Shrinkage Properties of Kenaf Bio Fibrous Concrete Composite for Sustainable Construction

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An experimental study had been carried out to investigate the fresh and shrinkage properties of kenaf bio fibrous concrete composite (KBFCC). A short discontinuous natural fibre commonly called kenaf fibre was used in the mix production as against the commonly used steel or synthetic fibre. The fresh property investigated in this study is concrete workability, which was tested using the slum, VB and compacting factor. Eighteen different fibrous concrete mix proportions and one plain concrete mix (control) were cast. The volume fraction, V_f for the fibrous concrete was a varying percentage between 0.25% to 2% at an interval of 0.25% and a fibre length at 25 mm, 50 mm and 75 mm. The concrete strength was designed to achieve grade C30 at 28 days. The results revealed that the inclusion of bio fibres in concrete decreased the workability of concrete due to its hydrophilic nature and affinity for water. It was observed that the concrete containing 50 mm fibre length and fibre volume of 5% gives the most appropriate combination as regards to the workability of the concrete. KBFCC demonstrated substantially lesser shrinkages compared to plain concrete specimens. The lowest shrinkage strain was recorded for 50 mm Kenaf fibre length mixture containing fibre below 1% tested at 28 days hydration period. It was also observed that Kenaf fibres become more active in restraining free drying shrinkage of concrete as the age of drying increases. The reduced shrinkage of the KBFCC when compared to PC can be attributed to the moisture holding capacity of kenaf fibres and the presence of randomly oriented fibres around the cement gel which create a condition of confinement inhibiting the shrinkage development of concrete.

Keywords: Bio fibrous concrete, Composite, Kenaf fibre, Shrinkage, Sustainable construction

1.0 Introduction

The inclusion of short discontinuous randomly oriented fibres (natural, glass, steel, and synthetic) has remained a practice among others towards contributing to the improvement of the two negative properties of concrete mentioned earlier (Babafemi & Boshoff, 2015; Arango *et al.*, 2012; Ogunbode *et al.*, 2019; García-Taengua *et al.*, 2014; Fládr *et al.*, 2012; Hasan *et al.*, 2015; Ali *et al.*, 2012). It has been reported by American Concrete Institute (ACI) 544 (1988), Mehta and Monteiro (2006) stated that fibre inclusion offers a bridging capability once the initial crack take place afore the full parting of a concrete beam. Also these studies (see Ogunbode *et al.*, 2015; Babafemi & Boshoff, 2015; Vrijdaghs *et al.*, 2016) supported this assertion of ability of fibre to provide concrete with post crack strength. The improvement of the mechanical and durability properties of concrete such as; crack opening, stiffness, crack promulgation, tensile strength and deformation characteristics such as shrinkage and creep of concrete amid others.

The structural performance of concrete composite can be significantly affected by time-dependent deformation of structural elements. For this reason, an adequate consideration must be given to time-dependent property such as shrinkage of concrete at the design stage of the engineering structures. In most cases, this deformation occurs as a result of environmental sustained load referred to shrinkage.

Fibrous concrete has gained favourable acceptance in becoming a widely used composite material in construction projects. Structural elements deform all the way through their lifespan (shrinkage), which may possibly lead to serviceability concerns such a deflection, cracking, etc. Whereas fibrous concrete has presented substantial ductility and energy absorption aptitude in the short term, the sustainability of such properties in the long term is still undefined. These sustained loads could be as a result of environmental stress from temperature and relative humidity causing the shrinkage of concrete elements. It has been widely acknowledged that shrinkage of concrete is greatly influenced by the surrounding ambient and admixtures. Also shrinkage has been seen to induce the deflection of structural member with time. Hence the study on time dependent properties of concrete such as shrinkage is necessary to prevent failure of structure (Sakthivel & Ramakrishnan, 2014; Neville, 2011). While shrinkage has been described as time-dependent volume change property of concrete that occurs due to a number of mechanisms. Shrinkage has been reported to occur due to the movement of water in both fresh and hardened states (Neville, 2011). The shrinkage and creep of concrete element are categorised as time-dependent deformation properties of concrete. There exist several types of fibres that is incorporated in concrete, but the most commonly used are the natural (vegetable), steel, glass, asbestos, carbon and polypropylene type of fibres (Tejchman & Kozicki, 2010; Ali *et al.*, 2012; Arango *et al.*, 2012; Hasan *et al.*, 2012; Blanco, 2013). These resource fibres have gains in the matrix proportioning of cement composites. Bio fibres are believed to be more environmentally pleasant to the users; this is why they are currently getting appreciable consideration for substituting the glass, synthetic and steel fibres (Ali *et al.*, 2012; Thielemants & Wool, 2013). Researchers (Reis, 2006; Ramaswamy *et al.*, 1995; Lam & Jamaludin, 2015) in the past years have investigated and compared the benefit and properties of natural, steel and synthetic fibre. They succinctly described natural fibres to possess many benefits than the synthetic and other type of fibres. Such advantages are low density, carbon dioxide requisitioning, low cost, recyclability, issue of sustainability, biodegradability, and competitive specific mechanical properties (Tolêdo *et al.*, 2003; Amar *et al.*, 2005; Hatta *et al.*, 2008). However, if the compressive and tensile strength of bio fibre concrete is to some degree lesser than the control concrete mix, its deformation behaviour displays more enhancements in ductility (Ramaswamy *et al.*, 1983; Hasan *et al.*, 2015; Ramaswamy *et al.*, 1983; Lam & Jamaludin, 2015). Some studies have been carried out on the properties of concrete with the bio fibres which is usually referred to as fibrous concrete from sugar cane, coconut coir, malva, hemp, ramie bast, jute, pineapple leaf, elephant grass, bamboo, akwata and sisal with encouraging results recorded (Ali *et al.*, 2012).

Recently, a huge research effort has been tailored towards the usage of bio fibres in concrete composite reinforcement (Hasan *et al.*, 2015; Lam & Jamaludin, 2015). The increasing interest in it usage is due to the several favourable properties it offers to concrete when compared to conventional plain concrete, steel, with low tensile strength compared to high modulus fibre such as steel fibre. Steel fibres' large tensile strength does not account for the improved properties of fibrous concrete composites. Thus, the fibre-matrix bond strength and fibre aspect ratio are responsible for the improved properties exhibited by fibrous concrete composites (Ramaswamy *et al.*, 1983). Therefore, it is evident that considering bio fibres for concrete composite reinforcement is worthwhile and of immense advantage to the environment, and contributing to a greener planet. The possibility of using low modulus fibres in concrete composite reinforcement is corroborated by the successful use of relatively soft fibre such as sisal, jute, bamboo, coir, and polypropylene in previous researches conducted (Ramaswamy *et al.*, 1983; Tara Sen & Jagannatha, 2011; Babafemi, 2015). Recently, Kenaf fibre is receiving increasing attention both in the research field and industrial application environs (Mohd *et al.*, 2014; Aminah *et al.*, 2004). Its application in composite production among other natural fibres is due to the ease of accessibility of Kenaf fibre locally, and its economic benefits with regards to price. Other reasons include; improvement of life cycle and durability in structure, resistance to corrosion, and other tremendous properties it possesses when compared with other bio fibres. Interest is also rising towards the inclusion of Kenaf fibre in concrete; this is meant to obtain a sustainable green material and save our environment from being dominated with concrete products that could pollute and contribute to global warming. Concrete composite made of short discontinuous Kenaf fibres has been under broad research in the past few years and has several interesting engineering properties when likened with the plain conventional concrete composite (Hasan *et al.*, 2015, Lam & Jamaludin, 2015) Application of this green material in civil engineering construction is geared towards building floor constructions, concrete beams, concrete pavement and bridge deck. By virtue of craving to apply Kenaf fibre in construction, an understanding of mechanical and time dependent property of KBFCC under environmental load (shrinkage) is evidently required. This is of utmost importance because; shrinkage can prompt excess deflection and or stress relaxation which may invariably lead to the deformation of the concrete and subsequently to collapse in respect to time. Limited study on the effect of bio fibre reinforcement on shrinkage deformations of cementitious materials at varying fibre content, increasing fibre length and different testing age are reported in the literature. Also, literature has explained that concrete degree of hydration is affected by its compressive strength and other strength properties (Shafiq, 2011). Therefore, parameters such as fibre inclusion, temperature, curing type, humidity and age of testing, which influence hydration of cement, will also affect the development of strength.

Therefore, this paper presents the analysis of the fresh state properties and time dependent properties of KBFCC under environmental load (shrinkage) with the view of producing a sustainable green and durable concrete both technically and environmentally.

Materials and Methods

Materials and Mix Proportion

To obtain a 28 days target compressive strength of 30 N/mm^2 concrete used in this research work, the DoE concrete mix designed method was adopted. A determined water cement ratio of 0.55 was used for the entire concrete mixture category. A Type 1 ordinary Portland cement (OPC) was used as the binding agent, Crushed granite with maximum size of 10 mm was used as coarse aggregate and river sand with a maximum size of 5 mm was used as fine aggregate. Treated Kenaf fibre (KF) of 3 varying length (25 mm, 50 mm and 75 mm) were used in the production of the different category of concrete at fibre volume fraction of 0.25%, 0.50%, 0.75%, 1.0%, 1.25%, 1.50%, 1.75% and 2.0%. A curled long Kenaf fibre is presented in Figure 1. The fibrous concrete mixture was bench marked against a plain concrete (0% V_f) mix as control for comparison. The detail information on the physical and chemical properties of KF is presented in Table 1. Rheobuild 1100 brand of Superplasticizer was applied to the concrete mixture at 1% of the cement content used to enhance the concrete workability owing to the hydrophilic property of natural fibre in concrete. The proportions of the concrete constituent for 1 m^3 of concrete are presented in Table 2.

Figure 1: Curled long Kenaf fibre

Table 1: Details of Kenaf Fibre (KF)

Consideration	Description/value
Type	Natural fibre
Length (mm)	25, 50 and 75
Diameter (μm)	65.4
Density (kg/m^3)	1200
Tensile Strength (N/mm^2)	135-930
Elongation (%)	1.6
Elastic Modulus, *E* (MPa)	14-53
Reaction with water	Hydrophilic
Cellulose (%)	31-57
Hemicelluloses (%)	21-23
Lignin (%)	4.79-19.0
Pectin (%)	2.0

Table 2 Proportions of Constituent for 1 m^3 of Concrete

Mix type	KF length (l_f) (mm)	KF volume (V_f) (%)	Cement (Kg/m^3)	CA (Kg/m^3)	FA (Kg/m^3)	Water (Kg/m^3)	KF volume fraction (V_f) (Kg/m^3)
Control (PC)	0	0	418	1002	725	230	0
KBFCC 1A	25	0.25	418	1002	725	230	3
KBFCC 2A		0.50	418	1002	725	230	6
KBFCC 3A		0.75	418	1002	725	230	9
KBFCC 4A		1.00	418	1002	725	230	12
KBFCC 5A		1.50	418	1002	725	230	18
KBFCC 6A		2.00	418	1002	725	230	24
KBFCC 1B	50	0.25	418	1002	725	230	3
KBFCC 2B		0.50	418	1002	725	230	6
KBFCC 3B		0.75	418	1002	725	230	9
KBFCC 4B		1.00	418	1002	725	230	12
KBFCC 5B		1.50	418	1002	725	230	18
KBFCC 6B		2.00	418	1002	725	230	24
KBFCC 1C	75	0.25	418	1002	725	230	3
KBFCC 2C		0.50	418	1002	725	230	6
KBFCC 3C		0.75	418	1002	725	230	9
KBFCC 4C		1.00	418	1002	725	230	12
KBFCC 5C		1.50	418	1002	725	230	18
KBFCC 6C		2.00	418	1002	725	230	24

KF – Kenaf Fibre, FA- Fine Aggregate, CA – Coarse Aggregate

Concrete Testing

Fresh Concrete Properties Test

The extent to which the mix proportion is compacted determines the shrinkage properties of a concrete. In fact, In order to obtain the desirable durability, it is necessary to have the consistency letting the mix to be transported, placed, and finished appropriately. The first 48 hours are very important for the performance of the concrete structure because it is the context in which the wetness can be evaluated. The fresh concrete tests were done based on slump, compacting factor, and vebe time.

Slump Test (ASTM C143/C143M, 2017)

The workability of concrete was evaluated in terms of slump to give an estimate of concrete ease of handling in fresh state (**Error! Reference source not found.**). This test method is characteristically used to ensure a consistent workability. Once it has being established that a particular FC mix has satisfactory handling and placing characteristics at a giving slump, the slump test value will be used as quality control test to monitor the FC consistency from batch to batch. The target slump of the concrete is in the range of 30-60mm.The procedure followed, in measuring the slump is in accordance with ASTM C143/C143M (2017). Slump readings are obtained as soon as the concrete was mixed. In order to obtain a satisfactory slump, Rheobuild 1100 SP mentioned earlier was used in both the PC and the FC. Although, there is no standard requirement on the quantity of SP on concrete, the slump was monitored by gradual increase of SP at the rate of 0.25% of the total cementitious material. The result of the test is presented in Section 3. The addition of 1% superplasticizer by weight of cement produced a satisfactory slump.

Vebe Test (BS EN, 12350-3: 2009)

The Vebe test described in the BS EN 12350-3, (2009), measures the behaviour of concrete subjected to external vibration which is acceptable for determining the workability of concrete placed using vibration, including Fibrous concrete (**Error! Reference source not found.**). It effectively evaluates the mobility of FC, that is, its ability to flow under vibration, and helps to assess the ease with which entrapped air can be expelled.

(a) (b) (c)

Figure 2 An operational procedures for slump test: (a) Abrams slump apparatus, (b and c) Measurement of slump

(a) Set up for Vebe test (b) VB apparatus in operation

Figure 3 Operational procedures for Vebe test

Compacting Factor Test (BS 1881-103: 1993)

Compaction factor test is designed by Glanville (1947). It is applied to compute the rate of compaction. This test is considered as a reliable method to evaluate workability of the concrete. The test is done in accordance to BS 1881-103 (1993). After carrying out the test, compacting factor, which is the proportion of the weight of the partially compacted concrete to completely compacted concrete, is computed. It should be noted that for the range of concrete to be considered normal, the compacting factor should be within the range of 0.8 to 0.92. Compact test machine is demonstrated in **Error! Reference source not found.**. The compact factor value is achieved with the Equation 1.

Shrinkage Test

The drying shrinkage test was performed in compliance to ASTM C157/C157M (2017). The test was performed on a set of three 100 mm x 100 mm x 285 mm prisms as specified. The specimen is prepared inconsonance with the guidelines of ASTM C192/C192M (2018). The specimens were moist cured in the mould and stainless steel studs were embedded on the specimens to facilitate measurement of length change. The specimens were demoulded, 24 hours after mixing. The specimens were placed in lime saturated water, and maintained at 23 ± 0.5 0C for a minimum of 30 minutes, before being measured for length change. This is to reduce the disparity in length due to temperature variant. At an age of 24 ± 1⁄2 hrs after the addition of water to the cement during the mixing operation, the specimen was remove from water storage one at a time, wipe with a damp cloth, and the initial comparator reading was immediately taken. After the initial comparator reading, the specimens was store in lime-saturated water at 23 ± 2 °C until they have reached an age of 7 or 28 days, including the period in the moulds.

$$CF = \frac{weight\ of\ partially\ compacted\ concrete}{weight\ of\ fully\ compacted\ concrete} \quad (1)$$

Figure 4 Operational procedures for compacting factor test

At the end of the curing period, a second comparator reading was taken after the specimens have been brought to a more closely controlled temperature as was done prior to the earlier reading and in the manner described above. The specimens were then moved into the drying room, and then subsequent comparator readings of each specimen was taken every day for two weeks, weekly for one month and monthly up to a period of ten months. These readings were taken in a room maintained at a relative humidity of 50 ± 4 % while the specimens are at a temperature of 23± 2 °C. Marks placed on the specimens for identification or positioning are made by a soft pencil. The comparator (Demec gauge) used for shrinkage measurement is shown in **Error! Reference source not found.**. **Error! Reference source not found.** illustrate the Operational procedure for the shrinkage test. To calculate the shrinkage strain (length change) of the specimens at any age after initial comparator reading, Equation 2 is applied:

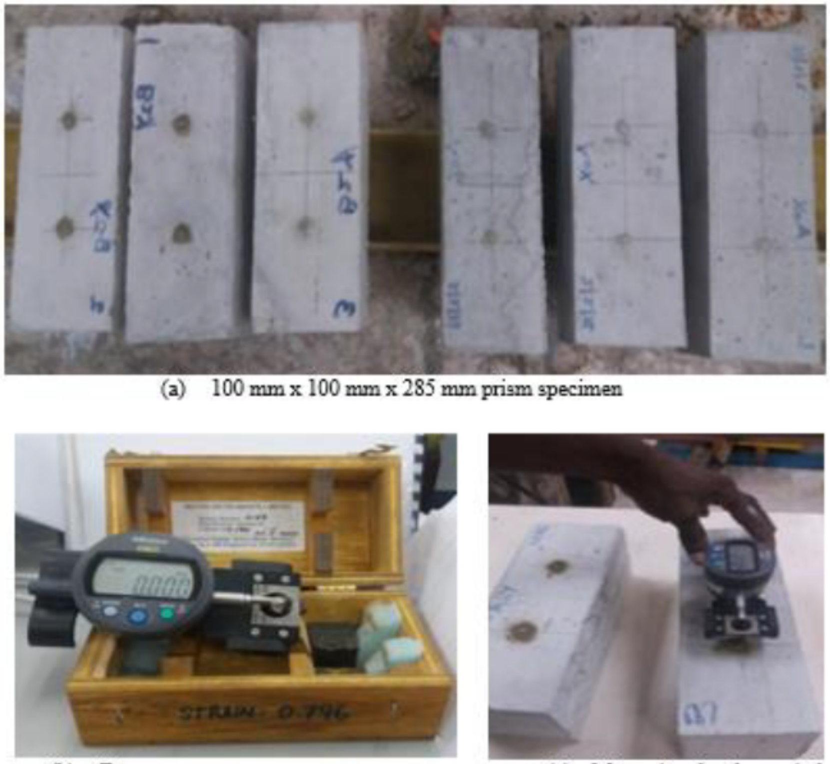
$$\varepsilon_{sh} = \frac{1}{16}\sum_{i=1}^{16}\frac{(l_i - l_0)}{l_0} \qquad (2)$$

Where:

ε_{sh} = Shrinkage strain (length change of the specimens at any age)

l_i = Measured distance between i^th^ pair of gage points

l_0 = Original distance between i^th^ pair of gage points measured immediately after demoulding.



(a) 100 mm x 100 mm x 285 mm prism specimen

(b) Demec gauge (c) Measuring the change in length

Figure 5 An operational sequence for Shrinkage test

Results and Discussion

Concrete Workability

Results of Fresh State Properties of PC and KBFCC

A total of 19 different concrete mixes comprising of one PC mix which stands as control for the experiment, and 18 different mixes of KBFCC at varying fibre volume fraction (v_f) and fibre length (l_f) was tested. These mixes were tested for workability (slump, compacting factor and Vebe test), unit weight and the results are reported and discussed.

Workability

It has being established from previous researches done that bio fibres (Kenaf fibre) influence the workability of fibrous concrete (Razavi, 2017; Hasan *et al.*, 2015; Lam & Jamaludin, 2015; Vajje & Krishna, 2013). Concrete mixture workability is an essential property in the determination of precise proportion of fibre volume fraction and length. The results of the workability of the respective PC and KBFCC were obtained with respect to slump, compacting factor and vebe test. The results obtained are discussed as in the following section.

Effect of Kenaf Fibre on the Slump of Concrete

The result of workability in terms of the slump of PC and KBFCC at varying fibre volume fraction (v_f) (0-2%) and fibre length (l_f) (0, 25, 50, and 75 mm) is shown in Figure . As the Kenaf fibre volume fraction increases, it was observed that the slump of the KBFCC decreases. This necessitated the need to include an optimum content of 1% of superplasticizer dosage so as to maintain workability of the concrete within a tolerable limit of the design.

The fibre length (l_f) and volume (v_f) was varied, as much as possible among the mixtures for comparison purposes; in order to obtain the lowest possible optimum fibre content and volume with adequate slump values that will make target compressive strength, tensile strength, flexural strength, durability and long term properties achievable among all the mixtures. Prior to concrete mixing, the aggregates (fine and coarse) were tested for their moisture content and were brought to a saturated surface dry (SSD) condition throughout the test.

Figure revealed the primary effect of fibre content and length on the KBFCC mixture. The observation, therefore, suggests that the higher volume content of Kenaf fibre results in lowering workability of concrete mixture as compared to PC. The slumps for KBFCCs were 5–100 mm and slump for PC was 120 mm. Though, KBFCC with fibre content below 1% was workable in spite of its low slump. For fibre volume of 1% and above, the workability of concrete drastically decreased and became very stiff. A balling effect is observed in the concrete mixture containing fibre volume fracture of 1%, 1.5% and 2%. This balling effect causes the mixture of the concrete to be difficult to mix and it causes void in the concrete. The slump of KBFCC with 25 mm long fibres increased as compared to that with 50 mm long fibres for all considered fibre contents. The slump decreased when the fibre length (l_f) increased from 50 to 75 mm. The slump of all KBFCCs was less than that of PC. The stiffening of the concrete mixture and the reduction of the concrete workability, influenced by fibre inclusion in mechanically mixed concretes reflects the primary effect of fibre content and fibre length (Johnson, 1994). It was noted that the knitting of fibres resists the flow of fresh concrete affecting the workability of concrete. This is in agreement to the findings of previous researches (Hasan *et al.*, 2015; Lam & Jamaludin, 2015; Ali *et al.*, 2012).

Effect of Kenaf Fibre on the Vebe of Concrete

Since fibres greatly increase concrete mixture stability, the slump test does not reflect the placeability of KBFCC using the vibratory consolidation equipment that is normal in practice, and consequently mixtures with fibres exhibit what appears to be unacceptable low slump when compared to mixtures without fibres that have the same placeability under vibration (Johnson, 1994). Test appropriate for measuring placeability of KBFCC under vibration include the test for time of flow through the vebe test which measure primarily mobility. The result of workability in terms of the Vebe of PC and KBFCC at varying fibre volume fraction (0-2%) and fibre length (l_f) (0, 25, 50, and 75 mm) is shown in Figure . As the Kenaf fibre volume fraction increases, it was observed that the Vebe time of the KBFCC increased. This necessitated the need to include an optimum content of 1% of superplasticizer dosage so as to maintain workability of the concrete within a tolerable limit of the design.

Figure revealed that as the fibre with longer fibre length (l_f) was introduced to the concrete mix, the Vebe time also increased for the same fibre content. This is due to the fact that long fibres tend to mat together while short fibres does not interlock and can be dispersed easily by vibration. The experimental results obtained in this study are in close agreement with the research findings from Razavi (2017).

The Vebe times for KBFCCs were 3–79 seconds and Vebe time for PC was 3 seconds. Though, KBFCC with fibre content below 1% was workable in spite of its high Vebe time. For fibre volume of 1% and above, the workability of concrete drastically decreased and became very stiff.

Effect of Kenaf Fibre on the Compacting Factor of Concrete

The compacting factor test was conducted to investigate workability of PC and KBFCC. The compacting factor value of all the concrete mixes for different fibre length (l_f) and fibre volume fraction (v_f) are presented in Figure . As shown in Figure , compacting factor values of concrete decreased as the l_f and v_f increased. Meanwhile, for fibre volume of 1% and above, the workability of concrete drastically decreased and became very stiff. It was noted that the knitting of fibres resists the flow of fresh concrete affecting the workability of concrete. This is in agreement to the findings of Awal & Shehu (2013) and Hasan *et al.* (2012). The fibre length (l_f) of Kenaf fibre has a prime influence on the workability of concrete mixtures. The compacting factor value has been found to decrease in concrete mixture produced from fibre length of 25 mm, 50 mm and 75 mm. A significant drop from 0.951 to 0.809 for fibre length of 25 mm, 0.947 to 0.799 for l_f of 50 mm and 0.931 to 0.793 for fibre length of 75 mm. Figure revealed that as the fibre with longer fibre length was introduced to the concrete mix, the compacting factor also decreased for the same fibre content.

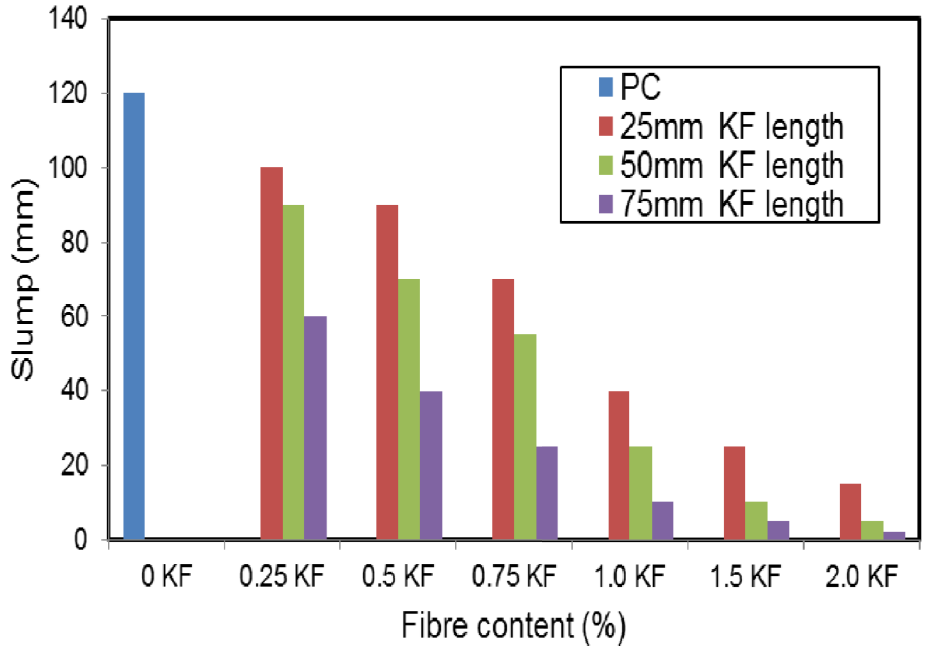


Figure 6 Effect of fibre volume fraction (v_f) and length (l_f) on slump of concrete

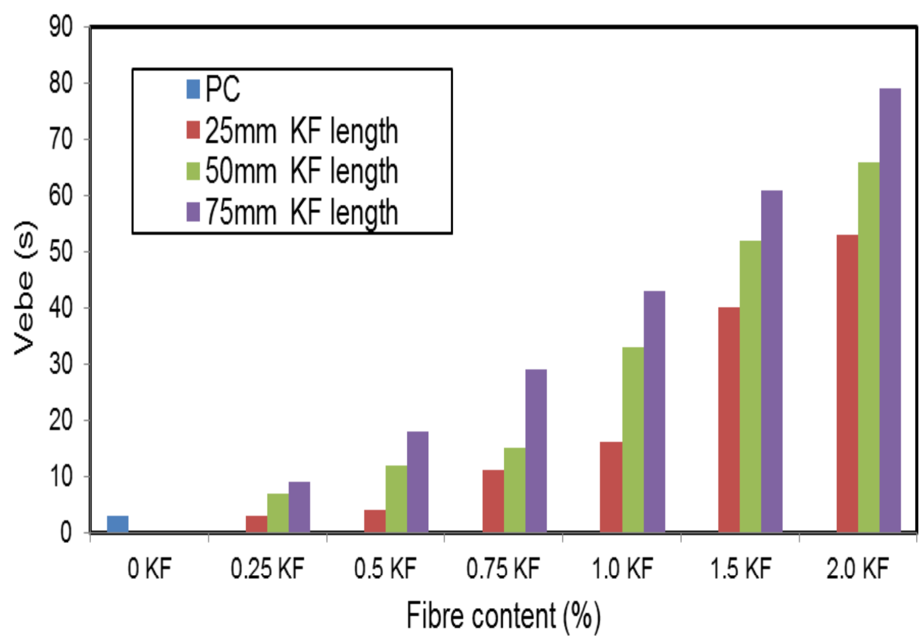


Figure 7 Effect of fibre volume fraction (v_f) and length (l_f) on Vebe of concrete

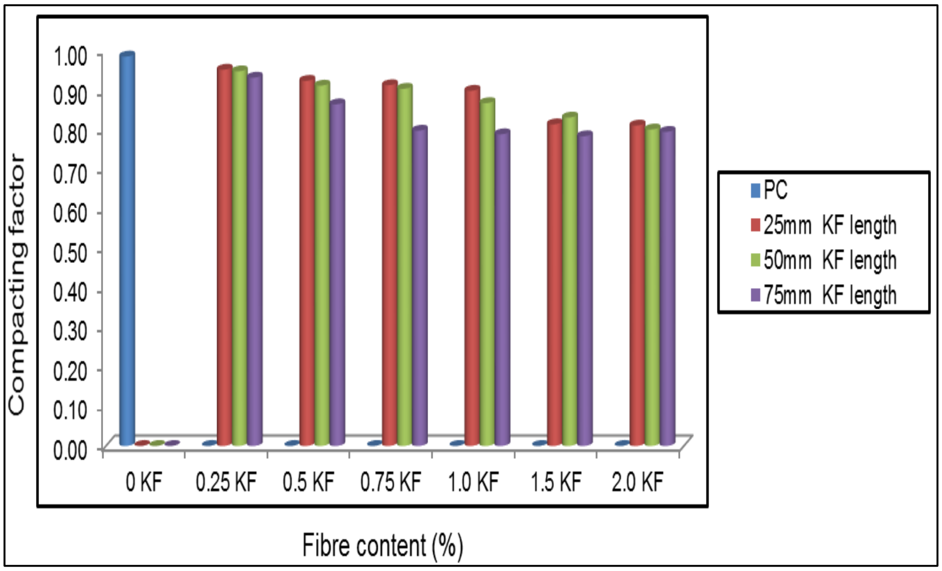


Figure 8 Effect of fibre volume fraction (v_f) and length (l_f) on compacting factor of concrete

Shrinkage Behaviour of KBFCC

Shrinkage is an injurious 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 unappealing cracks, which in practice is an issue of concern to all designers and engineers. This study presents the experimental outcome of the influence of kenaf fibre inclusion in concrete as regards the length change of KBFCC mix made of varying fibre content (0% to 2%) at 25 mm, 50 mm and 75 mm fibre length compared to PC.

The drying shrinkage of PC and KBFCC tested in this experimental work are reported as deformation strain. Autogenous shrinkage deformation of the specimen was not considered in this test because strain reading for this test began after 7 and 28 days curing period of the concrete specimens. This made it impossible to capture the autogenous strain deformation of the specimens because the greatest part of the hydration processes would have occurred.

Figure 9 presents the free drying shrinkage strain in microns for PC and KBFCC specimens beginning investigations at different age. Concrete Specimen exposed earlier to shrinkage testing at 7days hydration period, exhibited a higher drying shrinkage strain when compared with specimen exposed at an older age of 28 days. The ensuing ins and outs explain these facts about the specimen's behaviour. To begin with, the ageing effect has resulted in slower moisture diffusion in the well cured older concrete (Chern & Young, 1989). Also, the increase of stiffness due to ageing effect resists the shrinkage of concrete more effectively. The inclusion of Kenaf bio fibre caused the concrete specimen to parade a considerable lesser drying shrinkage compared to concrete without Kenaf fibre. By inspection, this fibre influence can be seen in Figure 9, 10, and 11. A similar inclination has been stated by Ramaswany et al. (1983) 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 a testing duration of 60 days. The aptitude of bio fibres to hold moisture can be ascribed as the reason for the reduced free drying shrinkage of the KBFCC. In addition, the

randomly oriented bio fibre presence around the cement gel creates a confinement 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 9, 10, and 11.
By inspection of the graphs, it was observed that the shrinkage deformation strain of the PC and KBFCC made with Kenaf fibre of 25 mm, 50 mm and 75 mm fibre length at 0%, 0.25%, 0.5%, 0.75%, 1.0%, 1.5% and 2.0% showed that concrete with higher fibre volume fraction, above 1% and PC exhibited higher strain. This could be due to the high amount of void present in the concrete due to poor workability and stiffness of the concrete mix.

Generally, it was observed that the inclusion of Kenaf fibre in concrete reduce shrinkage strain deformation. This behaviour is as a result of the effect of volume of water or moisture in concrete mix which controls shrinkage of concrete which normally takes place in the cement paste. Bio fibre in which Kenaf fibre belongs, immensely contributes to the reduction of the shrinkage of KBFCC compared to the PC specimen. This performance can be attributed to water or moisture retaining ability of bio fibres (Kenaf fibre), which in other words referred to as hydrophilic nature of bio or cellulosic fibre. In addition, the randomly oriented Kenaf fibre in the concrete specimen located around the cement gel generate a kind of quarantine situation to constrain the development of shrinkage in the concrete specimen (Ramaswany *et al.*, 1983).

According to Neville (2011), PC shrinkage strain deformation is typically between 400 x 10^{-6} and 1000 x 10^{-6}. However, the recorded drying shrinkage for all mixtures exposed earlier to shrinkage testing at 7 and 28 days hydration period as presented in Figure 9 ranged between 261 x 10^{-6} and 444 x 10^{-6} for mixtures made with 25 mm Kenaf fibre length. Specimen made with 50 mm Kenaf fibre length ranged between 212 x 10^{-6} and 371 x 10^{-6} (Figure 10). A range between 342 x 10^{-6} and 507 x 10^{-6} was recorded for specimen containing 75 mm Kenaf fibre length (Figure 11). The control PC specimen exhibited strain of 402 x 10^{-6} for specimen exposed to shrinkage testing at 7 days while specimen tested at 28 days showed a lower strain of 365 x 10^{-6}. However, the lowest shrinkage strain in Figure 9 to 11 was recorded for 50 mm Kenaf fibre length mixture containing fibre below 1% exposed to testing at 28 days hydration period. This is because the fibres have strong bonding properties with the concrete matrix which provided sufficient restraint to the mixture and therefore, reduced shrinkage. The higher shrinkage strain was recorded for normal concrete and concrete mixture made with 25 mm and 75 mm Kenaf fibre length. This is due to the high tendency of loss of moisture caused by the created air voids due to the high content and longer length of fibres in the mixture.

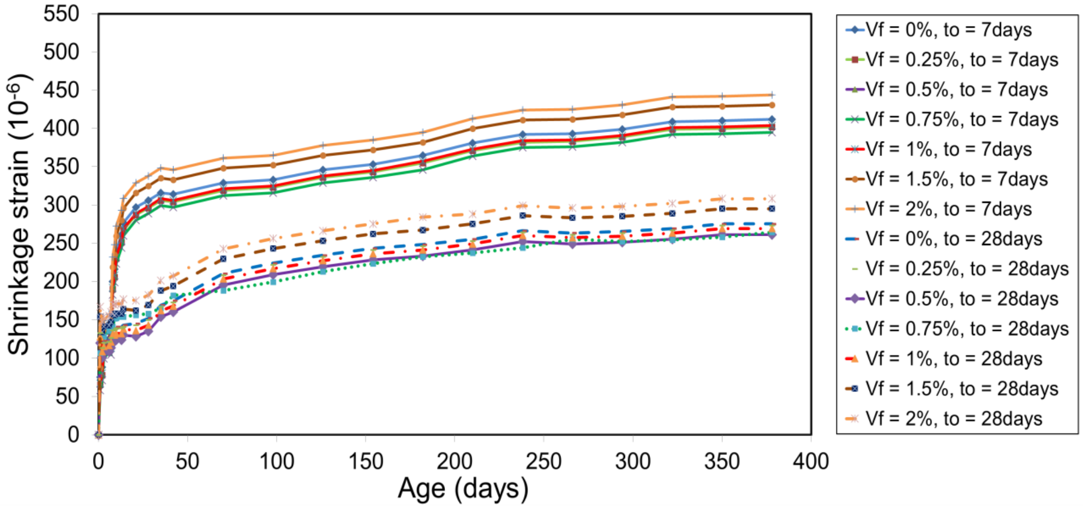


Figure 9: Influence of 25 mm Fibre length and age of exposure on the free drying Shrinkage of concrete

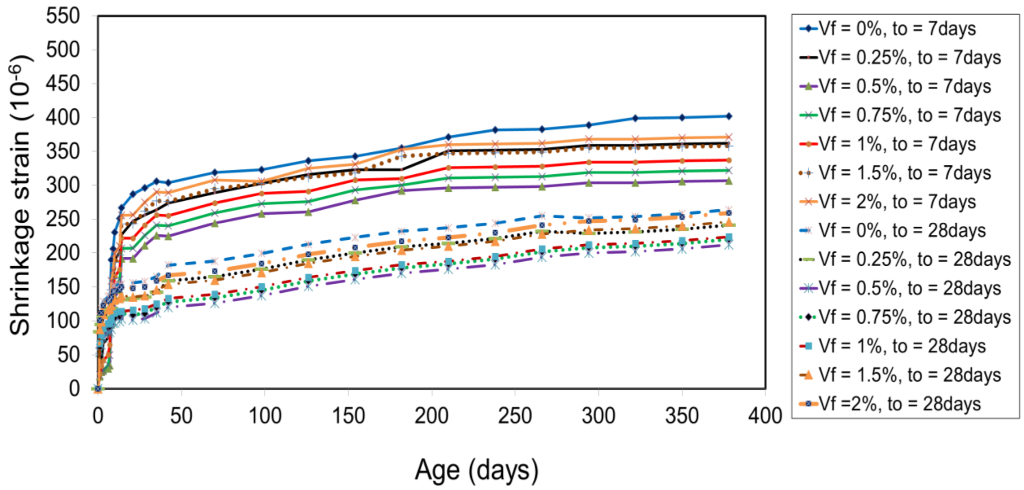


Figure 10: Influence of 50 mm Fibre length and age of exposure on the free drying Shrinkage of concrete

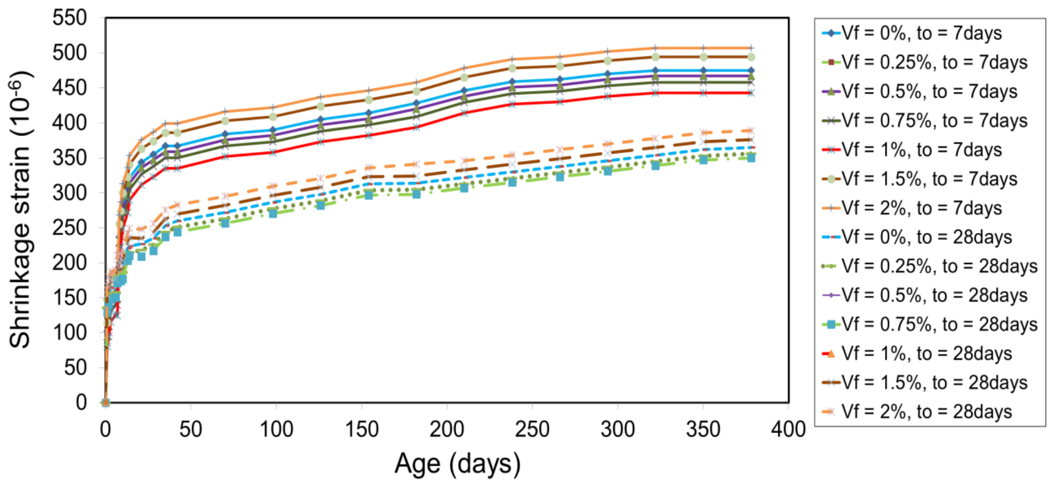


Figure 11: Influence of fibre addition 75 mm Fibre length and age of exposure on the free drying Shrinkage of concrete

*V_f = Volume of kenaf fibre, t_o = exposure age of specimen to shrinkage testing

Conclusions

Based on the experimental results and careful analysis, the following deductions thus emerged:

1. The introduction of Kenaf fibres decreased the workability of the ensuing concrete mix. 1% Superplasticizer was added to the concrete mix achieve a desirable slump. Through a fibre volumetric content above 0.5%, the workability is known to decrease due to greater interfacial actions during mixing between the fibres and cementitious materials in concrete. Furthermore, mixes with longer fibre length of 75 mm demonstrated lower slump, lower VeBe time and higher compacting factor value compared to shorter fibre length of 50 mm for the same fibre volume addition.

2. The shrinkage results of the BFCC and PC up to 376 days pointed out that KBFCC mixes exhibited lower drying shrinkage than the PC (control). This may be due to the hydrophilic nature of Kenaf fibres, absorbing water during the fresh state of concrete. The incorporation of natural fibres in concrete in low volume fraction (<1%) is mostly recognised to be effective in controlling and mitigating the susceptibility to plastic shrinkage cracking. However, the result of this study has corroborated this assertion. Accordingly, it can be stated that in cases where reducing concrete shrinkage is important, the use of Kenaf fibre should be used.

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