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5 authors, including:

Ezekiel Babatunde Ogunbode
Federal University of Technology Minna

Jamaludin Mohamad Yatim
Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Meisam Razavi

Mohd Yunus Ishak
Universiti Teknologi Malaysia

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Experimental Study of Kenaf Bio Fibrous Concrete Composites

Ogunbode Ezekiel Babatunde[1,2], Jamaludin Mohamad Yatim[1,*], Meisam Razavi[1], Ishak Mohd. Yunus[1], and Norazura Mizal Azzmi[1]

[1]*Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia*
[2]*Department of Building, Federal University of Technology Minna, Niger State, Nigeria*

The objective of this study is to evaluate the suitability of treated Kenaf fibre as reinforcement in concrete composite production for high performance structures. A comparison of both Plain concrete (PC) and Kenaf bio fibrous concrete composite (KBFCC) was made. The bio fibrous concrete mix was made of three different fibre contents (0.5%, 0.75% and 1%) and corresponding two different fibre lengths of 25 mm and 50 mm. A high workability and rheology mix proportion of grade 30 N/mm^2 at 28 days was prepared. A test on workability of the fresh mix, compressive strength, flexural strength, splitting tensile strength, and shrinkage on the hardened concrete was done and the results were recorded at curing age of 7 and 28 days. The study showed that the workability and density of the concrete is reduced due to the inclusion of Kenaf fibre. A lower compressive strength and elastic modulus was exhibited by KBFCC as compared to PC. Splitting tensile and flexural strengths of KBFCC were however improved. The obtained result on shrinkage revealed that the drying shrinkage strain of KBFCC was lower than that of PC. The optimum fibre length and fibre volume fraction was established as 50 mm and 0.5%, respectively. The results obtained in this study indicated that Kenaf fibre can suitably be used as fibre reinforcement in concrete with satisfactory performance.

Keywords: Bio Fibrous Concrete, Kenaf Fibre, Strength, Elasticity Modulus, Drying Shrinkage.

1. INTRODUCTION

Low tensile strength and low energy absorption capacity of concrete apparently exposes it to collapse.[1,2] This adversely limits the performance of concrete under loading. The inclusion of short discontinuous randomly oriented fibres has remained a practice among others towards contributing to the improvement of low tensile and brittleness of concrete. The concept of sustainability, such as the inclusion of natural biodegradable fibre in concrete has been one of the emphases of the construction industry.[1] This is due to the current global challenge of carbon foot print. The use of biodegradable product, such as Kenaf bio fibrous concrete is being advocated for Ref. [1]. The acceptance and use of bio fibres in the construction industry are on the increase in both the developing and developed countries.

In recent years, research improvements have been carried out concerning the practice of fibre reinforcement for improving concrete components performance for structures. However most of this works has been on steel fibre and non-renewable materials.[3–7] Kenaf fibre is extracted from Kenaf plant stem and is a non-woody fibre that flourishes in the tropical climate and sub-tropical climate zones, and possesses similar properties to jute fibre and cotton fibre.[8,9] The fibre has a mean diameter of 67.6 μm.[10] Historically, it is from the Malvaceae family with a specie name normally referred to as *Hibiscus cannabinus*. The use of Kenaf fibres in the production of numerous industrial raw materials made it to be classified as an industrial fibre. Interestingly, Kenaf fibre is commercially accessible at moderate price tag when compared with other cellulose fibres and his obtainable in huge amounts.[11] Kenaf fibre superb features and properties make it a choice fibre as against other fibres because of its high mechanical tensile strength and high toughness,[12] high impact resistance,[13] causes minimal equipment abrasion,[14–16] excellent flexibility,[15,16] low density,[6] high aspect ratio,[17] and high modulus.[18] They are also renewable and biodegradable,[19] they cause less skin and respiratory problems,[20] vibration damping[13,21] and have better energy recovery.[20,22] These physiognomies and mechanical properties make them fit for application as reinforcing agent in cement, concrete and polymer composites.[23]

Conversely, Kenaf fibre being a cellulose fibre possesses a negative property of high water soptivity. This negative property leads to its poor fibre surface matrix bonding and degrading of the fibre when used as reinforcement in hydrophobic matrices.[24,25] Several researches have being done in respect of curtailing the hydrophilicity shortfall of Kenaf fibre used in

*Author to whom correspondence should be addressed.

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cement and concrete composite. A method referred to as mercerization (alkalinisation) was found to be the best. This is done by using sodium hydroxide to treat the surface of the fibre. The chemical procedure reduces the moisture soptivity of Kenaf fibre and improves its mechanical bonding property. Kenaf fibre comes inform of a curled long fibre after undergoing retting process. For its application in concrete composite, it is chopped in smaller length as required (Fig. 1).

Previously, researchers have studied the influence of various kinds of fibres (steel, synthetic and natural fibres) on the short term quasi-static properties, and time dependent deformation properties of concrete.[26,27] However limited study has been conducted on KBFCC. Studies on KBFCC have recently been on the rise among researchers due to the fast-growing acceptance of Kenaf plant in the agro world and its vast influence on bio-based economy drive.[28] Generally, in the field of composite, bio-based materials have emerged to be currently in the foreground of research endeavours even though studies on bio-fibrous concrete are still limited. Attention is increasingly being drawn to the utilization of Kenaf fibre as a reinforcing agent in concrete composite due to its nature of being environmentally friendly. This is not far from the call made for sustainable development and transition into a bio based economy by the Kyoto protocols in 2009 on the need to decrease CO_2 and all gases that are referred to as greenhouse gases.[28] In Refs. [1, 29, 30] the influence of Kenaf fibres on the physical and mechanical properties of concrete at varying fibre length and volume were investigated. All their studies were associated with the short-term behaviour of fibrous concrete under load. Their studies gave a resolution that Kenaf fibre causes the workability of the fresh concrete mixture, ultra-pulse velocity and compressive strength of the hardened concrete to decrease with respect to fibre volume increase.

Nevertheless, Kenaf fibre have proven to be a positive contributor to flexural and tensile strength of concrete.[1,29,30] The inclusion of Kenaf fibre in concrete is quite new, only a few studies on performance have been done. These studies are still limited to the general properties and short term deformation of KBFCC. There is still a wide gap of information in literature on the performance of Kenaf bio fibrous concrete composite under time dependent deformations such as creep and shrinkage.[31]

Despite the positive enhancement of the mechanical properties of concrete composite using bio fibres, the accrued advantage has not been explored yet in concrete composite engineering practice. The reason is not far from the dearth of data on the time dependent deformation performance of bio-fibrous concrete composites (BFCC). Until this information is available and all the properties understood, the mechanical advantages cannot be used in or included in design guidelines. Hence, a dare need for the understanding of the shrinkage and creep behaviour of the concrete composite is required. This has led to the initiation of an investigation to study the mechanical and shrinkage behaviour of KBFCC.

2. EXPERIMENTAL PROGRAMME

The physical, mechanical and time dependent performance (shrinkage) of Kenaf biofibrous concrete composite (KBFCC) was experimentally investigated. The Kenaf fibre geometry was in two varying lengths of 25 mm (1 inch) and 50 mm (2 inches). The Kenaf fibres used in the study are alkaline treated fibres. The inclusion of the fibres was made at a volume fraction of 0.5, 0.75, and 1% which is equivalent to dosages of 6, 9, 12 kg/m^3 (10.11, 15.17, and 20.23 lb/yard^3), respectively, to epitomise the usual practice on the site.

These mix proportions were done for the investigation of the physical and mechanical properties. The determined optimum fibre length at 50 mm and fibre content at 0.5% was used to study and estimate the shrinkage deformation property of KBFCC. All specimens used in this experiment were cast and demoulded within 24 hours. The specimens used for the mechanical properties test were cured in water for a further 6 and 27 days before testing. Specimens meant for shrinkage test were moist cured in a climate controlled room with a temperature of 23 ± 2 °C [73.5 ± 3.5 °F] and a mean relative humidity of 50 ± 4% for 7 and 28 days before testing. The shrinkage test was done in the climate controlled room in accordance to ASTM C 157.[32]

2.1. Materials and Methods

The constituent material used in this study were ASTM Type I cement (OPC), fine aggregate (SSD) passing through 4.75 mm sieve with fineness modulus (FM) of 2.46, coarse aggregate (crushed granite) passing through 9.5 mm sieve size (SSD), tap water, Rheobuild 1100 superplasticizer as admixture and treated Kenaf fibre. The raw Kenaf was acquired from Malaysian Agricultural Research and Development Institute (MARDI). The fibres collected were extracted from the Kenaf plant bast through bacteria retting process and delivered in curled long fibres.

Fig. 1. Kenaf fibre: (a) Untreated long curled fibre, (b) drying treated fibre, (c) chopped treated kenaf fibre.

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Sodium Hydroxide (NaOH) used as the treatment chemical for the investigation was supplied by Merck Sdn. Bhd. Malaysia. The details and properties of the fibre are presented in Figure 1 and Table I. The mixing of the concrete was done using a 0.25 m^3 (9 ft^3) capacity revolving pan mixer in the laboratory.

2.2. Mix Proportions

The mix proportions of KBFCC were developed for the investigation as given in Table II. A control mix, PC was also made for the purpose of comparison, and three fibre volume fractions (V_f) of 0.5, 0.75, and 1.0% were employed in this investigation.

2.3. Physical and Mechanical Test

The preparation, casting and testing of concrete samples to obtain their physical and mechanical properties are illustrated in this section.

The compressive strength test was done using 100×100 mm cube specimens as prescribed in BS EN 12390,[33] Splitting tensile and Elastic modulus test was done using 100 Ø × 200 mm cylindrical specimens in accordance to ASTM C496[34] and the flexural test was done using the $100 \times 100 \times 500$ mm prism according to ASTM C78.[35] The shrinkage deformation test was done using 100 Ø × 200 mm cylinder specimens to determine the performance of the mixes with and without Kenaf fibre in accordance to ASTM C517.[32]

The entire mechanical properties tests were measured at 7 and 28-days hydration period. The fresh PC and KFBCC mix workability was measured by the slump, compacting factor and Vebe time test in accordance with BS EN 12350-2,[36] BS 1881-103,[37] BS EN 12350-3,[38] respectively.

2.4. Shrinkage Test

A total of eight cylindrical specimens were used to investigate the dry shrinkage deformation of the PC and KBFCC. Four readings were taken for each specimen, giving a total of sixteen readings for the four cylindrical specimens with each representing a mix type. The specimens were tested unsealed with a gauge length of 100 mm attained by using a Demec gauge stud. A comparator (Demec gauge) was used to acquire the strain measurements. The initial shrinkage of specimens was taken at 7 and 28 days. Choosing 7 point for the shrinkage test was meant to simulate real condition of composite concrete structure at the end of curing and removal of formwork on site. Also, 28 days testing of specimens was meant to determine the material behaviour when the fibre-less and the fibrous concrete composite have attained the targeted strength.

Table I. Physical, mechanical and chemical characteristics of Kenaf fibres.

Constituent material Proportion (kg/m^3)	
Diameter (μm)	39.7–115.1
Density (g/cm^3)	1.04–1.5
Elastic modulus (GPa)	14–53
Elongation (%)	1.6
Tensile strength (MPa)	135–930
Chemical composition	
Cellulose (%)	31–57
Hemicelluloses (%)	21–23
Lignin (%)	4.79–19
Pectin (%)	2.0

Table II. Mix Proportions of KBFCC.

Constituent material	Proportion (kg/m^3)
Ordinary Portland cement (ASTM Type I)	418
Fine aggregate (river sand)	725
Coarse aggregate (Crushed granite)	1002
Potable water	230
Kenaf fibre (0.5, 0.75, and 1% by volume)	6,9, and 12
Super plasticizer (1%)	4.18

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Results of Fresh PC and KBFCC Properties

The properties of fresh PC and KBFCC such as workability and unit weight (density) are presented in Table III. Slump, Vebe time and compacting factor test of concrete mixtures at the same water/cement ratio of 0.55 was carried out to measure the workability of PC and KBFCC with fibre geometry of 25 and 50 mm long. Kenaf fibre was included in the concrete at varying volume fraction (V_f) of 0.5, 0.75, and 1%. By inspection, it can be observed from Table III that the workability of concrete with Kenaf fibres reduced and became stiffer as the fibre length (l_f) and fibre content in the concrete increased. Slump and compacting factor values of concrete also decreased as the l_f and V_f increased. Meanwhile, Vebe time of concrete increased as the l_f and V_f increased.

For fibre volume of 1%, the workability of concrete drastically dropped and became very stiff. It was noted that the knitting of fibres resists the flow of fresh concrete affecting the workability of concrete. This agrees with some existing findings.[30,39] It should be noted that the presence of 1% super plasticizer in the concrete mix had led to the attainment of this workability. Absence of super plasticizer or lesser quantity would have given a sturdier and unworkable concrete mix. The result on the unit weight of concrete, presented in the same table showed that concrete unit weight dropped uniformly with the increase in fibre volume fraction. This negates the outcomes of a study done using steel fibre.[39] This is due to the low density of Kenaf fibre (1200 kg/m^3) which is lower than most constituent of the concrete. Regardless of fibre volume, it was further observed that the unit weight of KBFCC decreased as the fibre length is increased as a result of air content in the concrete due to fibre orientation and the distribution of long fibres in concrete. The drop-in unit weight (density) of the fibrous concrete is a benefit of using the Kenaf fibres in plummeting the total mass of structure.

Table III. Workability and unit weight values for fresh concrete mixtures of PC and KBFCC.

Mixture ID	l_f (mm)	V_f (%)	Slump (mm)	Vebe time (s)	Compacting factor	Unit weight (kg/m^3)
PC	0	0	120	3	0.98	2362
KBFCC-1	25	0.50	90	4	0.92	2307
KBFCC-2	25	0.75	70	11	0.91	2289
KBFCC-3	25	1.00	40	16	0.90	2222
KBFCC-6	50	0.50	70	12	0.91	2350
KBFCC-7	50	0.75	55	15	0.90	2345
KBFCC-8	50	1.00	25	33	0.87	2280

Table IV. Mechanical properties of Hardened PC and KBFCC.

			Compressive strength (N/mm^2)		Spitting tensile strength (N/mm^2)		Flexural str. (N/mm^2)		Elastic modulus (GPa)		UPV (m/s)	
Mixture ID	l_f (mm)	V_f (%)	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
PC	0	0	28.56	36.03	3.19	3.68	4.59	4.65	23.82	27.21	4364	4452
KBFCC-1	25	0.50	25.77	30.96	3.35	3.77	4.46	4.82	23.56	26.19	4310	4388
KBFCC-2	25	0.75	19.57	21.91	3.30	3.397	4.04	4.12	22.82	24.38	4257	4325
KBFCC-3	25	1.00	14.78	15.35	2.47	2.758	3.31	3.93	22.56	23.07	3937	4075
KBFCC-6	50	0.50	25.98	31.04	3.23	3.95	4.78	4.98	23.65	26.21	4311	4400
KBFCC-7	50	0.75	21.40	25.51	2.91	3.26	4.09	4.24	22.68	25.10	4199	4281
KBFCC-8	50	1.00	17.64	21.84	2.88	3.02	3.87	4.03	21.56	24.37	4097	4267

3.2. Compressive Strength, Ultra-Pulse Velocity and Modulus of Elasticity

Kenaf fibre content and fibre length influences on compressive strength, ultra-pulse velocity (UPV) and elastic modulus is presented in Table IV. By inspection, it was observed that compressive strength reduced with higher fibre content and improved with longer fibres. Due to the increase in fibre content, compressive strength of KBFCC reduced up to 66% when compared to that of PC. A similar behaviour was reported by Refs. [29, 30]. This could have been caused by the created air voids due to the content of fibres in the mixture. Even though the compressive strength of KBFCC was much affected by the presence of fibre, the manner of failure, nevertheless, displayed a substantial change from fragile to ductile state. The cubic specimens used for the compression test did not crush. It was observed that they held their integrity from the commencement of the test to the end. The behaviour of the KBFCC specimen in this manner was own to bridging effect of the fibre in the concrete. A typical failure mode of PC and KBFCC in compression was illustrated in Figures 2(a) and (b). It was also observed that, as the fibre content increases, the value of UPV decreases. However, the UPV values of the PC and KBFCC are within the range of 4267–4452 ms^{-1}, which is considered good based on the quality Criteria Classification for Concrete on the basis of pulse velocity, as proposed in Ref. [40].

The elastic modulus of the PC and KBFCC were determined using the alternative expression Eq. (1) given in BS 8110-2.[41] The 28-day modulus of elasticity is determined from the cube strength of the concrete at 28 days.

$$E_{m28} = 20 + 0.2 f_{\text{cus28}} \tag{1}$$

In determining the elastic modulus of concrete at 7-day hydration period, BS 8110-2[41] presented another estimating expression Eq. (2). The elastic modulus E_m (t_o) in GPa is related to concrete cube compressive strength, $f_{\text{cus}}(t_o)$ as presented in Eq. (2).

$$E_m(t_o) = E_{m28}[0.4 + 0.6(f_{\text{cus}}(t_o)/f_{\text{cus28}})] \tag{2}$$

where E_m is the elasticity modulus in GPa and f_{cus} is the concrete cube compressive strength at either 7 or 28 day.

The results acquired obviously demonstrated that the modulus of elasticity of KBFCC in association with its lower compressive strength was lesser compared to PC. For instance, the 28-day modulus of elasticity of PC with the equivalent compressive strength of 36.03 N/mm^2 was seen to be 27.21 GPa. A slightly lesser value of 26.21 GPa was obtained for concrete with 0.5% volume and 50 mm length of Kenaf fibres having 28-day compressive strength of 31.04 N/mm^2. This is anticipated, since elastic modulus normally increases with an increase in the concrete compressive strength.

3.3. Indirect Splitting Tensile and Flexural Strength

Indirect splitting tensile and bending strength of PC and KBFCC were measured at hydration period of 7 and 28 days. Splitting tensile strength (STS) and Flexural strength (FS) decreased with higher fibre volume fraction. Though, it first increases and then a tad drops with increasing length of the fibre (Table IV). A comparison of the effect of fibre content on STS and FS of KBFCC, at both fibre length (25 and 50 mm) shows that better performance was obtained at fibre length of 50 mm, as fibre content increases. Data obtainable in Table IV suggest that with increase in curing age, the addition of Kenaf fibre in the concrete mixes had a progressive response on tensile strength of concrete. In the STS test, the PC cylinders were broken into two halves at maximum load, while KBFCC cylinders were held together after cracks and even when the test was continued up to its maximum failure load for all KBFCC cylinders. The test on KBFCC specimens was continued beyond maximum load failure in order to observe the post peak behaviour. The two pieces of the specimens

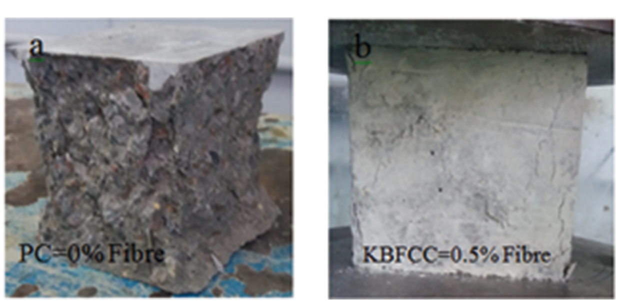

Fig. 2. Failure mode of (a) PC cube specimen, (b) KBFCC cube specimen under compressive load.

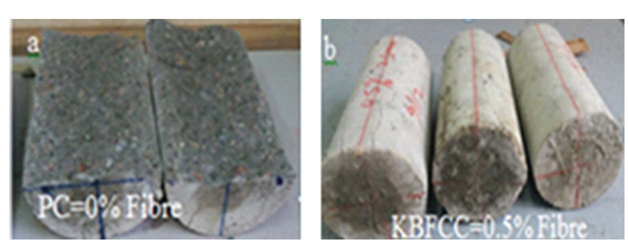

Fig. 3. Failure mode of cylindrical specimen in indirect splitting tensile (a) PC specimen, (b) KBFCC specimen.

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Fig. 4. Failure mode of prism in flexure (a) PC specimen, (b) KBFCC specimen, (c) Kenaf fibre bridging the cracked planes.

were held together by the fibres up to the end of the test. One of the tested PC and KBFCC cylinder specimens are presented in Figures 3(a) and (b). Compared to the STS of PC, the addition of fibres at 0.5% in the concrete mixture can increase the STS up to 7%. In general, KBFCC tensile strength was found to increase beyond that of PC with 50 mm fibre length at 0.5% fibre content. Optimal performance of FS of KBFCC was obtained with fibre length of 50 mm at 0.5% fibre volume (KBFCC-6). At this optimal level, FS of KBFCC is 7% higher than the control PC. The test results attained in this investigation are consistent with earlier studies.[29, 30]

One of the purposes of fibre inclusion in concrete is to constrain the propagation of cracks on concrete. This usually occurs due to concrete low tensile strength of the concrete. PC specimens tested in the experiment were seen to fail under flexure catastrophically by a single crack and parting into two halves (Fig. 4(a)). Conversely, the fibrous concrete specimens, even at small fibre volume fraction were seen to retain post cracking post cracking ability to carry loads. Few short and narrow cracks were observed on almost all the KBFCC samples (Fig. 4(b)). Figure 4(c) shows the spread of Kenaf fibres bridging the cracked planes.

4. TIME DEPENDENT PROPERTY OF CONCRETE

Shrinkage is an adverse time dependent deformation property of concrete. Durability and long term strength of concrete are its victims. Length and or volume change of concrete leads to cracks, which in practice is an issue of concern to all designers and engineers. The average shrinkage strain of four cylindrical samples is presented in Figure 5. Figure 5 presents the free drying shrinkage strain in microns for PC and KBFCC specimens. Concrete specimens tested for shrinkage at 7-day hydration period,

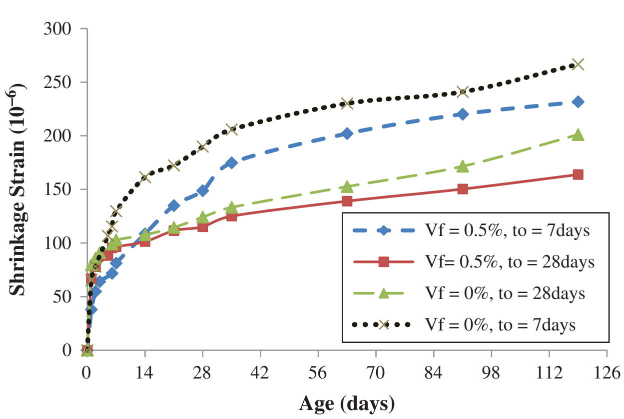

Fig. 5. Influence of fibre addition and age of exposure on the free drying Shrinkage of concrete, $^*t_o$ = exposure age of specimen to shrinkage testing.

exhibited higher drying shrinkage strains compared to specimens tested at 28 days. The properly cured older concrete experiences slower moisture diffusion due to ageing effect,[42] also, ageing effect resists the drying shrinkage of concrete effectually causing the rise of concrete stiffness. The inclusion of Kenaf biofibre caused the concrete specimen to show a considerable lesser drying shrinkage compared to concrete without vegetable fibre. A similar inclination has been stated by Ref. [43] who observed a considerably lower drying characteristic of the order of 50 to 70% for jute and coir fibre reinforced concrete, respectively, compared to those of plain concrete at 60 days. The aptitude of bio-fibres to hold moisture can be ascribed to the cause for the reduced free drying shrinkage of the KBFCC. In addition, the randomly oriented bio fibre presence around the cement gel creates a confining condition which inhibits drying shrinkage progression in the concrete. However, Kenaf fibres becomes more active in restraining free drying shrinkage of concrete as the age of drying increases as can be observed from Figure 5.

5. CONCLUSION

The study has investigated the influence of Kenaf bio-fibre on concrete at varying fibre length and volume fraction. From the findings of this study, the following conclusions can be made.

Kenaf fibre inclusion in concrete influenced the fresh concrete properties and hardened concrete properties. This effect ensued in reducing workability and unit weight (density) of the concrete. The concrete elastic modulus in connexion with the value of compressive strength was found to reduce with the increase in the fibre volume fraction. Nonetheless, Kenaf fibre considerably improved the flexural and the splitting tensile strength of the concrete. The Optimal performance of FS of KBFCC was obtained with fibre length of 50 mm at 0.5% fibre volume. Also, KBFCC demonstrated appreciable lower drying shrinkage strain notwithstanding the exposure age. The stability of these bio fibres appears to be good enough, but a need for long term test under sustained loading are of necessity in other to fully evaluate their performance in durability and in serviceability. The present results have shown that KBFCC application in the rural and civil construction works for the production of structural elements are realizable, dependable and beneficial to the environment. Moreover, this composite from Kenaf fibrous concrete could serve as an alternative to fibrous concrete like asbestos fibrous concrete which is attributed with detrimental effects on the health of all living thing.

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