Effects of Kenaf Fibre on Fresh Properties of Fibrous Concrete

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As a result of global quest for sustainable materials to achieve a bio based economy and low carbon foot print environment, the use of fibre to produce fibrous concrete composite has continuously received significant research attention. While several researches have been conducted on metallic and synthetic fibrous concretes, they exhibit several unavoidable drawbacks and bio fibrous concrete has proven to be a better alternative. Therefore, the effect of fibre volume fraction and fibre length on fresh properties of concrete was investigated. The bio fibrous concrete mix was made of six different fibre volume fractions (0.25%, 0.5%, 0.75%, 1%, 1.5% and 2%) and corresponding three different fibre lengths of 25 mm, 50 mm and 75 mm. A concrete mix proportion of grade 30 N/mm^2 at 28 days target strength was prepared. A total of 19 different concrete mixes comprising of one PC mix was the control for the experiment, and 18 different mixes of Kenaf bio fibrous concrete composite (KBFCC) at varying fibre volume fraction (v_f) and fibre length (l_f) were tested. These mixes were tested for workability (slump, compacting factor and Vebe test) and fresh density. The slump and Vebe time for KBFCCs were 5–100 mm and 3–79 seconds respectively. The slump and Vebe time for PC were 120 mm and 3 seconds respectively. A significant drop from 0.951 to 0.809 for fibre length of 25 mm, 0.947 to 0.799 for fibre length of 50 mm and 0.931 to 0.793 for fibre length of 75 mm was observed for the compacting factor value. Though, KBFCC with fibre content below 1% was workable in spite of its low slump, its high Vebe time and low compacting factor. For fibre volume of 1% and above, the workability of concrete decreased and became very stiff with balling effect. It was seen that fresh density of PC concrete (2358 kg/m^3) was higher compared to those of KBFCC (2105-2339 kg/m^3), however, both values were lower than 2400 kg/m^3 threshold specified by the BS code of practice. The study therefore recommended that fibre contents lesser than 1% and 50 mm length can be used in order to have good fresh properties performance.

Keywords: Composite, concrete, fresh properties, Kenaf fibre, workability

INTRODUCTION

Fibrous Concrete Composite (FCC) is a class of high performance concrete that possesses an improved tensile strength and ductility with restraint to shrinkage and creep under sustained load compared to plain concrete (PC) (Razavi, 2017; Ogunbode, 2017). As a result of the global quest for sustainable, renewable and green materials to achieve a bio based economy and low carbon foot print environment, the use of fibre to produce fibrous concrete composite has continuously received significant research attention. While several researches have been conducted on metallic and synthetic fibrous concretes, they exhibit several unavoidable drawbacks and bio fibrous concrete has been proved to be a better alternative (Ogunbode, 2017).

In practice, various types of fibres have been used in fibrous concrete production. These fibre types such as bio (natural), glass, steel, plastic materials, possess different length, shape and geometry (Mehta & Monteiro, 2006; Ogunbode, 2017). Fibrous concrete is made up of aggregate, water, hydraulic cement, and discontinuous discrete fibres of various length, shapes and sizes (ACI 544.1R-96, 2002). Fibrous concrete are mostly used for structural and non-structural construction (Mehta & Monteiro, 2006). The use of fibres in building materials is not a new concept. Since ancient times, fibres have been used to reinforce brittle materials. Straw was used to reinforce sun-baked bricks, and horse hair was used to reinforce masonry mortar and plaster (Acikgenc *et al*., 2013). In modern times, a wide range of engineering materials (including ceramics, plastics, cement, and gypsum products) incorporate fibres to enhance composite properties. The enhanced properties include tensile strength, compressive strength, elastic modulus, crack resistance, crack control, durability, fatigue life, resistance to impact and abrasion, shrinkage, expansion, thermal characteristics, and fire resistance (ACI 544.1R-96, 2002).

However, despite the applauded plausible benefits attained from the inclusion of fibres in concrete. Poor workability is experienced when the mix proportion is poor, which is a major drawback of fibre inclusion in the fresh properties of fibrous concrete (Hasan *et al*., 2015; Lam & Jamaludin, 2015; Razavi, 2017). Fibrous concrete, especially bio fibrous concrete like the one made from Kenaf fibre, thus, adversely affect workability**,** because bio fibres are hydrophilic in nature and possess high affinity for water (Lam & Jamaludin, 2015). Even distribution of fibres throughout the concrete is also a concern. There may also be a danger of fibres balling during mixing. Thus, many experimental studies have showed that, length and volumes/content of bio fibres have negative influences on fresh properties of bio fibres concrete (BFC) (Ogunbode, 2017). For instance, Alyousef *et al*. (2019) reported that sheep wool fibres have a negative effect on fresh properties of the Fibre Reinforced-Self Compacting Concrete (FR-SCC) mix. In a related development, Alyousef (2018) observed that the reduction of workability of the concrete varied with the increase of the fibre content and with the fibre type. Basalt fibre decreased significantly the fresh properties of the developed concrete; also basalt fibre was observed to absorb some water of mixing, and hence decreased the capability of concrete mix to flow more.

Therefore, considering the inclusion of fibre in concrete and its effect on fresh property of concrete, Uygunoglu (2011) investigated the fresh properties of a series of steel fibre reinforced concrete (SFRC) with two type fibre aspect ratios and five different fibres content by means of different mixing times. According to the results, it is reported that as the fibre content increases, the workability of SFRC mixtures decreases. Existing studies have shown that workability of concrete is an important property of concrete in the compressive strength of the concrete (Razavi, 2017; Ogunbode, 2017; Alyousef, 2018). If concrete is not workable, construction work will be very difficult, because it is very difficult to handle low workable concrete, and thereby leading to quality issue of construction work.

Furthermore, workable concrete allows concrete pouring easier. A workable concrete is a must to do construction work without much difficulty. Therefore, it is much important to study the factors affecting workability of fibrous concrete. The fibre length and content are parts of the determinants regarding the quantity of water to be added to the concrete mix. A highly workable concrete is desirable to obtain full compaction through a reasonable amount of effort (Alyousef, 2018). Workability is more of a parameter that shows the ease of working with concrete which must be studied and understood for any new material or concrete be accepted for use in the construction industry. This physical parameter affects the strength, durability, cost of labour, compaction effort, and also the final appearance (Ogunbode, 2017). The purpose of study is to evaluate the effects of fibre length and fibre volume fraction of Kenaf fibre on the workability and the fresh density of KBFCC.

MATERIALS AND METHODS

The physical characteristics of Kenaf fibre and fresh properties of KBFCC were experimentally investigated.

Materials

The constituent materials used in this study were ASTM Type I cement (OPC), fine aggregate (river sand) passing through 4.75 mm sieve (SSD) 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. The Kenaf fibre geometry was in three varying lengths of 25 mm, 50 mm and 75 mm. The Kenaf fibres used in the study were alkaline treated fibres. The inclusion of the fibres was made at a volume fraction of 0.25%, 0.5%, 0.75%, 1.0%, 1.5% and 2.0% which was equivalent to dosages of 3, 6, 9, 12, 18, 24 kg/m^3, respectively, in order to simulate the usual practice on construction site. Sodium hydroxide (NaOH) used as the treatment chemical for the investigation was supplied by Merck Sdn. Bhd. Malaysia. Chopped treated Kenaf fibre is presented in Figure 1.

Figure 1: Chopped Kenaf fibre

Methods

Test on diameter of Kenaf fibre

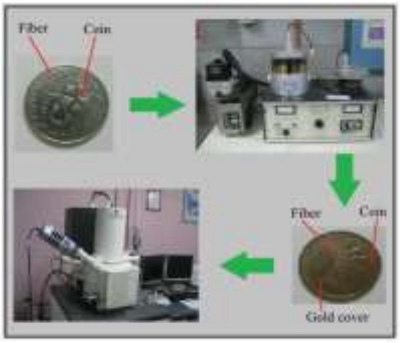
The diameter is a parameter that is very important to determine the fibrous mix design, tensile strength of fibre and Young's modulus of fibre. ASTM D2130-90, a standard test method to determine the diameter of wool and other animal fibres by using Micro projection, was to determine the diameter of bio fibres. This procedure was considered due to the difficulty in obtaining tensile properties for one filament of the fibre. The procedure for measuring the diameter of one filament of fibre is presented below:

i) Determination of fibre diameter was by making the length and weight consistent. The fibre was measured constantly to 300 mm length and weighed to 0.06 gram by using a weighing scale.

ii) The fibre was spun by hand as shown in Figure 2(a). The sizing process is needed to ensure the fibres were easy to spin and handle so that the diameter of fibres can be obtained accurately.

iii) The Kenaf bundle was tied onto 1 cent coins purposely to measure the diameter of fibres under SEM (Scanning Electron Microscope) with 30 times magnification. The average diameter of fibres was obtained from 90 results. Also, Figure 2(b) showed the coating procedure before conducting the measurement of fibre diameter using the SEM.

(a) Spin Fibre Strand for test



(b) Coating Procedure and SEM Equipment

Figure 2: Test for Kenaf fibre diameter

Test on density of Kenaf fibre

The density of Kenaf fibres under study was measured using Archimedes principle by immersing the samples in distilled water. The apparatus for density test was fixed with the bracket, holder and precision thermometer. A number of ten samples of fibre was prepared as shown in Figure 3(a) in which the fibres were grouped randomly and spun together by hand to obtain the known weight. The sample was weighed in one of the two brackets. Mettler-Toldeo Balance was used in weighing the fibre (Figure 3b). Then, the sample was immersed in the distilled water and the weight was recorded. All the results were quickly recorded since the bio fibres have high sensitivity to water content and the calculation that was related in this method is shown in Equation 1.0:

$$\rho = \frac{A}{A - B}\rho^{0} \qquad (1.0)$$

Where, ρ = Density of the sample (gr/cm^3), A = Weight of the sample in air (g), B = Weight of the sample in the distilled water (g), $\rho 0$= Density of distilled water at the given temperature (gr/cm^3).

(a) Fibre sample prepared for density test

(b) Apparatus for density test (Mettler-Toldeo Balance)

Figure 3: Kenaf fibre density test spun fibre sample and apparatus

Concrete mix design and optimization

The concrete mix proportions were designed based on the Department of Environment's Design Method (DOE Method). The mix proportion was required to produce a grade 30 concrete. A verification of the mix design was done using the outcome of the trial mixes test. KBFCC suitable mix design and appropriate mixing procedure were developed after several trial mixes were conducted. Additionally, an existing best practice reported in the literature benchmarked the decision on the trial batches and procedures for the concrete mixture (Yassin, 2008; Slowik & Wittmann, 2003). The fibre volume content was chosen as a result of the measured weight of the fibres. The mixture proportion presented in Table 1 is the same for all the specimens. The fibre length and volume fractions for the mixtures are given in Table 2. The water-cement ratio of 0.55 and superplasticizer dosage of 1% were used to improve the workability of the W/C. Kenaf fibre was included to the resulting concrete by weight from 0% up to 2.0% (interval of 0.25%) at three varying lengths of 25 mm, 50 mm and 75 mm. The water/cement ratio was kept constant.

Table 1: Plain Concrete Mix Design

Constituent Materials	Cement (Kg/m^3)	Coarse aggregate (Kg/m^3)	Fine aggregate (Kg/m^3)	Water (Kg/m^3)	Super-plasticizer (Kg/m^3)
Quantities	418	1002	725	230	4.18

Table 2: Details of Mixture

Mix ID	Fibre Length (l_f) (mm)	Fibre Volume Fraction (v_f) (%)	Fibre Volume Fraction (v_f) (Kg/m^3)
PC	0	0	0
KBFCC 1A		0.25	3
KBFCC 2A		0.50	6
KBFCC 3A	25	0.75	9
KBFCC 4A		1.00	12
KBFCC 5A		1.50	18
KBFCC 6A		2.00	24
KBFCC 1B		0.25	3
KBFCC 2B		0.50	6
KBFCC 3B		0.75	9
KBFCC 4B	50	1.00	12
KBFCC 5B		1.50	18
KBFCC 6B		2.00	24
KBFCC 1C		0.25	3
KBFCC 2C		0.50	6
KBFCC 3C		0.75	9
KBFCC 4C	75	1.00	12
KBFCC 5C		1.50	18
KBFCC 6C		2.00	24

KBFCC mixing procedure

Sequel to batching, the total batch volume was first calculated based on the required mix proportion. During the batching process, about 20% of the estimated concrete quantity was added to cater for waste that may ensue during mixing and casting. The quantities of the constituent materials for the respective concrete batches were determined based on the adjusted mix proportion as shown in Tables 1 and 2. Although the mix design was based on the absolute volume of the concrete, the equivalent weight of the respective constituent materials was used for batching. For a uniform fibre distribution in the concrete mixture, the Kenaf fibres were pre-opened by hand before mixing. The water required for mixing was weighed, including the extra water to allow for Kenaf fibre absorption (saturated surface dry, SSD). The water and Kenaf fibre were added to a water vessel, stirred slowly and allowed to soak for an hour. A maximum aggregate size of 10 mm was used as the coarse aggregate to increase the workability of the KBFCC. The coarse and fine aggregates were then first charged into the concrete mixer and blended with one-quarter of the water required for mixing for 4 minutes. The mixer was stopped for 2 minutes, to allow the air-dried aggregate to absorb water required for saturation. This was necessitated to avoid the absorption of the superplasticizer by the aggregates. After that, the OPC cementing material was poured into the mixer. The mixing was restarted, and the stirring continued 6 minutes with the addition of the second and third quarter of the mixing water. All the water and fibre soaked were slowly drizzled into the matrix to ensure even distribution of the fibres. A considerable drop in the fresh concrete workability was observed due to the inclusion of Kenaf fibre as a result of the hydrophilic characteristic of Kenaf fibre, leading to significant absorption of water meant for the concrete mixture and hydrolysis. The superplasticizer was then discharged in the fourth quarter of the mixing water and then added to the concrete mix and stirred for 5 minutes. Mixing was stopped for 2 minutes. The mixing was then stirred for another 4 minutes before being poured and cast into the oiled moulds as required. The concrete mixtures were mixed using the revolving type pan mixer with a normal capacity of 0.25 m^3 (9 ft3) as shown in Figure 4. All the specimens were cast, and water cured conforming to ASTM C192 (2021) specification. The chart describing the mixing procedure is given in Figure 5.

Figure 4: Revolving pan mixer for mixing fibrous concrete

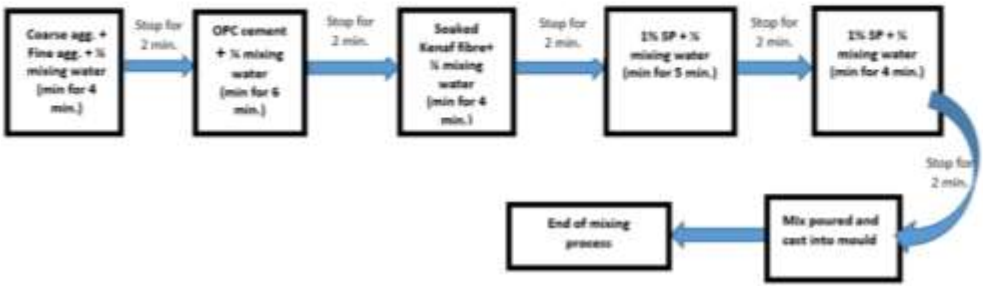


Figure 5: Mixing procedure for KBFCC

Fresh properties test of KBFCC

The preparation and testing of the concrete samples to obtain their fresh property which includes workability and wet density of KBFCC are illustrated in this section.

Workability test

The workability of the concrete was evaluated in terms of slump, compacting factor, VeBe time. The slump test was meant to give an estimate of concrete ease of handling in fresh state. This test method is characteristically used to ensure a consistent workability. Once it has being established that a particular fresh concrete 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 fresh concrete consistency from batch to batch. The target slump of the concrete was in the range of 30-60mm. The procedure followed, in measuring the slump was in accordance with ASTM C 143 (2021). The Vebe test described in the BS EN 12350-3 (2019) measured the behaviour of concrete subjected to external vibration which is acceptable for determining the workability of concrete placed using vibration, including fibrous concrete. It effectively evaluated the mobility of fresh concrete, that is, its ability to flow under vibration, and helps to assess the ease with which entrapped air can be expelled. Compaction factor test used in computing the rate of compaction. This test was considered as a reliable method to evaluate workability of concrete. The test was conducted in accordance with BS 1881 (1993). After carrying out the test, compacting factor, which is the proportion of the weight of the partially compacted concrete to completely compacted concrete was 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 (Ogunbode, 2017).

Wet density properties test

The density of concrete largely depends on the unit weight of the aggregate used in the mixture. The density of KBFCC was determined using a vessel connected to the instrument used to evaluate compacting factor. Before placing the mixed concrete into the vessel, the load and volume of the vessel is measured, then density was estimated.

RESULTS AND DISCUSSION

This section presents the physical properties of Kenaf fibre and the properties of fresh concrete mixes, such as, slump, compacting factor, Vebe time and fresh density.

Kenaf Fibre Diameter

The test on Kenaf fibre diameter was carried out on both the treated and untreated fibre bundle. The treated fibre used was in the range of 5%, and 7% NaOH treatment at 3 and 24 hours soaking period. The determination of the diameter of the fibres was carried out using SEM. Figure 6 displays the SEM image of typical fibre bundle specimen treated with 5% NaOH at 3 hours immersion time.

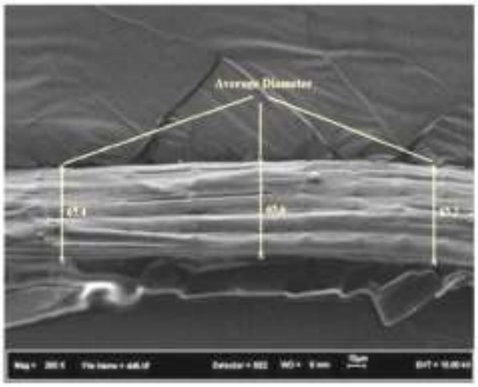


Figure 6: The diameter of a typical fibre bundle

The diameter of Kenaf fibre tested varied from 31.8 μm to 120μm, and this deviance is wide due to the cellulosic nature of Kenaf fibre. Table 3 presented the statistical parameter of the tested fibre diameter. Five samples were tested for each test conducted to obtain an average diameter value. From the study, it could be given that the average diameter of untreated Kenaf fibre is 69.8μm. While the treated Kenaf fibre at 5% NaOH in 3 hours was 65.4µm, 5% NaOH in 24 hours was 62.1µm, 7% NaOH in 3 hours was 63.7µm and 7% NaOH in 24 hours was 60.5µm as illustrated in Figure 7. It was observed that the higher the percentage of NaOH and period of immersion of the fibre in the alkaline environment, the smaller the diameter of the fibre becomes. This was due to the removal of the cellulose and lignin content in the fibre.

Table 3: Statistical parameter of Kenaf fibre diameter

Fibre Category	Range of Diameter (µm)	Average of Diameter (µm)	Standard Deviation (SD)	Coefficient of Variation (COV%)
Untreated Fibre	41.1-120	69.80	12.87	18.5
Treatment 5%-3hr	39.70-115.10	65.40	13.53	20.7
Treatment 5%-24hr	34.40-100.50	62.10	13.72	22.10
Treatment 7%-3hr	36.80-108.30	15.03	15.03	23.60
Treatment 7%-24hr	31.80-92.30	60.50	10.82	17.90

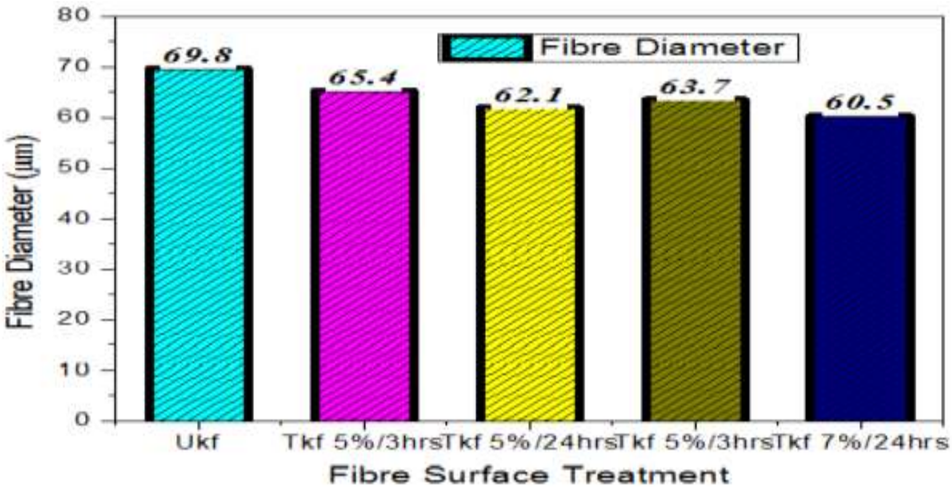


Figure 7: Average diameter of the untreated and treated Kenaf fibre

Kenaf Fibre Density

Kenaf fibre was tested for density using an average of 8 samples each for the untreated and treated fibre. The result is shown in Table 4. The density of the treated Kenaf fibre was observed to be 1.202gr/cm^3, which was lesser than the density of the untreated Kenaf fibre (1.206gr/cm^3). This slight difference in density between the treated and untreated Kenaf fibre was due to the fibre alkaline treatment. The removal of the cellulose pectin and lignin influenced the density value reduction observed. The details and properties of the Kenaf fibre are presented in Table 5.

Table 4: Kenaf fibre density

Type of Fibre	Density (gr/cm^3)	Standard Deviation (SD)	Coefficient of Variation (COV-%)
Treated Kenaf fibre	1.202	0.0308	2.56
Untreated Kenaf fibre	1.206	0.0356	2.95

Table 5: Physical, mechanical and chemical characteristics of Kenaf fibre

Physical and Mechanical Characteristics			Chemical Composition		
Diameter	(µm)	65.40	Cellulose	(%)	31-57
Density	(gr/cm^3)	1.202	Hemicellulose	(%)	21-23
Elastic modulus	(GPa)	39.77	Lignin	(%)	4.79-19.00
Elongation at yield	(%)	1.77	Pectin	(%)	2.00
Tensile strength	(MPa)	704.00			

Workability of KBFCC

It has being established from previous researches done that bio fibres especially Kenaf fibre influence the workability of fibrous concrete (Vajje & Krishna, 2013; Hasan *et al*., 2015; Lam & Jamaludin, 2015; Razavi, 2017). 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 slump test of PC and KBFCC is illustrated in Figure 8. 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 9. 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) were varied as much as possible among the mixtures for comparison purpose; 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 8: Slump of PC and KBFCC

Figure 9 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 was observed in the concrete mixture containing fibre volume fracture of 1%, 1.5% and 2%. This balling effect caused the mixture of the concrete to be difficult to mix and it caused 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 (lf) 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 reflected the primary effect of fibre content and fibre length (Razavi, 2017). It was noted that the knitting of fibres resists the flow of fresh concrete affecting the workability of concrete. This is in agreement with the findings of previous researches (Hasan *et al*., 2015; Ali *et al.*, 2012; Lam & Jamaludin, 2015).

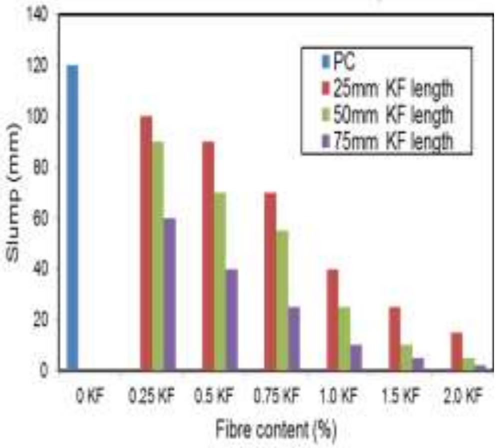


Figure 9: Effect of fibre volume fraction (vf) and length (lf) on slump of concrete

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 exhibited what appeared to be unacceptable low slump when compared to mixtures without fibres that have the same placeability under vibration (Razavi, 2017). Test appropriate for measuring placeability of KBFCC under vibration include the test for time of flow through the vebe test which measures 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 (lf) (0, 25, 50, and 75 mm) is shown in Figure 10. 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 10 revealed that as the fibre with longer fibre length (lf) was introduced to the concrete mix, the Vebe time also increased for the same fibre content. This was 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 agreement with the 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.

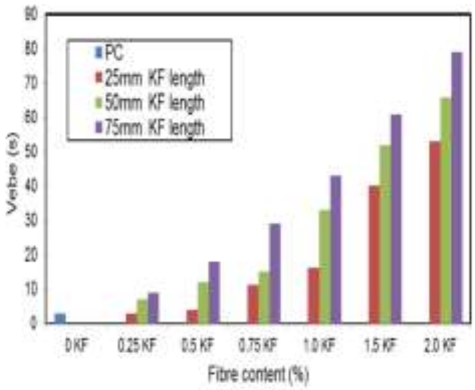


Figure 10: Effect of fibre volume fraction (vf) and length (lf) on Vebe of concrete

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 (lf) and fibre volume fraction (vf) are presented in Figure 11. As shown in Figure 11, compacting factor values of concrete decreased as the lf and vf 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 resisted the flow of fresh concrete affecting the workability of concrete. This is in agreement to the findings of Awal *et al* (2013) and Hasan et al. (2015). The fibre length (lf) 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 fibre length of 50 mm and 0.931 to 0.793 for fibre length of 75 mm. Figure 11 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.

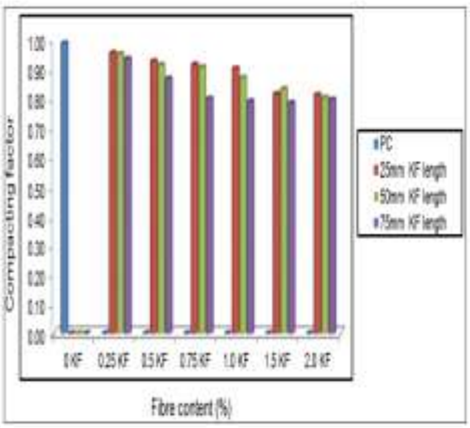


Figure 11 Effect of fibre volume fraction (vf) and length (lf) on compacting factor of concrete

Correlation between vebe time and slump of PC and KBFCC

Figure 12 illustrated the correlation between the Vebe time and the slump of the concrete, at fibre length of 25 mm, 50 mm and 75 mm with varying fibre volume fraction of 0 – 2% by volume of concrete. The measured Vebe time (VBT) were used as a response parameter with the slump of concrete (SLC) as their predicator parameter. A negative relationship between the Vebe time of concrete and the slump of concrete can be observed in the Figure 12. Linear regression was used to correlate the experimental data resulting in the equation shown in the Figure, with a coefficient of determination R^2 lying between 0.6947 – 0.8431. The correlation developed between the results for 25 mm and 50 mm fibre length was strong while that of 75 mm fibres length was low, nonetheless, the 3 fibre length type showed uniformity in the correlation due to similar trend demonstrated by their equations. The low level of R^2 of 75 mm fibre length mixture might be attributed to the material composition in terms of long lengths of the fibre which might have impaired the workability in the mixtures.

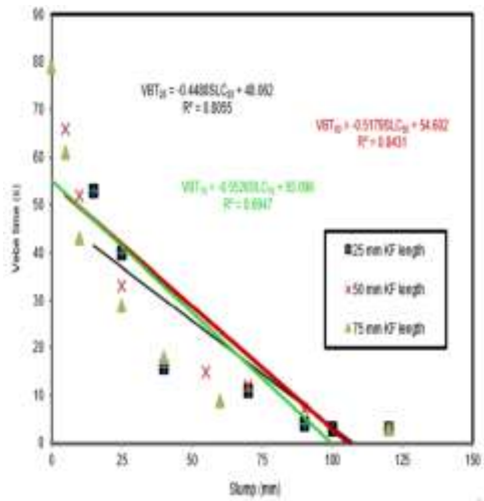


Figure 12: Correlation between Vebe time and Slump of concrete

Correlation between compacting factor and slump of PC and KBFCC

A coefficient of determination was established to evaluate the relationship between compacting factor (CPT) and the slump of concrete (SLC). As can be seen in Figure 13, the CPT values of the respective PC and KBFCC at fibre length of 25 mm, 50 mm and 75 mm with varying fibre volume fraction of 0 – 2% by volume of concrete, range between 0.782 and 0.984, while the slump value varied in the range of 5 to 120 mm. A positive coefficient of determination of 0.9077, 0.9646 and 0.9166 for 25 mm, 50 mm and 75 mm fibre length respectively were obtained between the SLC and CPT as can be seen in Figure 13. This level of correlation was established due to the fact that both SLC and CPT are affected by the fibre content.

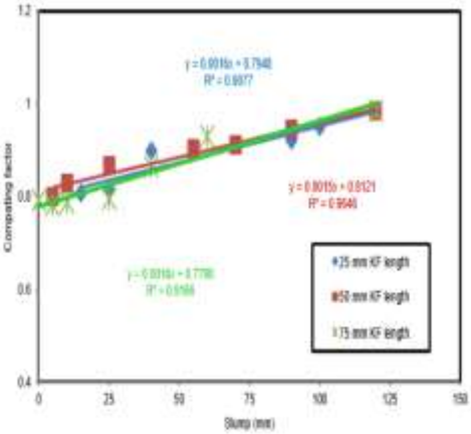


Figure 13: Correlation between Compacting factor and Slump of concrete

Correlation between compacting factor and vebe time of PC and KBFCC

The compacting factor (CPT) of the respective PC and KBFCC ranges between 0.782 and 0.984. As can be seen in Figure 14 the CPT decreases as the fibre content and fibre length increases. The coefficient of determination for the respective PC and KBFCC at fibre length of 25 mm, 50 mm and 75 mm with varying fibre volume fraction of 0 – 2% by volume of concrete were 0.8975, 0.9267 and 0.6638 respectively. These coefficients showed that the two parameters have a good and linear correlation. The negative correlation was due to the increases in the Kenaf fibre length and volume fraction in the concrete mix, thus reducing the workability, thereby increasing the vebe time of the concrete mixture.

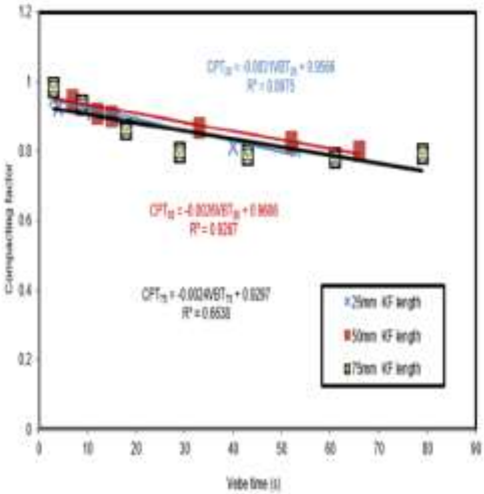


Figure 14: Correlation between Compacting factor and Vebe time of concrete

Importance of the correlation between variables associated with fresh properties of PC and KBFCC

The establishment of the relationship between the fresh characteristic of the respective PC and KBFCC will provide a very good platform for the determination of one property of concrete if the other is known without necessarily passing through the rigour of undertaking tedious laboratory experimentation. This study is therefore very significant in the sense that it will minimise cost by reducing material wastage during optimisation test for carrying out the laboratory work. The following relationships have been established between and among the respective fresh properties of the KBFCC and presented in Table 6.

Table 6: Summary of relationship between respective fresh properties of the KBFCC from linear regression

Workability test Method	Fibre length (l_f) (mm)	Relationship	R^2
	25	$VBT_{25} = -0.4488SLC_{25}+48.062$	0.8055
Vebe	50	$VBT_{50} = -0.5179SLC_{50}+54.602$	0.8431
	75	$VBT_{25} = -0.5526SLC_{75}+55.096$	0.6947
	25	$CPT_{25} = 0.0016SLC_{25}+0.7948$	0.9077
Slump	50	$CPT_{50} = 0.0015SLC_{50}+0.8121$	0.9646
	75	$CPT_{75}= 0.0018SLC_{75}+0.7798$	0.9166
	25	$CPT_{25} = -0.0031VBT_{25}+0.9566$	0.8975
Compacting	50	$CPT_{50} = -0.0026VBT_{50}+0.9606$	0.9267
Factor	75	$CPT_{75} = -0.0024VBT_{75}+0.9297$	0.6638

Also, using multiple regression, the following relationships that could serve as a model were established to consider the fresh properties of the respective KBFCC in respect of the three variables (CPT, VBT and SLC) as presented in Table 7.

Table 7: Summary of relationship between respective fresh properties of the KBFCC from multiple regression

Fibre length (l_f) (mm)	Relationship	R^2
25	$CPT_{25}= -0.002VBT_{25}+0.001SLC_{25}+0.870$	0.9520
50	$CPT_{50}= -0.001VBT_{50}+0.001SLC_{50}+0.869$	0.9880
75	$CPT_{75}= 0.0001VBT_{75}+0.002SLC_{75}+0.789$	0.9180

Fresh Density

The study of the fresh density of concrete demonstrated in Figure 15 showed that fresh density values decreased as the Kenaf fibre content increased in concrete. It can be seen that fresh density of PC concrete (2358 kg/m^3) was higher compared to those of KBFCC, however it was slightly lower than 2400 kg/m^3 specified by the BS code of practice (BS EN 12350-6, 2009). Nevertheless, the density values for those of KBFCC are in the range of 2105-2339 kg/m^3, making it lighter than the plain concrete (fibreless concrete). Critical observation revealed that, though the density was lower in KBFCC mix type, the values are within an appreciable range. The lower value can be ascribed to the bio fibre content that might have displaced quite an amount of aggregate in the mixture. Though there is limited literature on the fresh density of KBFCC, comparative observation with polypropylene fibre showed somehow a similar trend (Leung & Balendran, 2003). Therefore, fibre inclusion in concrete reduces the density of concrete mixture at fresh state.

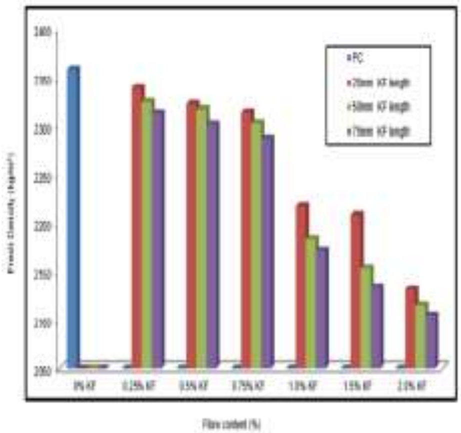


Figure 15: Fresh density of PC and KBFCC

CONCLUSION

In this study, the effects of Kenaf fibres on the fresh properties of concrete with three different fibre length and 6 fibre volume fractions were investigated. It was observed that fibre volume fractions and fibre length have been very effective on workability and fresh density of concrete. Firstly, the addition of Kenaf fibre has reduced the workability of KBFCC; longer fibres such as 75 mm length reduced the workability more than short fibres. The establishment of the relationship between the fresh characteristic of the respective PC and KBFCC will provide a very good platform for the determination of one property of concrete if the other is known without necessarily passing through the rigour of undertaking tedious laboratory experimentation. This study is therefore very significant in the sense that it will minimise cost by reducing material wastage during optimisation test for carrying out the laboratory work. Also, the study showed that fibre inclusion in concrete reduced the density of concrete mixture at fresh state.

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