, the amplified frequency examined in the bamboo particle was a signal of increased bond strength. This finding is in tandem with the submission of Karthik et al. [1].

Tests on GCHA and RHA

The characterization of the GCHA and RHA was done through SEM and XRF analysis. The GCHA and RHA were sieved with a 90 µm sieve so as to conform to the standard for cementitious material as defined by BS 8615 [32].

The SEM micrograph of RHA (Figure 6) was observed through a 15 kV accelerating voltage and display magnification of 1000 was used to produce the morphological characteristics of the particles of the RHA. It has cluster of amorphous highly dense particles. The texture of the graphic is rough with irregular shapes containing pores. It shows the porosity of particles due to the presence of silica in high proportion. The micro-particles are closely packed, and the particles are less dispersed within the polymer matrix.

The SEM of the GCHA (Figure 7) shows the morphology for a magnification of 1000. Each micro-particle of GCHA lies over one another to produce

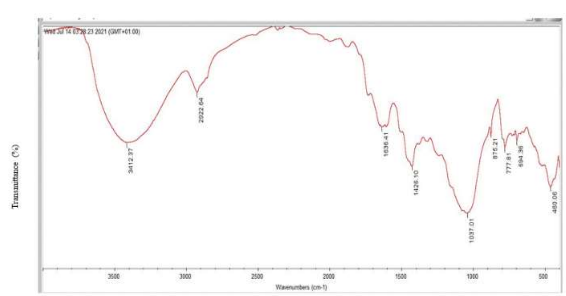


Figure 5. Transmittance of bamboo power

mountain-like clusters of honeycombs like texture and valley-like pores and large surface areas. It has very large porosity due to the large pores present in them. It also contains few rod-like shapes which are intertwined which will likely increase some of the mechanical properties when in the concrete mix.

The result for the oxides of GCHA as summarized in Table 5 was done using X-ray fluorescence (XRF) analysis.

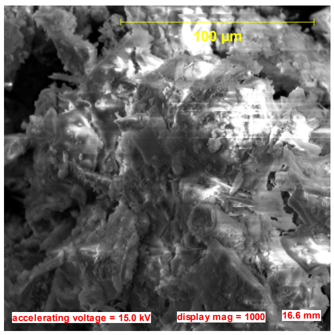


Figure 6. SEM image of RHA

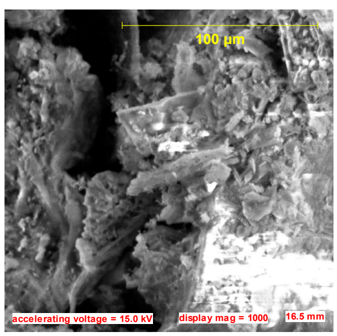


Figure 7. SEM image of GCHA

Table 5. Oxides composition of GCHA

Content	Percentage
SiO_2	61.62
Al_2O_3	5.95
Fe_2O_3	6.72
CaO	10.80
MgO	0
K_2O	10.25
Na_2O	0
SO_3	4.29
MnO	0.060
ZnO	0.31
LOI	0

The summation of the oxides in SiO_2, Al_2O_3 and Fe_2O_3 of the GCHA is 74.29% which fulfills the condition for a supplementary cementitious material stipulated in BS EN 197-1 [33]. Also, the reactive silicon dioxide content of 61.62% is higher than the minimum 25% by mass stipulated by the standard.

Figure 8 shows graph obtained from the XRF test done for the chemical composition of the GCHA.

The result of the oxides of RHA as presented in Table 6 was done using X-ray fluorescence (XRF) method. BS EN 197-1 [33] defines the sum of SiO_2, Al_2O_3 and Fe_2O_3 of a supplementary cementing material as not less than 70%. The total sum of SiO_2, Al_2O_3 and Fe_2O_3 of RHA tested is 92.31% which is more than the 70% specified by BS EN 197-1 [33]. The result of Silicon dioxide (SiO_2) has the highest percentage of oxide covering about 87.53% of the total compositions. These results are similar to the ones reported by Kanthe et al. [34, 35]. Figure 9 shows the graph obtained from the XRF test done for the chemical composition of RHA.

Compressive strength

The compressive strength tests of the concrete containing GCHA, RHA and quarry dust were all obtained in

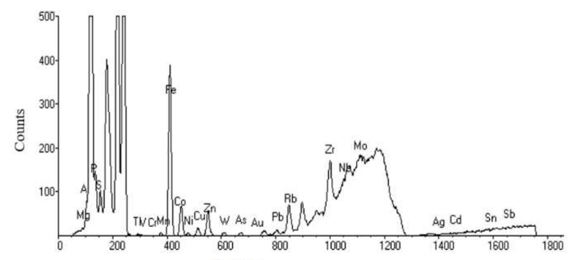


Figure 8. X-Ray Florescence graph for the chemical composition of GCHA

Table 6. Oxide composition of RHA

Content	Percentage
SiO_2	87.53
Al_2O_3	3.99
Fe_2O_3	0.79
CaO	1.47
MgO	0.58
K_2O	3.27
Na_2O	0
SO_3	2.08
MnO	0.17
ZnO	0.12
LOI	0

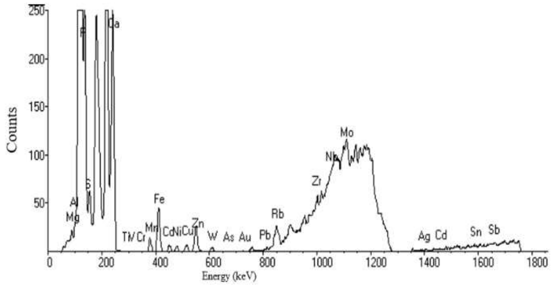


Figure 9. X-Ray florescence graph chemical composition for RHA

accordance to BS EN 12390-3 [36] and as shown inFigure 10. The results reveal that using river sand instead of quarry dust in concrete has a significant influence on its compressive strength. The partial replacement of river sand with quarry dust lowers the 28th day strength of the concrete by 7.87%. It was also noticed that the introduction of RHA and GCHA as partial replacement of cement and full use of river sand in concrete lowers the 28th day strength of concrete by 14.4%. The 28th day compressive strength of the control mix reduced by 36.51% when RHA and GCHA were introduced as partial replacement for cement and river sand was partially replaced with quarry dust. However, all the mixes can be adopted for reinforced concrete structures since their strength are higher than Grade 20 recommended for reinforced concrete structures [37].

Split-tensile strength

The split tensile strength tests of concrete containing GCHA, RHA and quarry dust were done in accordance to BS EN 12390-6 [38] and as presented in Figure 11.

From the result of the split-tensile strength all the mixes improved with each curing age. At 7 days of curing, M_3 and M_4 had the lowest value. This could be owing to a delayed reaction caused by the silica

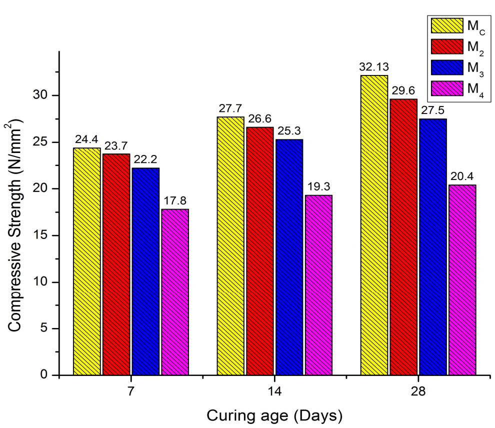


Figure 10. Compressive strength results graph

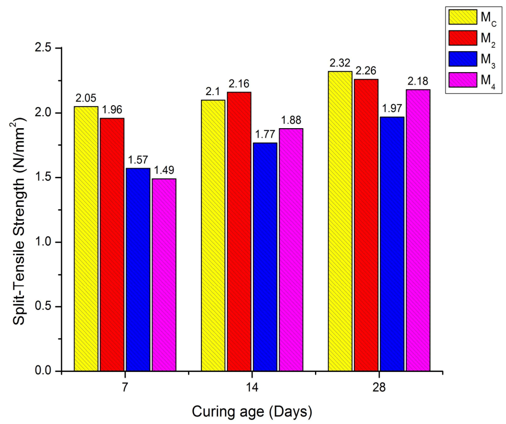


Figure 11. Split tensile strength graph

component in RHA, which can only be broken down by the alkalinity of the pore water, which takes time to reach a high pH after hydration. M_4 later had a rapid in its strength after 14 and 28 days with about 26% and 15.96% strength gain respectively. This is very close to the strength of conventional concrete. This underscores the significance of RHA, GCHA and quarry dust in the split-tensile strength of the composite. M_2 had a flexural strength of 2.16 N/mm^2 at 14 days which is more than the split tensile strength of M_C with a strength of 2.10 N/mm^2 being 2.86% less than M_2. However, M_C increased to 2.32 N/mm^2 at 28 days by 2.65% to surpass M_2 which has 2.26 N/mm^2. Figure 11 is the graphical representation of the split tensile strength of all the mixes at each curing days.

Flexural strength

The flexural strength of the bamboo and steel reinforced concrete were determined in accordance to BS EN 12390-5:2019 [39] and the results are in Figure 12.

It was observed that at all curing days the flexural strengths of the bamboo reinforced mixes were lower than that of the steel reinforced mixes. This is due to bamboo having lesser tensile strength than steel and lower bond strength between bamboo and the concrete composite. M_2 has the highest flexural strength for bamboo and steel reinforced concrete mixes at all curing days because of the replacement of sand by 50% quarry dust in the concrete. This result is in tandem with the submission of Meisuh et al. [19].

However, the flexural strength of M_3 and M_4 containing RHA and GCHA is higher than the strength reported by Karthik et al. [1] for the same mix of concrete containing fly ash and ground granulated blast furnace slag and manufactured sand. This significant flexural performance underscored the valuable influence of RHA, GCHA and quarry dust. Consequently, they can be proposed for incorporation in construction of structural elements requiring high flexural resistance.

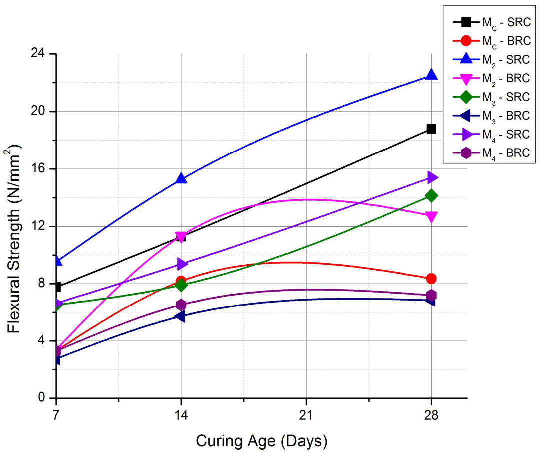


Figure 12. Flexural strength of the bamboo and steel reinforced concrete for M_C

Crack pattern failure mode

The crack pattern obtained from each reinforced concrete samples was obtained after the beams have failed under their respective maximum loads. It was noticed that the crack pattern formed on each beam was typical to the type of reinforcements embedded in the beams. The beams incorporated with steel reinforcements had a progressive crack pattern (Figure 13) implying that the beam is stronger in flexure hence the shear strength limit was reached before the bending strength. The beam with bamboo strips in them had a brittle-like crack pattern (Figure 14) indicating a flexural failure due to the low tensile strength of the bamboo and the weak bond between the bamboo strip and the concrete composite.

Figure 13. The progressive-like pattern of crack for steel reinforced beam

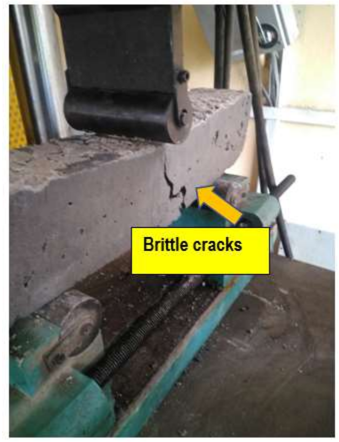


Figure 14. The brittle-like pattern of crack for bamboo reinforced beam

CONCLUSIONS

The following were the conclusions drawn from the study:

1. The FTIR and SEM results revealed that bamboo is ductile with some substantial tensile strength. This makes bamboo a suitable substitute for steel. Also, because of its sturdily bonded particles, it can be a useful reinforcement material for structural members in compression and those subjected to bending.
2. Although, the compressive strength of concrete containing RHA and GCHA is lower than that of normal concrete, it is nevertheless suitable for structural applications. Their split-tensile and flexural strengths are closer to that of conventional concrete. Consequently, they can be proposed for incorporation in construction of structural elements.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Persian Abstract

چکیده

افزایش هزینه تولید بتن به دلیل رکود جهانی اقتصاد جهانی ناشی از همه‌گیری کووید-۱۹ و گازهای گلخانه‌ای منتشر شده از تولید سیمان، نیاز به مواد جایگزین برای سیمان را ضروری نموده است. در این مطالعه از نوارهای بامبو و میلگردهای فولادی به عنوان تقویت‌کننده در بتن ترکیبی سه تایی برای تعیین خواص مقاومتی آنها استفاده شد. مطابق با الزامات استاندارد برای آزمایش، نمونه‌های بتن ۷، ۱۴ و ۲۸ روزه برای مقاومت کششی، شکافی و خمشی مورد آزمایش قرار گرفته‌اند. ویژگی‌های مورفولوژیکی و پیوند بامبو به ترتیب از طریق میکروسکوپ الکترونی روبشی(SEM) و طیف‌سنجی مادون قرمز تبدیل فوریه (FTIR) تعیین شد. در حالی که مقاومت کششی آن با آرماتورهای فولادی تعیین و مقایسه شد. این نتایج نشان داد که بامبو انعطاف‌پذیر است و دارای طیف ارتعاشی کششی است. ترکیب خاکستر و غبار معدن، ماسه رودخانه، خاکستر پوسته برنج (RHA) و خاکستر پوسته ذرت گینه (GCHA) به ترتیب مقاومت کششی ۲۰/۴ نیوتن بر میلی‌متر مربع و ۲/۱۸ نیوتن بر میلی‌متر مربع را به همراه داشت. بتن با ۵۰ درصد شن و ماسه رودخانه و ۵۰ درصد خاکستر و غبار معدن، به ترتیب برای بتن مسلح بامبو (BRC) و بتن مسلح فولادی (SRC) در ۲۸ روز با مقاومت ۱۲/۷۵ نیوتن بر میلی‌متر مربع و ۲۲/۴۹ نیوتن بر میلی‌متر مربع در خمش بهتر عمل کرده است. بنابراین می‌توان از بامبو، خاکستر و غبار معدن، پوسته برنج و خاکستر پوسته ذرت هندی برای تولید بتن مسلح استفاده کرد.