Flexural Creep Performance of Pre-cracked Kenaf Bio Fibrous Concrete Composite Subjected to Sustained Bending Loading

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Flexural Creep Performance of Pre-cracked Kenaf Bio Fibrous Concrete Composite Subjected to Sustained Bending Loading

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Abstract--- *Fibre inclusion in fresh concrete mix is meant to enhance the residual strength and ductility of the concrete element. Currently, structural applications of fibrous concrete composites remain relatively scarce as its time-dependent behaviour is still poorly understood. This paper presents the possible usage and experimental campaign regarding the flexural creep of cracked Kenaf bio fibrous concrete composite (KBFCC). In the test setup, prismatic plain and fibrous concrete specimens were considered and the concrete material is characterized according to the ASTM and BSEN Standards. Also, the samples were pre-cracked to localize the creep deformations and for in-service simulation. The PC and KBFCC specimens were subjected to a sustained bending load, whereby two different load levels (25% and 35%) with respect to the individual residual, post crack, flexural strength are considered at 7 and 28 days loading age. The experimental studies revealed that cracked KBFCC shows less creep compared to fibreless concrete and magnitude of sustained load level and loading age are the major sources of the creep behaviour.*

Keywords--- *Fibrous Concrete, Flexural Creep, KBFCC, Kenaf fibre, Pre-Cracked.*

I. INTRODUCTION

The deployment of bio fibre is one of the fundamental issues of green concrete and bio-based economy strategies in many parts of the world. With the progress in fibre and concrete technology, the use of bio fibres in the concrete industry has advanced with time prevalently because of its ecological, technological and economic benefits. The brittleness of concrete due to its two major negative properties commonly referred to as low tensile strength and large brittleness usually depicts it as a material prone to crack and possible collapse when exposed to sustained loads. As a result of these negative properties of concrete, an enhanced concrete with high energy absorption capacity is required in different concrete applications such as highway paving, concrete beams, industrial floors, bridge decks, building floor constructions, etc. In enhancing the ductility properties of concrete, the inclusion of fibres to concrete is expedient [1–3]. Fibrous concrete composite (FCC) is a concrete material composed of ordinary Portland cement (OPC), coarse and fine aggregates, and randomly dispersed discontinuous short fibres. Over the years, several types of fibres have been applied in the production of concrete mixes due to the accrued potentials of

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fibres [4–7]. However, metallic fibres, bio fibres, glass fibres, pre and post-consumer wastes fibres, and synthetic fibres are the most used in fibrous concrete production. A fundamental problem associated with fibrous concrete as being the establishment and evaluation of different fibres real properties and merits [1]. In time past, some bio fibres such as Kenaf, coir, sisal, bamboo, banana fibre etc., have been positively utilised as a reinforcing agent. These fibres are meant to enhance the tensile properties, crack bridging feat and ductility properties of concrete [7–10]. Varying fibre volume fraction and length of bio fibres ranging from 0.25% to 5% and 20 mm to 50 mm, respectively, have been reported. The reports states that this various fibre content and length have been used as reinforcement in enhancing the energy absorption capacity and crack resistance ability of concrete [2,8,10–13]. These reports have asserted that these fibre geometries and contents are capable of enhancing the ductility and tensile properties of plain concrete at short-term loading. Though, there still exists a dearth of knowledge on bio fibrous concrete behaviour under long-term flexural loading to the understanding of the authors. The lacuna in the knowledge on time-dependent deformation of bio fibre calls for in-depth research on the flexural performance of bio fibrous concrete under long-term sustained loading. Lots of research have been undertaken to consider the energy absorption capacity of metallic and synthetic fibrous concrete by flexural creep test. This studies have revealed that the inclusion of these fibres substantially improved the long-term performance of the fibrous concrete under sustained loads [4,14–19].

In recent years, interest and acceptance of bio fibres as reinforcing elements in concrete for practice in research and concrete industries is rising. One of the widely used bio fibre today is the Kenaf fibre [20,21]. Kenaf fibre is from the bast (outer) and core (inner) fibres of Kenaf plant (Hibiscus Cannabinus L.). Kenaf has a high carbon dioxide (CO_2) assimilation rate and ability to clean the air by consuming large quantities of CO_2. Also, it thus absorbs nitrogen and phosphorous in the soil and is a potential oil spill absorbent. Kenaf plant is significantly important due to its environmental friendliness and ability to control the greenhouse emission effect [22]. It is a herbaceous annual plant that is cultivated commercially in the Brazil, United States, Cuba, Southeast and East Asian [23,24]. Kenaf plants grow up to a height of 2.4 to 6 m at an average of 150 days, which is a benefit to the farmers in the downstream and a significant boost to the national economy and sustainable development [22].

In recent times, concrete material scientist and engineers have studied the influence of Kenaf fibres on various short-term properties of concrete. It has been concluded that Kenaf fibre reduced the workability and compressive strength of concrete, while an enhanced tensile strength, flexural strength, and toughness was exhibited by concrete containing Kenaf fibre [7,9–11]. Despite the fact that limited research works have been conducted on the use of Kenaf fibres in concrete to improve the general properties of concrete. It was also observed that these investigations are majorly short term based. It is essential to conduct the flexural creep performance test to understand the behaviour of Kenaf fibre in concrete when exposed to sustained loading over a long term.

Flexural creep is a significant time-dependent property for measuring the deformation behaviour of fibrous concrete used for infrastructural construction. Up to date, there is no standard code or guidelines documented for measuring the flexural creep of fibrous concrete generally, none the less the bio fibrous concrete. Though various approaches with different guidelines have been proposed to investigate the flexural creep of fibrous concrete by various researchers, they all used either metallic or synthetic fibres as the reinforcing element in the concrete

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[4,5,14–16,18,19,25–27]. None of this study had used bio fibrous element in their investigations. As a result of the sustainability and environmentally friendliness advantages of Kenaf fibre, its ease of access for procurement, its bio-based economy potential benefit and its contribution to enhancing the ductility and crack resistance capacity of concrete. A research work on the use of Kenaf fibre as reinforcing elements in concrete has been carried out in the Faculty of Civil Engineering, Universiti of Teknologi Malaysia (UTM). This paper presents experimental outcomes on the influence of the inclusion of Kenaf fibre in enhancing the strength properties and flexural creep demeanour of concrete.

II. MATERIALS AND TEST METHODS

2.1. Materials

In this experiment, ordinary Portland cement (OPC) (ASTM Type I) was used. Kenaf bio fibres were collected from Malaysian Agricultural Research and Development Institute (MARDI) as curled long untreated fibre as shown in Fig. 1a. The multi-filament Kenaf fibres were treated using NaOH (Fig 1b) and chopped to 2 different lengths of 25 mm and 50 mm. A typical electron micrograph showing the untreated and treated Kenaf fibre surface is presented in Fig. 2.

The general properties of the alkaline treated Kenaf fibre used in this study are illustrated in Table 1. Inspecting Table 1, it was observed that the treated Kenaf fibre has a density of 1.2 g/cm^3, a diameter of 65.4 µm and a tensile strength of 704 MPa. Kenaf fibre being a bio-fibre exhibit a hydrophilic behaviour when in contact with water or moist. This hydrophilic propensity of Kenaf bio fibre and poor fibre surface interfacial bond is catered for by fibre surface modification using the mercerisation process. Kenaf fibre could be used for the reinforcement of concrete. Nonetheless, considering the source and type of the fibres, variation in properties is inseparable. Moreover, the importance of utilisation of Kenaf fibre besides its engineering properties, is the sustainability benefits, its reduction in overall cost of construction, and its carbon foot print reduction contribution to the environment, since the fibre is bio-based and generated from agriculture.

(a) Untreated Kenaf Fibre (b)3 Hours Immersion of Kenaf fibre in 5% Alkali Solution

Fig. 1: The Physical Appearance of Kenaf Fibre Before and After Alkali Treatment

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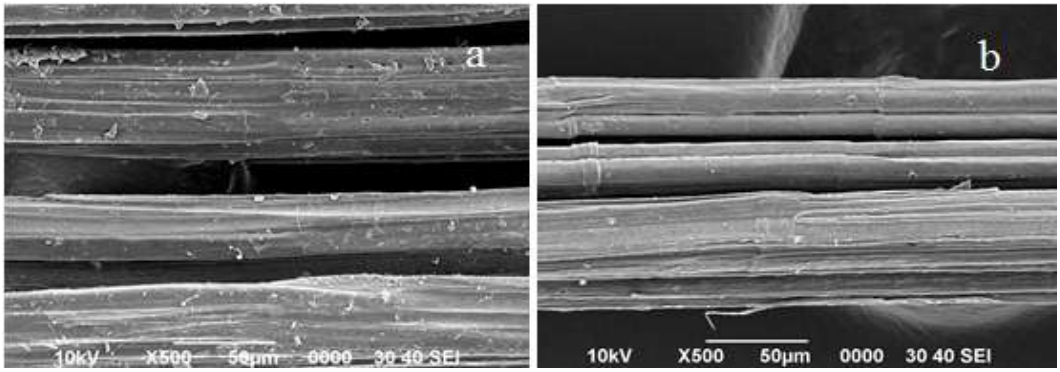
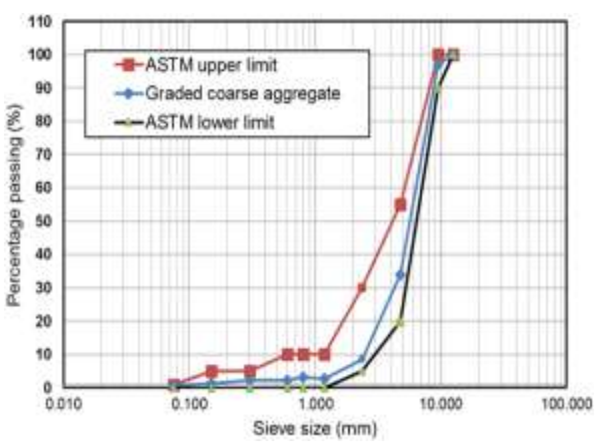


Fig. 2: Scanning Electron Micrographs of Kenaf Fibre Surface (a) Untreated (500x), (b) Treated by Mercerisation (500x)

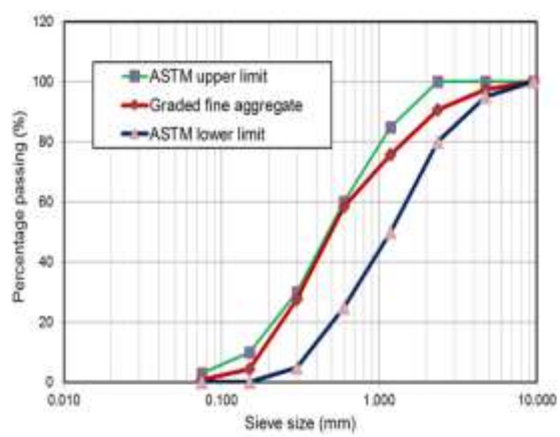
Table 1: Physical, Mechanical and Chemical Characteristics of Kenaf Fibres

Physical and mechanical characteristics		Chemical composition	
Diameter (µm)	65.40	Cellulose (%)	31.0-57.0
Density (g/cm^3)	1.20	Hemicellulose (%)	21.0-23.0
Elastic Modulus (GPa)	39.77	Lignin (%)	4.79-19.0
Elongation at Yield (%)	1.77	Pectin (%)	2.0
Tensile Strength (MPa)	704.00		

The fine aggregate used in this study is river sand in a saturated surface dry condition with a fineness modulus of 2.46, passing through 4.75 mm sieve. It has a specific gravity of 2.61, and a water absorption of 1.90% was used as the fine aggregate. The coarse aggregate is a crushed granite with a maximum size of 9.5 mm, a specific gravity of 2.80 and a water absorption of 1.44%. Fig. 2 presents the particle size distributions of the coarse and fine aggregates in conformity with the limits of ASTM C33 standard. To enhance and increase the workability of the fibrous concrete mixture, 1.0% by weight of cement polymer-based superplasticiser with brand name Rheobuild 1100 was applied to the concrete mix. A constant water/cement (w/c) ratio of 0.55 was used in all batches of mix employed for this experimental work. The water used for both mixing and curing purposes throughout this study was supplied from the tap in the laboratory.



coarse aggregates



Fine aggregates

Fig 3: Grading Curve of the Coarse and Fine Aggregates in Consonance to ASTM C 33 Limits

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2.2. Mix Proportioning

Table 2 presents the mix proportions of the Plain Concrete (PC) and Kenaf Bio Fibrous Concrete Composite (KBFCC). 13 concrete mixes were made of which the first batch was the control mix without Kenaf fibre. Among the twelve other mixes, six batches contained 25 mm length Kenaf fibre with volume fractions of 0.25%, 0.5%, 0.75%, 1.0%, 1.5% and 2.0% (KBFCC 1A – KBFCC 6A). The other six batches were made with 50 mm length Kenaf fibre for the same fibre volume fractions (KBFCC 1B – KBFCC 6B).

Table 2: The Mix Proportions of the Concrete Mixtures

Mix ID	L_f (mm)	V_f (%)	V_f (kg/m^3)	Cement (kg/m^3)	Coarse agg.* (kg/m^3)	Fine agg.** (kg/m^3)	Water (kg/m^3)	**Super-Plasticizer** (Kg/m^3)	Slump (mm)	Comp. Factor***	VeBe (sec)
PC	0	0	0	418	1002	725	230	4.18	120	0.984	3
KBFCC 1A	25	0.25	3	418	1002	725	230	4.18	100	0.951	3
KBFCC 2A	25	0.50	6	418	1002	725	230	4.18	90	0.923	4
KBFCC 3A	25	0.75	9	418	1002	725	230	4.18	70	0.912	11
KBFCC 4A	25	1.00	12	418	1002	725	230	4.18	40	0.898	16
KBFCC 5A	25	1.50	18	418	1002	725	230	4.18	25	0.812	40
KBFCC 6A	25	2.00	24	418	1002	725	230	4.18	15	0.809	53
KBFCC 1B	50	0.25	3	418	1002	725	230	4.18	90	0.947	7
KBFCC 2B	50	0.50	6	418	1002	725	230	4.18	70	0.911	12
KBFCC3B	50	0.75	9	418	1002	725	230	4.18	55	0.903	15
KBFCC 4B	50	0.10	12	418	1002	725	230	4.18	25	0.867	33
KBFCC 5B	50	1.50	18	418	1002	725	230	4.18	10	0.829	52
KBFCC 6B	50	2.00	24	418	1002	725	230	4.18	5	0.799	66

*Coarse aggregate, **Fine aggregate, *** Compacting factor

L_f = Fibre length, V_f = Fibre volume fraction

2.3. Casting Program and Test Procedure

2.3.1. Workability and Strength Properties Test

The fresh state properties were examined using the slump, compacting factor and VeBe tests according to [28], [29] and [30] respectively. The compressive strength test was conducted using 100 mm cube specimens [31]. 100 mm x 200 mm cylindrical specimens were prepared for the splitting tensile strength test [32]. Prism specimens with dimensions of 100 mm x 100 mm x 500 mm were made for testing the flexural strength [33] at the ages of 7 and 28 days.

2.3.2. Flexural Creep Test Procedures

The measured and calculated flexural creep test results of PC specimen and KBFCC specimens containing 0.5% fibre volume and 50 mm fibre length of Kenaf fibre are done using 75 x 75 x 600 mm prisms produced from the same concrete batch. The whole samples used are compacted and treated in the same way so that the same physical and mechanical properties of PC and KBFCC specimen tested are assured. The test specimens required for testing of the flexural creep are shown in Figure 4. The test setup for the flexural creep followed the design concept reported in [15,26,34] with some minor modifications to the components of the creep rig and the measuring device. Figure 5(a-e) shows the arrangement of the flexural creep rig designed, developed, fabricated and used in this research.

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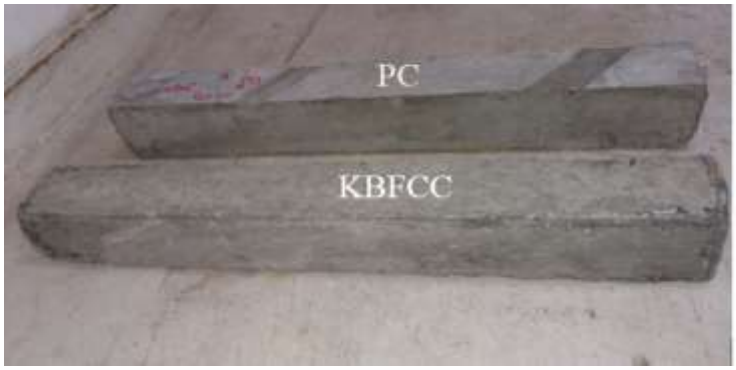

Fig. 4: 75 x 75 x 600 mm Prism Specimen for Flexural Creep Test

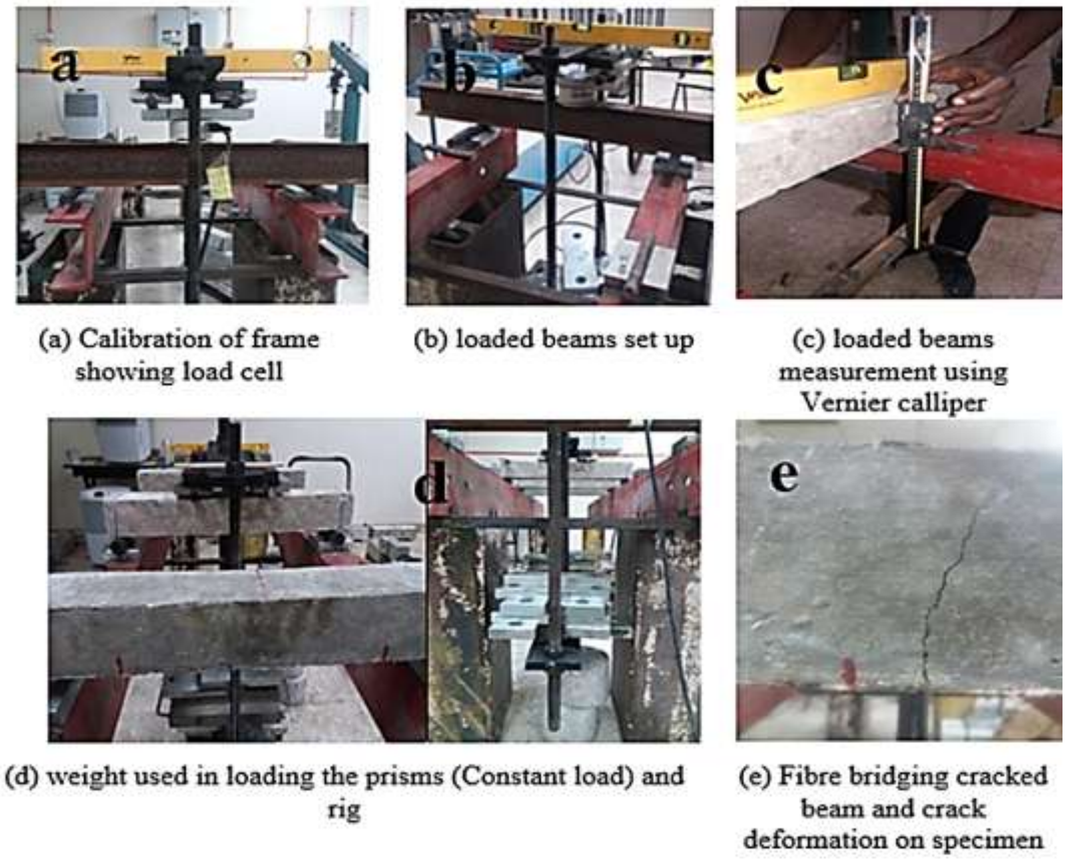

Fig. 5: Operational Procedure of Flexural Creep Test

The flexural creep test was commenced after the specimens had been pre-cracked in the Universal Testing Machine (UTM) and then unloaded under a third point bending test (Third point bending test is more suitable for determining of the tensile characteristics of fibre reinforced concrete than the centre-point bending test, because the results of the third-point bending test thus reflect a better uniformity achieved in fibrous concrete composite production). Before pre-cracking the specimens to be used for the flexural long term creep (PC and KBFCC). The residual tensile load (ARS) of the PC and KBFCC is determined by testing four beam specimens of the PC and KBFCC each until break of the beam. The third point bending test is applied on the PC and KBFCC samples until

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the deflection of 2.3 and 6 mm is reached, respectively, which represents full damage of the beam. Records from third point bending test of the load-deflection test specimens are shown in Table 3.

The average value of the load-deflection chart (F-δ) of these four specimens for the PC and KBFCC as presented in Fig. 6 provides information for determining of the required deflection value (the point of “activation of fibres” from the load-deflection (F-δ) chart recorded) for pre-cracking the long term test specimen. When the required deflection to cause macro crack is reached as determined from the load-deflection chart, the test is interrupted and the specimens are equipped for the long term testing and loaded with the creep load as shown in Figure 5(c).

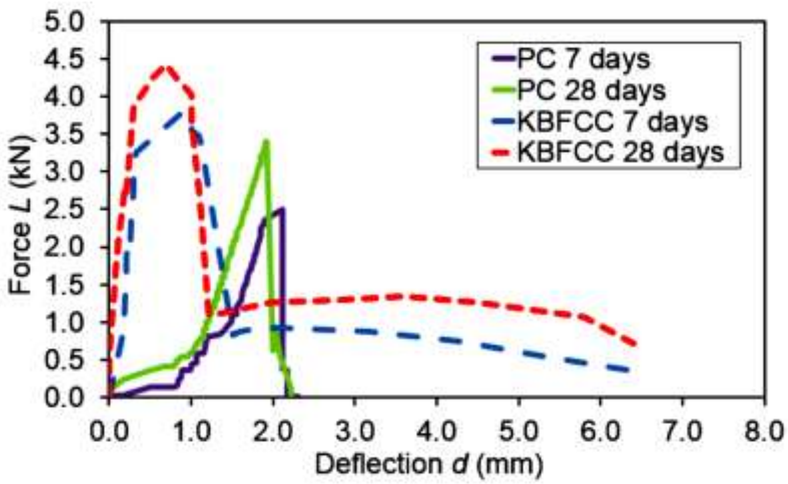

Fig. 6: Load-deflection (L-d) Diagram of the PC and KBFCC first Set Specimen at 7 and 28 Days Curing Age

Table 3: Loads Required for Fibre Activation and Flexural Creep Loading

Percentage (%) of Average residual strength used as load levels (%ARS)	Loading age (days)	Required load for fibre activation (kN)	Actual Applied Flexural creep loading values (kN)
PC 25%	7	0.343	0.086
	28	0.620	0.155
PC 35%	7	0.343	0.120
	28	0.620	0.217
KBFCC 25%	7	0.825	0.206
	28	1.100	0.275
KBFCC 35%	7	0.825	0.289
	28	1.100	0.385

The PC and KBFCC specimens were placed on a fixed support and long term load is applied under two stress levels at 7 and 28 day loading age. The equivalent sustained loads for each stress level was obtained as a percentage of the average PC and KBFCC residual strength. Prior to loading the cracked specimens on the creep rig, the rig set up was calibrated with a 50 kN load cell placed on the setup as described in Figure 5(a) and the I-steel section was put in the position where the actual concrete test specimens will be positioned and the transverse load plate connecting both threaded bars together was in turn placed on top of the load cell. It was ensured that the nuts did not exert any force on the specimens before the gravity loads were applied. It should be remarked that the load cell was not left in the frame during the actual tests as the constant gravity load needed to be sustained at the stress levels had been determined as illustrated in Figure 5(a). Each specimen representing the concrete mix type, age of loading and

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stress level were loaded with the gravity loads already determined during the calibration by gradually applying the weights as shown in Figure 5(c). A consistent and regular recording of deflection at chosen time intervals was done immediately the long term load is applied. Length of the time interval is chosen according to the required accuracy and speed of deflection increase. The increase of deflection is measured from the horizontal plane in the point of the macro-crack (in the middle of the beam). The horizontal plane is determined by the lower edge of the fixed datum on the rig.

III. RESULTS AND DISCUSSION

3.1. Workability

Table 3 presents experimental results recorded for slump, compacting factor and VeBe time tests of the PC and KBFCC mixtures tested in this experiment. It has been found that increasing Kenaf fibre content in the mixture of the concrete reduces the slump values of concrete mixes as compared to the fibreless concrete mix. The slump value recorded for the PC control mixture is 120 mm. The maximum slump value recorded for the KBFCC mixture is 100 mm in mixture containing 25 mm fibre at 0.25% fibre content. The minimum slump value was however, recorded as 5 mm for mixture containing 50 mm Kenaf fibre at 2.0% fibre volume fraction. The compacting factor values of the concrete mix also decreased as the fibre length and fibre content increased. Meanwhile, it was found that VeBe time increased linearly as the content of Kenaf bio fibre added to the concrete mix thus increased.

For fibre volume of 1% and above, the workability of concrete was observed to drastically decrease and become very stiff. It was noted that the knitting of fibres resists the flow of fresh concrete affecting the workability of the concrete. This agrees with some existing findings of [9–11,35]. It should be noted that the presence of 1% superplasticizer in the concrete mix had led to the attainment of this workability. Absence of superplasticizer or lesser quantity would have given a more sturdy and unworkable concrete mix. Additionally, [7,8] observed that the usage of bio fibre in concrete mixture made it harsher with a lower workability.

3.2. Compressive Strength

The cube compressive strength of concrete specimens was measured and presented in Fig. 7. The results show that the cube compressive strength of the concrete decreased with increasing fibre content; however, this reduction is not significant up to 0.5% fibre content inclusion with strength values in the range of structural applications. This describes the optimum recommended fibre content as 0.5%. Inspecting Fig. 7, it was observed that the fibrous concrete reinforced with 50 mm fibre length at 0.5 fibre volume fraction had a strength value in the range of structural applications and comparable with the PC and exhibits a better performance under load than the other fibrous mix tested under compression. As shown in Fig. 7, reinforcing the conservative plain concrete with 25 mm length Kenaf fibre caused a decrease of 14%, 14%, 39%, 57%, 54% and 66% in the 28 day cured concrete composite cube compressive strength at fibre volume fraction of 0.25%, 0.5%, 0.75%, 1.0%, 1.5% and 2.0%, respectively. Whereas, in mixtures reinforced with 50 mm Kenaf fibres and tested at 28 days, the compressive strength values decreased by 8%, 14%, 29%, 39%, 48% and 55% for mixtures containing 0.25%, 0.5%, 0.75%, 1.0%, 1.5% and 2.0%, respectively. A similar behaviour was reported by [10,35]. The curing day was observed to have significant effect on the strength of the concrete which is in consonant with the report of Ogunbode [36]. This

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could have been caused by the created air voids due to the high content of fibres in the mixture [1]. Even though KBFCC compressive strength was considerably affected as a result of the presence of fibre, the failure manner however, demonstrated a significant change from fragile to ductile state. The cubic specimens tested under compression was observed to have held their integrity up to the end of the test owing to the bridging effect of fibre in the concrete composite.

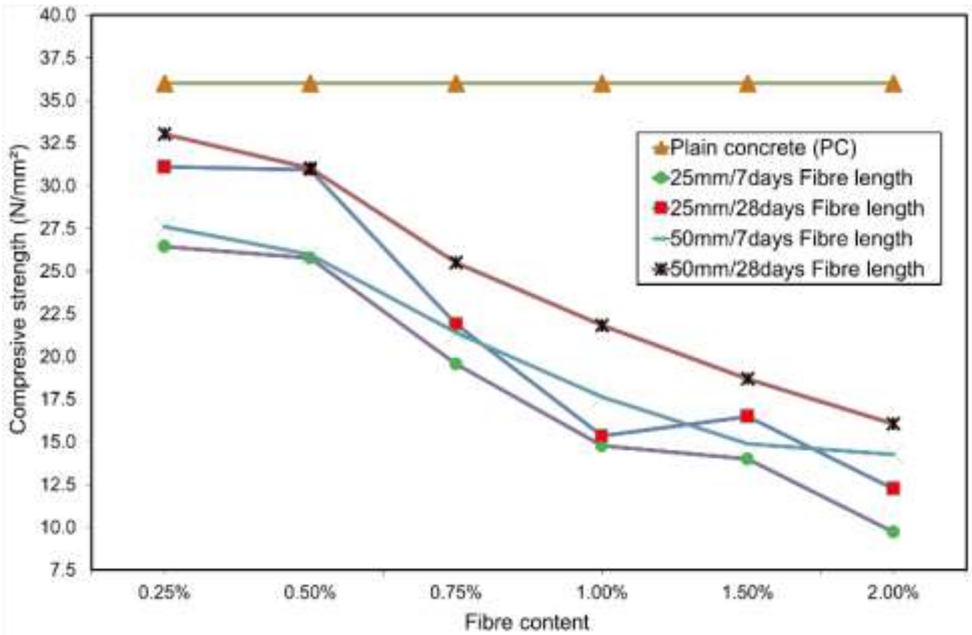

Fig. 7: Cube Compressive Strength of Kenaf Fibrous Concrete Composite

3.3. Splitting Tensile Strength

In this experiment, the indirect splitting tensile strength of the concrete mixture was measured at hydration period of 7 and 28 days. The Splitting tensile strength (STS) of the KBFCC was observed to decrease with increasing fibre content inclusion. However, the splitting tensile strength first increases and then slightly decreased with increasing fibre length (Fig 8.). In the case of increasing fibre content of 25 mm and 50 mm length Kenaf fibres, STS was observed to be higher with the longer length fibre. Data offered in Fig. 8 suggest that considering the curing time, the addition of Kenaf fibre in the concrete mix had a positive response to the tensile strength of concrete. The PC cylinders were seen to be broken into two halves at maximum load applied, while KBFCC cylinders held together after cracks under load and even when the test was continued up to its maximum failure load. When the splitting occurred and was sustained, the Kenaf fibres bridging the split parts of the specimens acted over the stress transfer from the matrix to the fibres, and gradually supported the full tensile stress. The conveyed stress improved the tensile strain capacity of the concrete matrix and, thus, enhanced the tensile strength of the fibrous mixtures over the PC mixture complement. By inspection, the data presented in Fig. 8 shows the effect of fibre content and fibre length on STS of KBFCC. STS decreases with higher fibre content above 0.5%. However, it first increases up to 0.5% and then slightly reduces with increasing fibre length. In the case of increasing fibre content of longer fibres at 50mm, STS is higher with the length of the fibre. Compared to the STS of PC, an addition of fibres

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thus increases the STS up to 7%. In general, the tensile strength of KBFCC was found to increase, having strength more than the PC with 50 mm fibre length at 0.5% fibre content. In general, the tensile strength of KBFCC with fibre volume fraction of 0.5%, and 50 mm length (KBFCC-2B) showed a potential maximum strength gain. The test results indicated that splitting tensile strength of KBFCC is about 5-10% higher than the control mixture. The results gotten in this study corroborates previous studies by [7,11].

An effective practice to examine the morphology of hydrated cement based products is the use of Scanning Electron Micrograph (SEM) image. After the completion of the STS tests, one of the tested cylinder failure surface was examined by way of identifying secondary electrons in a SEM machine wrought in a conditioned environment as presented in Fig. 9. Reviewing the SEM micrograph, it was observed that the Kenaf fibre is concealed with densely hydrated cement-matrix. The cement paste was homogeneously attached to the surface of the fibre, given a solid bond amongst fibre and hydrated cement matrix. Inspecting the interface between the fibre and the surrounding matrix point out an arced shaped failure surface which transmitted around the external surface of the fibre. This present that after the KBFCC cracking, the bond amongst the fibres and the surrounding matrix failed at the maximum tension region, while the fibres near the neutral axis thus transfer the tensile stress between the two faces of the crack. Thus, the measured STS of the KBFCC cylinder may have been owed to pull-out of the fibres and friction along the relatively coarse interface amongst the fibre and the surrounding matrix. The bonding between the fibre and cement matrix played a substantial role in the reduction of crack size. Comparable observations have been made by [7] who established that the inclusion of soft fibre; Kenaf fibre significantly improved the tensile strength of concrete.

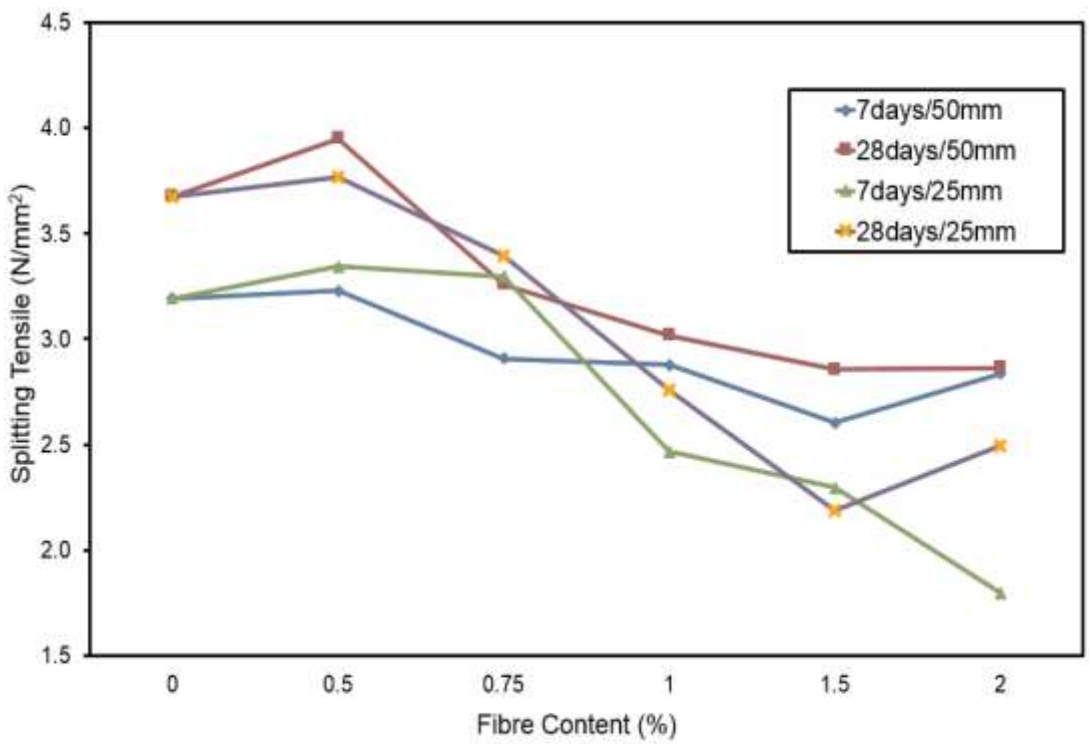

Fig. 8: Splitting Tensile Strength of Kenaf Fibrous Concrete Composite

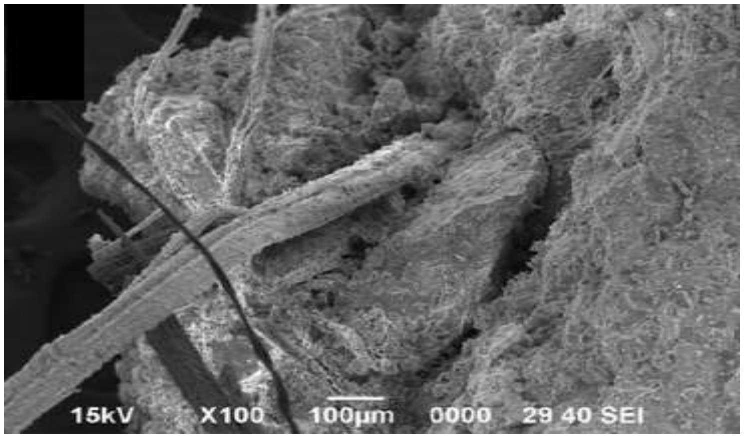

Fig. 9: SEM of fibre-matrix interface of KBFCC Cylinder Failure Surface

3.4. Flexural Strength

The conducted flexural test was to evaluate the effect of Kenaf fibres on the bending strength of KBFCC prisms. The bending strength of both PC and KBFCC was measured at hydration period of 7 and 28 days. The flexural strength of the concrete was found to increase with the increase in the fibre content up to 0.5%. Kenaf fibre reinforcement of the conservative concrete at 0.25%, 0.5%, 0.75%, 1.0%, 1.5 and 2.0%, for instance, led to 8.8%, 19.7%, 14.7%, 6.8% and 1% increase in the flexural strength of samples compared to the control mix respectively at the age of 28 days. Inspecting Fig 10, it was observed that the inclusion of Kenaf fibres in concrete slightly decreased the peak flexural strength of the concrete but significantly increased of the tested KBFCC prisms. The typical failure mode of the tested PC and KBFCC prisms are made known in Fig. 11a and Fig. 11b. Failure of the PC prisms ensued, owing to the development of a single crack within the central third of the prism which led to sudden, brittle failure of the prism. A similar crack was seen to be formed in the KBFCC prisms. However, the presence of the Kenaf fibres helped to bridge the crack, as shown in the figure, which led to a more ductile failure mode with greater toughness and residual strength.

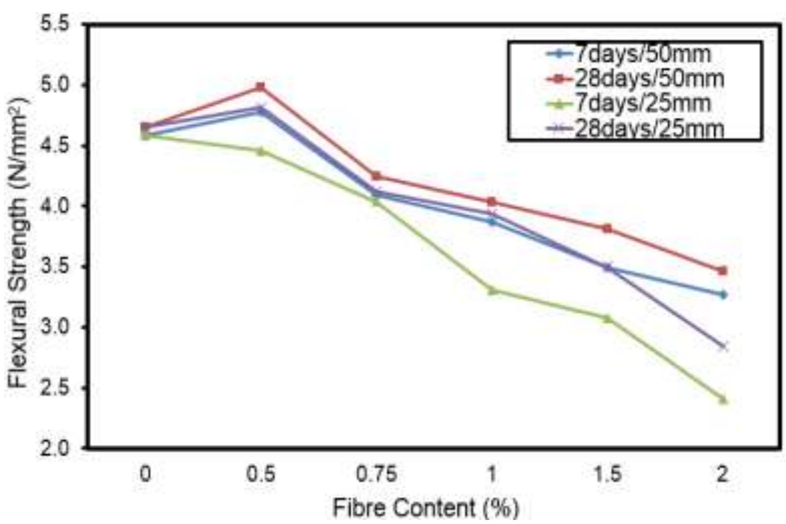

Fig. 10: Splitting Tensile Strength of Kenaf Fibrous Concrete Composite

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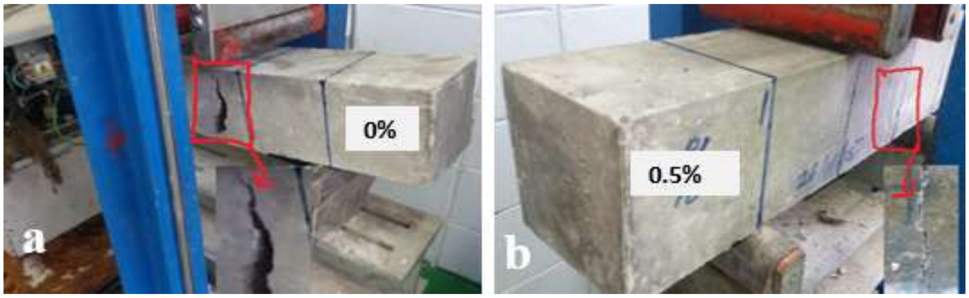

Fig. 11: Failure Manners of (a) PC-0% Specimen and (b) KBFCC-0.5% Specimens

At the instance of the formed crack on the PC and KBFCC creep specimens, the long-term creep loading was applied, and the deformation of the specimens was then monitored and recorded using a digital calliper. The specimens were placed on a static supports, and the long-term load applied as a third point loading on the specimen. The deflection of specimens was recorded at given time intervals. The increase of deflection is measured from the horizontal plane at the moment of the macro-cracking at the centre of the beam. The long-term load was applied for 259 days, and an increase of deflection was recorded and analysed over 259 days, and these records were analysed and illustrated in Fig. 12 and Fig. 13 (PC and KBFCC). The 7 days and 28 days PC specimen under 35% ARS load level were terminated at 119 day and 203 day, respectively, due to the collapse of the test sample.

Deflection records of PC specimens demonstrate increasing deflections all through the 119, 203 and 259 days of testing under 25% and 35% load level. Specimens with Kenaf fibres had an initial increase of deflection, and then the deflection remained somewhat constant. Also, the flexural creep test reveals that 0.064 mm/day and 0.073 mm/day deformation rate of KBFCC at 25% and 35% stress level becomes less significant after 40 days of loading. Bridging of fibres through the crack bending of the fibrous concrete element is triggered by cracking in the concrete composite. Fibres bridging the crack resists all flexural forces. The following effects govern crack openings; the resistance of fibres to rupture and strength of fibres. Also, fibre anchorage around the cement matrix is a major influence too. The effect of long-term loading, on the flexural creep deformation of fibrous concrete made with Kenaf fibres, was observed to be lesser compared to PC.

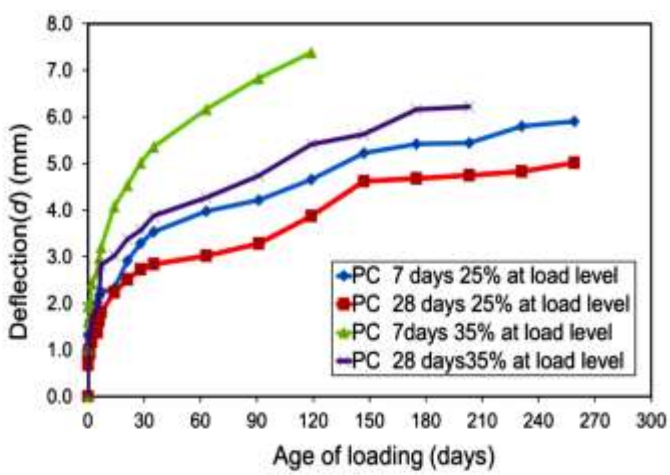

Fig. 12: Flexural Creep Deflections of PC Beam Specimen at 25% and 35% Load Level

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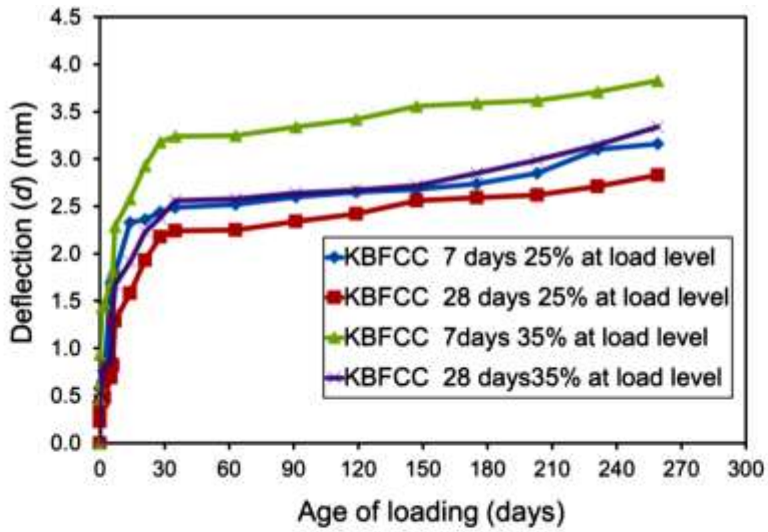

Fig. 13: Flexural Creep Deflections of KBFCC Beam Specimen at 25% and 35% Load Level

3.5. a) Effects of Loading Condition (Stress Level) on Flexural Creep Performance of PC and KBFCC

Stress level or loading intensities effects on the flexural creep of PC and KBFCC examined in this study are presented in Fig. 14.

As shown in Fig. 14, the concrete beam specimens loaded at 35% of the beam ARS develop substantially greater creep deflection than the samples loaded at 25% of the beam ARS at 7 and 28 day loading age. The significant effects of stress level on creep deflection can be observed from both the PC and KBFCC. As shown in Figure 6.26, the concrete mixtures with Kenaf fibre, tested after 7 days moist curing and loaded at 35% of the ARS have creep deflection deformation at 259 days to be 3.83 mm, around 21.2% higher than those loaded at 25% (3.16 mm) stress level. The 7-day moist-cured specimens from PC loaded at 35% of ARS did not have a corresponding creep deflection value at 259 days due to the collapse of the specimen causing the discontinuity of the investigation at 119 days. The ensued outcome of the deflection of the PC beam at 119 days was 7.39 mm, which showed a high deflection rate compared to the KBFCC specimen. Although the PC specimen loaded with a lesser percentage stress level of 25% did not collapse up to 259 days, but it deformation was as high a 5.91 mm.

A significant effect of loading conditions on creep behaviour was also seen from the samples moist-cured for 28 days. For the PC samples moist-cured for 28 days and loaded at 35% stress level, a similar behaviour as described on the PC 7 days specimen behaviour was observed. However, a long day of testing up to 203 days, which is 84 days more than the PC 7 days specimen before its collapse. KBFCC specimen moist-cured for 28 days and loaded at 35% stress level was observed to exhibit somewhat greater deformation up to 18% than the corresponding concrete loaded at 25% stress level.

Furthermore, the substantial effect of loading condition on flexural creep behaviour can be observed from the concrete mixtures without Kenaf fibre. A somewhat differing behaviour can be observed from the fibrous concrete mixtures. Higher load intensity at 35% had marginal effect on KBFCC compared to PC at 7 days and 28 days

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loading age. This deformation behaviour is due to the KBFCC improvement in ductility due to the fibre inclusion in the concrete.

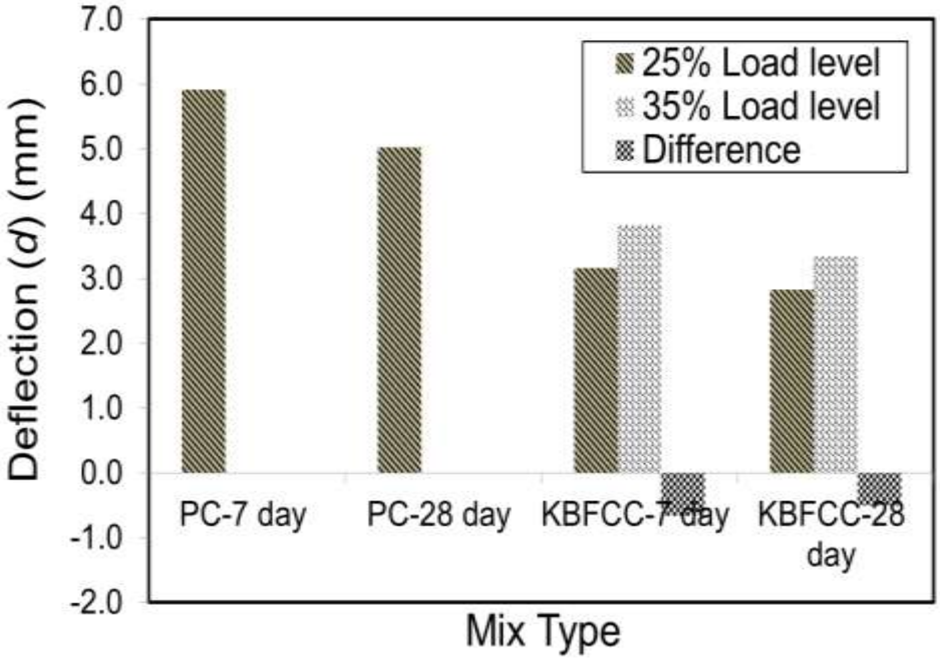

Fig. 14: Stress Level Effects at 259 Days Flexural Creep Value of PC and KBFCC Moist-cured for 7 and 28 Days

3.5. b) Effects of Loading Age Condition (moist curing) on Flexural Creep Performance of PC and KBFCC

Fig. 15 demonstrates the influence of concrete age at the time of compressive creep loading of PC and KBFCC. Two loading ages was adopted, they are, 7 days and 28 days. As shown in Fig. 15, the age of specimen loading or the curing condition of the specimen has a substantial effect on the flexural creep performance of PC and KBFCC mixtures. By and large, the concrete specimens moist-cured for 28 days had flexural creep deformation which was not as much of those moist-cured for 7 days within the range of 9.54% to 15%. This statement relates to the specimens loaded at both 25% of load level and 35% of load level at the two specified loading ages. Also, it is of significance to mention that, the effect of curing condition on creep deformation is extremely important for bio fibrous concrete composites. For example, 25% and 35% stress level on KBFCC specimens which was moist-cured for 28 days have a lesser long-term deflection of 10% and 15%, respectively at 259 days than those moist-cured for 7 days. The hydrophilic properties of Kenaf fibre might have probably contributed to this form of behaviour of this concrete. Hence, an improved hydration process of the concrete was due to it water absorbing characteristics. Therefore, a possible complete cement hydration needed in concrete is achieved as a result of the long-term moist curing condition in which the specimen is exposed to.

The remarkable effects of curing conditions on flexural creep performance of concrete have been observed to extend the deformation of PC mixtures. For example, the deflection of PC moist-cured for 28 days and loaded at 25% of compressive strength is 5.02 mm, which is 18% lower than the specimens moist-cured for 7 days and loaded at equivalent loading level.

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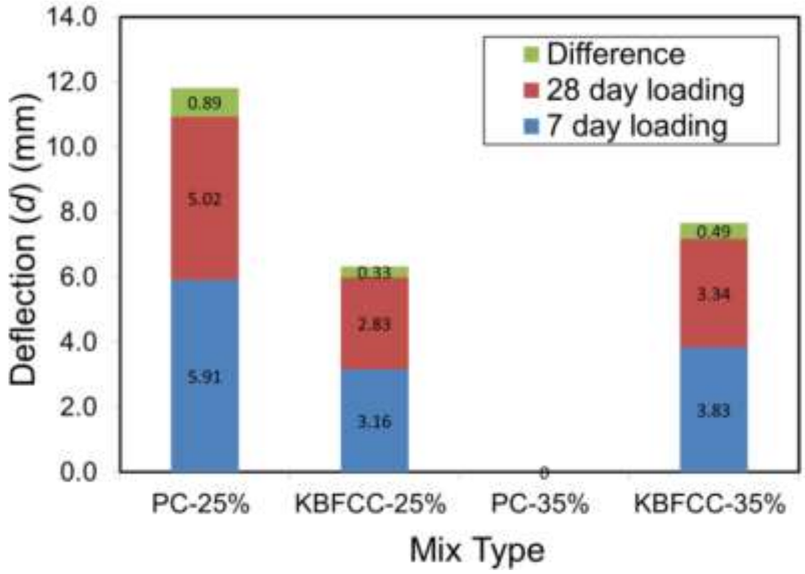

Fig. 15: Effects of Loading Age (Curing Condition) on Flexural Creep of PC and KBFCC Loaded at 25% and 35% of ARS at 259 Days

IV. CONCLUSIONS

The research conclusions of this study point out that Kenaf is a promising material for the production of sustainable, 'green' concrete by CO_2 sequestration from the atmosphere and represents a good replacement crop for the declining tobacco industry. Consequently, the influence of the inclusion of Kenaf fibre in conventional concrete at varying volume fractions ranging from 0.25% to 2.0% on compressive, tensile and flexural strengths, and the optimum fibre length and volume fraction of 50 mm and 0.5%, respectively for flexural creep of concrete was investigated experimentally. The observations from the experimental study are summarized and presented.

1. The use of Kenaf bio fibre in concrete basically affect the workability of concrete. Increasing fibre content resulted in a decrease of slump values, decrease of compacting factor and an increase of VeBe time value.
2. The compressive strength of KBFCC, in general, decreased with the increase in fibre content and fibre length. Despite the lower improvements in compressive strength of KBFCC, significant enhancements were noticed in the tensile and flexural strength values with similar w/c ratio. Kenaf fibre has been found to improve the tensile strength of concrete. This improvement has been shown to be prominent in the case of splitting tensile and flexural strength as compared to that of compressive strength. The 50 mm length fibre and 0.5% fibre volume fraction gave the optimum performance and strength development. In general KBFCC specimens exhibited more ductile behaviour with greater energy absorption and better distributed cracking patterns which is typical for fibrous concrete Additional, the results of the flexural tests indicate that KBFCC exhibits a ductile failure mode compared to conservative plain concrete. As a result, KBFCC could be used in the production of bending creep resisting members. Moreover, the observed improvement of the cracking and bending performance under sustained load improves the flexural creep and mechanical

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properties of concrete at relatively low cost and environmentally friendly concrete compared to the use of metallic and synthetic fibres.

3. At the age of 7 and 28 days, concrete containing Kenaf fibre performed better in the improvement of tensile and flexural strengths due to improved fibre-cement matrix interface. For mixes containing 0.5% of 50 mm length Kenaf fibre at 28 days, the tensile strength increased by 7% for KBFCC mixtures. The flexural strength also improved by 7% for the same conditions. The splitting tensile test and flexural tests experimental outcome point out that the ACI 318 [37] provisions associated with the tensile strength of the conservative plain concrete are also suitable for KBFCC.
4. The addition of Kenaf fibres in the conventional plain concrete lead to enhanced flexural creep and energy absorption capacity of the fibrous concrete. KBFCC specimen moist-cured for 28 days and loaded at 35% stress level was observed to exhibit somewhat greater deformation up to 18% than the corresponding concrete loaded at 25% stress level. A substantial effect of loading condition on flexural creep behaviour was observed on the PC mixtures. While a somewhat differing behaviour was observed from the fibrous concrete mixtures. Higher load intensity at 35% had a marginal effect on KBFCC compared to PC at 7 days and 28 days loading age. This deformation behaviour is due to the KBFCC improvement in ductility due to the fibre inclusion in the concrete.
5. The effect of curing condition on creep deformation is very important for bio fibrous concrete composites. For example, 25% and 35% stress level on KBFCC specimens which was moist-cured for 28 days have a lesser long-term deflection of 10% and 15%, respectively at 259 days than those moist-cured for 7 days
6. The SEM indicate the good bond amid the Kenaf fibres and the adjoining matrix and provide some hints concerning the probable failure manner and damage development of the KBFCC which could enable future modelling efforts. Bridging of fibres through crack bending of the fibrous concrete element is triggered by cracking. All flexural forces are repelled by fibres bridging the crack. Crack openings are governed by the following effects; the opposition of fibres to rupture and strength of fibres. Also fibre anchorage around the cement matrix is a major influence too. The effect of long-term loading, on the flexural creep deformation of fibrous concrete made with Kenaf fibres, was observed to be lesser compared to PC.
7. The results obtained and the observation made in this study propose that concrete incorporating Kenaf bio fibre can be used with reasonable engineering properties in the construction of building road pavements, slabs, bridge decks and other comparable usages under sustained bending load. Conversely, large-scale application of Kenaf fibre together with its performance in fibrous concrete structural members have been suggested as a recommendation for impending research. Future research should centre on the usage of cementitious inorganic admixtures to compensate the volume of cement usage in the production of KBFCC and a comprehensive life-cycle assessment of the concrete should be conducted.

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