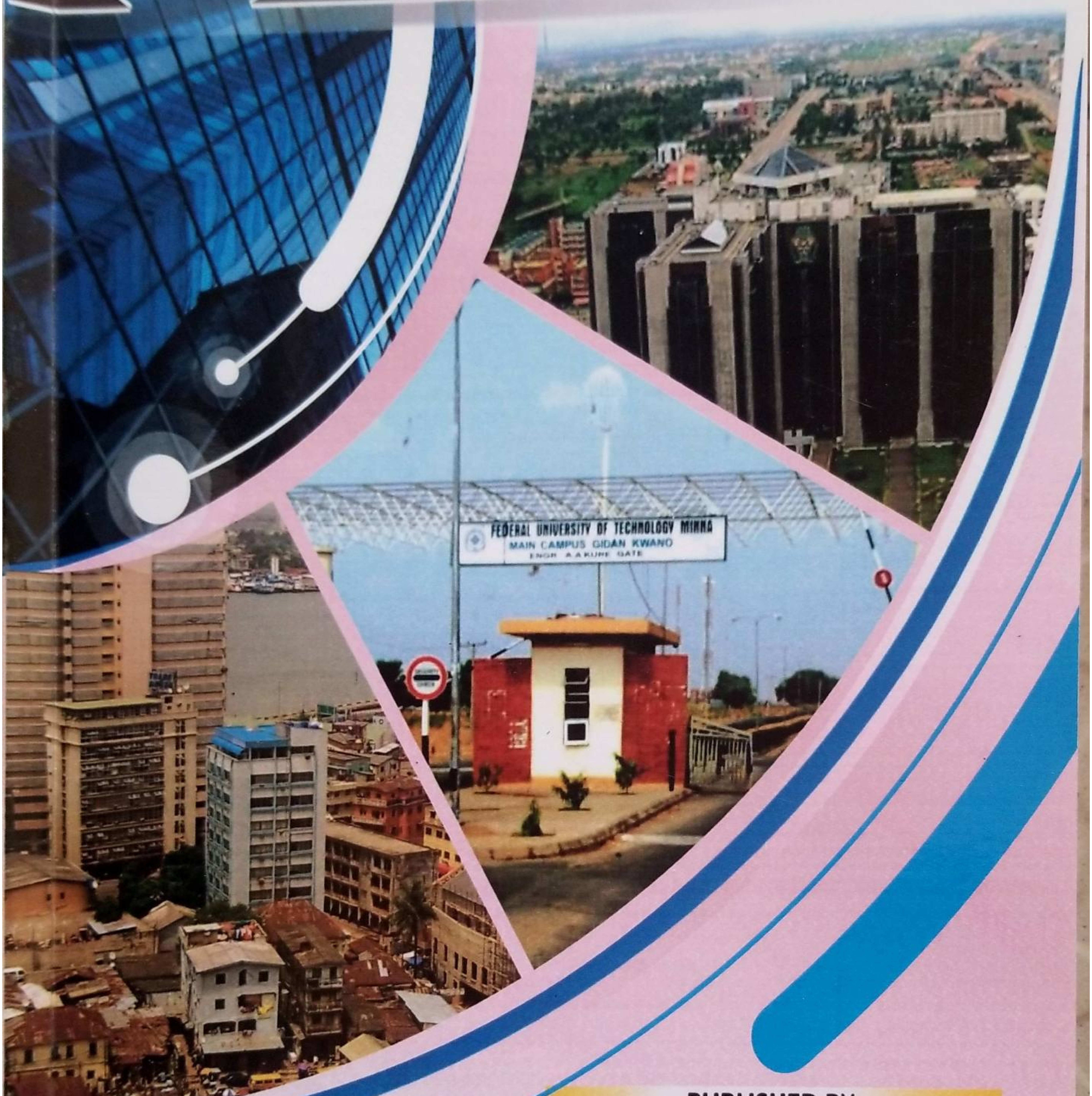
ENVIRONMENTAL TECHNOLOGY & SCIENCE JOURNAL (ETSJ)

VOLUME 10 | NUMBER 1 | JUNE, 2019 | ISSN 2006-0459



PUBLISHED BY
School of Environmental Technology
Federal University of Technology,
P.M.B. 65, Minna, Niger State, Nigeria.

Environmental Technology & Science Journal
Vol. 10 No.1 June 2019

Performance Evaluation of Bio Fibrous Concrete Incorporating Kenaf Fibre

[1*]Ogunbode, E. B., [2]Mohoro, I. S., [2]Adamu, B., [2]Musa, M. B. & [2]Sani, M.
[1]Department of Building, Federal University of Technology Minna-Nigeria
[2]Department of Building Technology, Niger State Polytechnic Zungeru-Nigeria
ezekiel@futminna.edu.ng

This study presents an experimental research program that is conducted to investigate some selected mechanical properties and time dependent properties of Kenaf Biofibrous Concrete Composite (KBFCC) under sustained load. The testing procedures are basically in accordance with the requirement of the American Standard of Testing and Materials (ASTM) and the British Standard (BS). 11 concrete mixtures were evaluated, and replicate batches for all these mixes were also being produced and evaluated. Kenaf fibre length of 25 mm and 50 mm, and fibre content of 0%, 0.5%, 0.75%, 1.0%, 1.5% and 2.0% by volume of concrete mix was incorporated in the mix design. 0.5% fibre content and 50mm fibre length was the optimum mix determined and was used in the production of specimen for compressive creep. The Kenaf fibre decreased the slump values and increased the VeBe time of fresh concrete. Likewise, the addition of Kenaf fibres did not improve the compressive strength. However, the positive interaction of concrete with Kenaf fibres leads to higher tensile and flexural strengths. Despite lower strength development, an increment in the post-failure compressive strength of concrete composite was observed in all mixes. A significant enhancement up to about 23.1% was also observed on the creep of the concrete composite containing Kenaf fibre, as compared to that of plain concrete. The study showed that the utilization of Kenaf fibre in the production of concrete is feasible from both environmental and technical points of view.

Keywords: Bio fibrous concrete, Creep, Kenaf fibre, Mechanical, Time dependent

Introduction

The usefulness of concrete in various Building and Civil engineering applications is incontestable. Over the years, it has so far been positively used in hydraulic structures, shotcrete, offshore structures, slabs on grade, structures in seismic regions, thin and thick repairs, architectural panels, crash barriers, precast products, footings, global transportation infrastructure systems such as network of roads, bridges, railways, airports, canals and many other applications. The reason for its widespread acceptability for use in various infrastructure productions is not far-fetched from the benefit of providing the lowest ratio between cost and strength as compared to other available materials (Tejchman & Kozicki, 2010; Bicanic *et al.*, 2011). Despite these applaudable qualities, two unattractive properties: low tensile strength and large brittleness (low energy absorption capacity) possessed by concrete still makes it prone to collapse which occurs shortly after the formation of deformation and first crack (Tejchman & Kozicki, 2010). This adversely limits the performance of concrete over long term when exposed to sustained loads like creep (Tan, 1996).

The inclusion of short discontinuous randomly oriented fibres (natural, steel, synthetic and glass) has remained a practice among others towards contributing to the improvement of the two negative properties of concrete (Bentur & Mindess, 1990; Soroushian, 1992; Mobasher & Shah, 1990; Mobasher *et al.*, 1991; Hannant, 1987). It has been reported by the ACI Committee 554, that fibre inclusion provides a bridging ability after the first crack occurs before the total separation of a beam (Mehta & Monteiro, 2006). The enhancement of the mechanical and durability properties of concrete has been encouraging by the outcome of numerous studies that have proven the effectiveness of adding fibres into concrete mixes as a great action to counter or control concrete creep deformation, it will also aid in converting the brittle characteristics of concrete to ductile one (Bentur & Mindess, 1990; Balaguru & Shah, 1992; Zollo, 1997). There exist several types of fibres, usually included in concrete, but the most commonly used are the natural (vegetable), steel, glass, carbon, asbestos and synthetic type of fibres. These resource fibres have advantages in the matrix proportioning of cement composites. Natural fibres are believed to be more environmentally friendly; this is why they are currently getting a lot of attention for replacing the steel and synthetic fibres (Thielemants & Wool, 2013).

Researchers for the past two decades have investigated and compared the benefit and properties of natural, steel and synthetic fibre. They succinctly describe natural fibres to possess many pluses than synthetic and other type of fibres. Such advantages are low density, carbon dioxide requisitioning, low cost, issue of sustainability, recyclability, biodegradability, and competitive specific mechanical properties (Toledo *et al.*, 2003; Amar *et al.*, 2005; Hatta *et al.*, 2008). Even if compressive strength of natural fibre concrete is to some extent lower than the control concrete mix, their deformation behaviour shows some improvement in ductility (Ramaswamy *et al.*, 1995). Some investigations have been carried out on the properties of concrete using the natural fibres normally referred to as fibrous concrete from coconut coir, hemp, sugar cane, bamboo, jute, elephant grass, akwata and sisal with encouraging results recorded (Bilba *et al.*, 2007; Elie *et al.*, 2010; Elie *et al.*, 2011). Usage of Kenaf fibre in concrete is however new with reports on its study being rear in literature. This study, thereby seeks to investigate the long term performance of Kenaf Biofibrous Concrete Composite (KBFCC) under sustained loads.

In view of the current global challenges, the construction industry has been focusing on the concept of sustainability particularly, the inclusion of natural biodegradable fibre in concrete (Ogunbode *et al.*, 2017). Serviceability and durability performance has been given more emphasis in the design and analysis of concrete structures. The ultimate limit state requirement is no longer the only main focus in structural design as durability and service performance are as well important for the safety, aesthetics and economic values of the structure or concrete composite. Creep is a critical property for the evaluation of stresses, deflection, cracking, buckling and failure of brittle materials such as concrete for structures under sustained loads (Ogunbode *et al.*, 2016).

The deformation experienced in concrete structure due to low tensile strength and large brittleness (low energy absorption capacity) problems is controlled by replacing it with fibrous concrete. This is a sustainable substitute concrete type where long-term performance and durability is the key consideration. Remarkably, the commonly used fibre types in the production of fibrous concrete such as steel, asbestos, synthetic and glass are usually associated with high cost, corrosion, non-renewability, high specific weight and harmful to environment. This is not good for our world and the construction industry in its striving towards achieving a sustainable environment. Therefore, Natural fibre such as Kenaf fibre which is cheaper, environmental friendly and viable choice is a need (Ogunbode *et al.*, 2015). To use this fibre a detail research on its time dependent properties under sustained load is require.

Recent studies revealed the immense potential and interest generated due to the application of Kenaf fibre in the construction material industry, automobile industry, wood-based sector and textile industry. Consequently, the Malaysian government and some other developing nations have pursued vigorously various measures to promote downstream value processing of Kenaf as well as its cultivation among small holders and estate owners (Mohd *et al.*, 2014). Recently, experimental and theoretical researches have been carried out to understand the mechanical properties of KBFCC (Elsaid *et al.*, 2011; Udoeyo, 2012). Most of these studies are limited to the short term performance of Kenaf bio-fibrous concrete composites under sustained static loads (Elsaid *et al*., 2011; Udoeyo, 2012; Ogunbode *et al*., 2018). However, studies of long term performance of KBFCC under sustained static loads of KBFCC to understand it time dependent behaviour has attracted none or little attentions. Though, it has been observed that the study on concrete composite system made from natural fibrous concrete has been of interest due to its need for the evaluation of stresses, deflection, cracking, bulking and failure of structures made from KBFCC (Ogunbode *et al*., 2016). The study on the time dependent properties of KBFCC will avail material engineers and structural designer's knowledge and data on the material properties and structural behaviour pertaining to serviceability performance.

The aim of this research is to investigate the long-term performance of KBFCC under sustained load. In other to achieve the above aim, the following specific objectives are formulated. To examine the fresh state and mechanical properties of concrete containing Kenaf fibre at varying fibre length and volume fraction, to investigate the performance of KBFCC under long term compressive creep loadings.

Materials and Methods

As mentioned above, this study is aimed at investigating the long-term performance of Kenaf bio fibrous concrete composite The fresh properties of Kenaf bio fibrous concrete composite (KBFCC) were slump, compacting factor and vebe time, while the hardened properties were compressive strength, splitting tensile strength, flexural strength, ultrasonic pulse velocity, elastic modulus, toughness, and shrinkage test. In a bid to understand the Time dependent behaviour of KBFCC, compressive creep test was carried out on the hardened concrete. The materials used and the methods for conducting the tests are presented in the following sections.

Materials

Cement corresponding to ASTM Type I from a single source was used throughout the experimental work. The coarse aggregate was crushed granite with a maximum size of 10mm. Natural river sand with fineness modules of 2.46 was used as a fine aggregate. Both coarse and fine aggregates were batched in saturated surface dry condition. Tap water was used for mixing, curing and other purposes throughout the study.

Rheobuild 1100, a commercial Polynaphthalene Sulfonate type superplasticizer conforming to ASTM C494-92 was utilized as high range water reducing agent in the concrete. The dosage of superplasticizer was kept constant at 1% for all concrete mixes in order to eliminate any apparent effect on the properties of hardened concrete.

Preparation of Kenaf Fibre

The Kenaf fibres were acquired from National Kenaf and Tobacco Board, Kelantan, Malaysia as curled long fibres, which have been through a bacterial retting process. Table 1 presents the physical, mechanical and chemical characteristics of the Kenaf fibre. A reagent grade Sodium hydroxide was used for fibre surface modifications. They were procured from Merck Sdn. Bhd. in Malaysia. As shown in Table 1, the Kenaf fibre samples principally composed of cellulose, hemicellulose, lignin, pectin and structural water which are all classified as sugar-based polymers components.

Table 1: Physical, Mechanical and Chemical characteristics of Kenaf fibres

Physical and Mechanical Characteristics			**Chemical Composition**		
Diameter	**(µm)**	39.7-115.1	**Cellulose**	**(%)**	31-57
Density	**(g/cm^3)**	1.2	**Hemicelluloses**	**(%)**	21-23
Elastic modulus	**(GPa)**	14-53	**Lignin**	**(%)**	4.79-19
Elongation	**(%)**	1.6	**Pectin**	**(%)**	2
Tensile strength	**(MPa)**	135-930			

Fibre treatment

The dry Kenaf fibre was exposed to mercerization treatments (alkali treatment) in order to improve sorption characteristics of the cellulose fibre. Fibres were immersed in 5% by weight of sodium hydroxide (NaOH) solution for 3h at 25°C ambient temperature. This was done to promote the hydroxyl group ionization to the alkoxide (Agrawal et al. 2000).

The resulting fibres were then washed many times in distilled water to clean the fibre surface from the NaOH solution so as to neutralize all remnant of the NaOH on the fibre surface and then dried at room temperature (Figure 1a).

In other to understand the effect of fibre treatment on water sorptivity of natural fibre such as Kenaf fibre under study, a water sorption test was carried out on both the treated and untreated Kenaf fibre.

Piloting the water sorption investigation, a 6 gram of dried samples of both treated and untreated Kenaf fibre were engaged. The average diameters of the untreated and treated fibres were 69.8µm and 65.4µm correspondingly. The investigation was conducted in conformity with ASTM D570-98 requirement. The samples were immersed in distilled water at room temperature. Increase in weight of the samples were noted and recorded at specific time interval in order to study the kinetics of water absorption of the fibre. This process was continued until equilibrium was attained. The values found were perfectly reproducible. The percentage of water absorption at any time, t, Mt, was calculated using Equation (1) (Najafi & Kordkheili, 2011; Zabihzadh, 2010).

The percentage equilibrium moisture absorption, M_{∞}, was calculated as an average value of several constitutive measurements that showed insignificant additional absorption.

$$\text{Fibre} - \text{OH} + \text{NaOH} \longrightarrow \text{Fibre} - \text{O}^{-} - \text{Na}^{+} + H_2O + \text{Surface Impurities}$$


(a) (b)

Figure 1: (a) Drying of treated Kenaf Fibre (b) Cut Kenaf Fibre ready for use

Water Absorption, M_t (%) =

$$\frac{w_{(t)} - w_{(o)}}{w_{(o)}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where $W_{(t)}$ and $W_{(o)}$ designate the initial weight of the sample and weight of the sample at time t respectively.

Concrete Mix and Preparation of Test Specimens

The treated Kenaf fibres were added at different fibre length (l_f) and volume fraction (v_f) to determine the applicability of the fibre as reinforcement in concrete. The varying fibre lengths (l_f) and volume fractions are 25mm, 50mm and 0%, 0.5%, 0.75%, 1.0%, 1.5% and 2.0%. A total of 66 cubic specimens, 102 cylindrical specimens and 66 prismatic specimens was fabricated and cured in water until testing. A characteristic strength of 30N/mm^2 and water to cement ratio settled to 0.55 according to DOE design method was used. A superplasticizer with brand name Rheobuild1100 was used as high range water reducing agent in the mix. This was done to provide good mechanical strength and adequate workability of the mixtures. The mix proportion of KBFCC is shown in Table 2.

A revolving pan type concrete mixer was used in preparing both plain and fibrous concrete. The mixing procedure was divided into three stages. In the first stage; cement, fine and coarse aggregates were weighed and mixed in the mixer until all constituent are mixed uniformly. In the second stage, two third of the mixing water was pour into the mix and the mixer was rotated for 2 min. Then the treated soaked Kenaf fibres were added slowly and uniformly to eliminate the fibres clumped together and mixed thoroughly for 2 min to obtain a homogeneous mix. In the final stage, the remaining one third of the measured mixing water and one percent by weight of cement of superplasticizer were added and mixer was again rotated for another 2 min. The slump, vebe and compacting factor test for PC and the KBFCC (varying fibre length and content) was always carried out to check for the workability of the various resulting concrete before pouring it into moulds.

Tests on Fresh Concrete

Test on fresh concrete was carried out by Slump test following ASTM C143 standard to measure the consistency of a concrete, which has a close indication to workability. Along with slump test, the compacting factor test conforming to BS EN 12350-4 and Vebe test conforming to ASTM C 1170 was conducted.

Tests on Hardened Concrete

In order to investigate the compressive strength of concrete, uniaxial compression test and ultrasonic pulse velocity test was carried out on 100 mm cube specimen conforming to BS EN 12390-3 and ASTM C597 requirements respectively. The splitting tensile test was however, performed on the standard test cylinders measuring 100 mm x 200 mm conforming to ASTM C496/C496M-04. The flexural strength test was conducted using 100 x 100 x 500 mm beams under third point loading following the ATSM C1609/C1609M -10 requisites.

Table 2: Mix design of Kenaf Biofibrous concrete composite (KBFCC)

Mixture code	l_f (mm)	v_f (%)	Cement (Kg/m^3)	Water (L/m^3)	Coarse Aggregate (Kg/m^3)	Fine aggregate (Kg/m^3)	Fibre (Kg/m^3)	SP (Kg/m^3)
PC	0	0	418	230	1002	725	0	4.18
KBFCC-1	25	0.5	418	230	1002	725	6	4.18
KBFCC-2	25	0.75	418	230	1002	725	9	4.18
KBFCC-3	25	1.0	418	230	1002	725	12	4.18
KBFCC-4	25	1.5	418	230	1002	725	18	4.18
KBFCC-5	25	2.0	418	230	1002	725	24	4.18
KBFCC-6	50	0.5	418	230	1002	725	6	4.18
KBFCC-7	50	0.75	418	230	1002	725	9	4.18
KBFCC-8	50	1.0	418	230	1002	725	12	4.18
KBFCC-9	50	1.5	418	230	1002	725	18	4.18
KBFCC-10	50	2.0	418	230	1002	725	24	4.18

Tests on Time dependent Properties of concrete

In this study, compressive creep which is one of the time dependent properties of concrete was studied to observe the contribution of Kenaf fibre to the effect of sustained load on concrete. The primary test parameters examined are fibre inclusion (0% and 0.5%), stress-strength ratio (load level at 25% and 35%) and loading age effect (7 and 28 days). Plain concrete specimens were also used as control specimens. The number of test specimens for each fibre volume fraction added is presented in Table 4. The compressive creep test specimens were made from 100 mm x 200 mm cylindrical steel moulds. They were demoulded after 24 hours of casting, and moist cured at a temperature of 23±2°C and a relative humidity of 60±10% (Figure 15a). In comparison with the recommendation in ASTM C 157/157M-13 (2013). The temperature and the relative humidity used in the creep test was the same. Figure 2(b to d) presents the Compressive creep setup, the creep rig and the Demec gauge that was used for acquiring the creep strain.

Results and Discussion

Properties of Fresh Concrete

In this study the slump, compacting factor and Vebe time tests were conducted to investigate workability of PC and KBFCC (Figure 3). The slump value, compacting factor value, and the Vebe time of all the concrete mixes for different fibre length (l_f) and fibre volume fraction (V_f) are tabulated in Table 3. As shown in Table 3, slump values of concrete decreased as the l_f and V_f increased. Meanwhile, Vebe time of concrete increased as the l_f and Vf increased. 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 *et al* (2013) and Hasan *et al*. (2015). The result on the unit weight of concrete, presented in the same table reveals that concrete unit weight decreased uniformly with the increase in fibre volume fraction. This negates the outcomes of other researchers that used steel fibres (Awal *et al*., 2000; Awal *et al*., 2013). This may be due to the low density of Kenaf fibre which is lower than most constituent of the concrete. Regardless of fibre volume, it was further observed that the unit weight of KBFCC decreased as the fibre length is increased as a result of air content in the concrete due to fibre orientation and the distribution of long fibres in concrete.

The fibre length (l_f) of Kenaf fibre has a prime influence on the workability of concrete mixtures. The slump value has been found to decrease in concrete mixture produced from fibre length of 25 mm and 50 mm. A significant drop from 120 mm to 10 mm for fibre length of 25 mm and 120 mm to 5 mm for fibre length of 50 mm. Table 2 reveals that as the fibre with longer fibre length 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 (Lam & Jamaluddin, 2015; Hasan, *et al*., 2015). The study has shown that slump and compacting factor of the concrete decreased as the fibre volume of Kenaf fibre increased. Like that of slump and compacting factor value, the Vebe time also found to be influenced by the fibre volume of Kenaf fibres. With an increase in the amount of fibre for 1 to 2 percent, the Vebe time of the KBFCC has been found to be almost double. This is to be expected because lower amount of fibre can easily disperse in the concrete matrix.

Like fibre volume fraction (V_f), the length of fibre (l_f) influenced the workability of fibre reinforced concrete. The longer the length of Kenaf fibre introduced in the concrete, the lower the slump value that will be obtained.

By more addition, the fibres start to clump together showing a balling effect. Furthermore, the interlocking and entangled around aggregate particles had considerably reduce the workability. Similar findings were reported by Lam & Jamaluddin (2015) and Hasan *et al*. (2015) who found that the density of fibrous concrete made with natural fibre decreases with the increase in fibre content for Kenaf fibre.

Table 4: Details of Time dependent test

Requirement	System Details	
Fibre content	0%V_f	0.5% V_f
Loading intensity	40% loading	40% loading
loading age	28days	28days
Nos of Rig	8	8
Duration of test	86 days	86 days

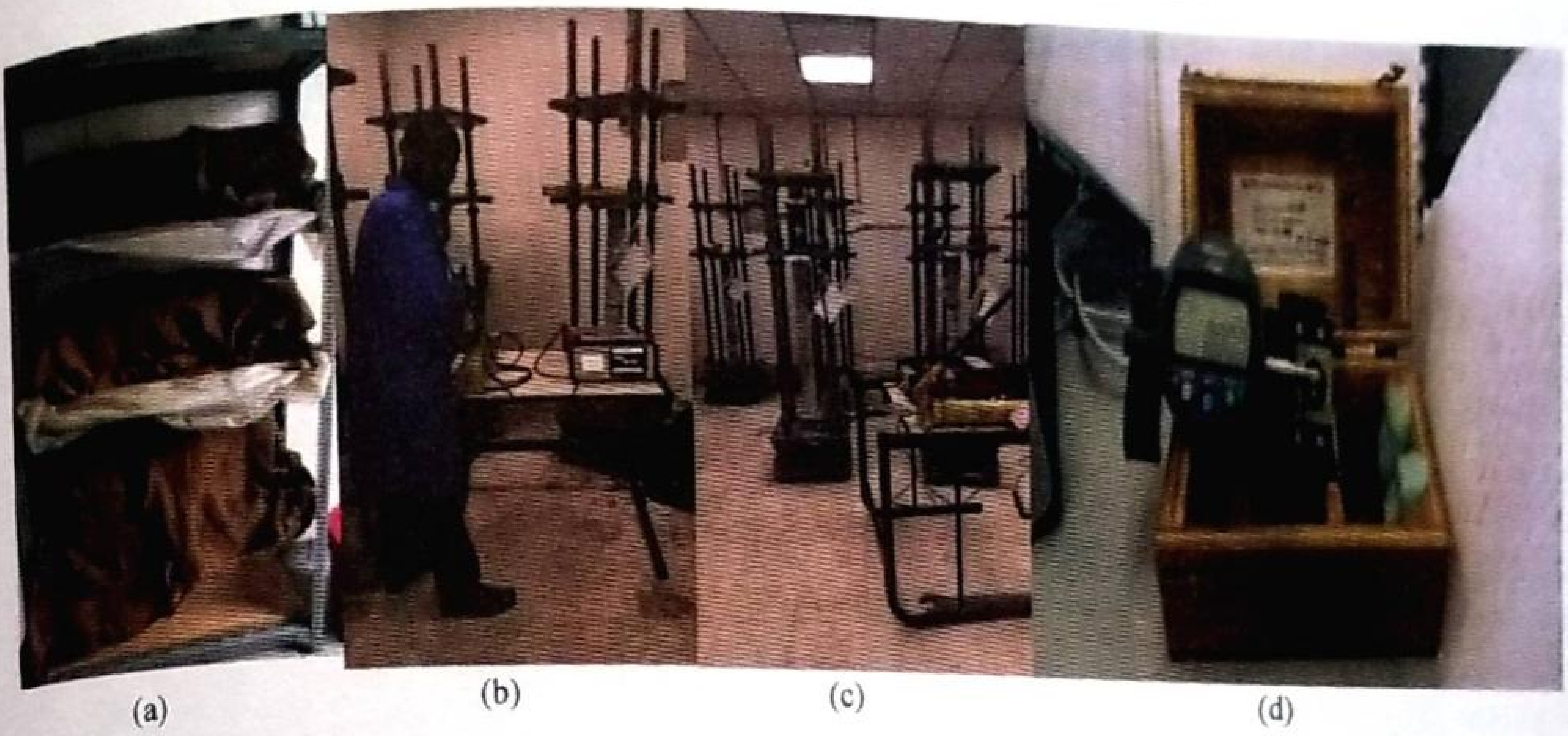

(a) (b) (c) (d)

Figure 2: (a) Moist curing rack (b) creep test set-up (c) Creep rig (d) Demec gauge.

Figure 3: Measurement of (a) Slump, (b) Compacting Factor and (c) Vebe for workability test

Table 3: Slump, Vebe time and unit weight of concrete mixtures.

Mixture code	l_f (mm)	V_f (%)	Slump (mm)	Vebe time (s)	Compacting factor	Unit weight (kg/m³)
PC	0	0	120	3	0.98	2362
KBFCC-1	25	0.5	90	4	0.92	2307
KBFCC-2	25	0.75	70	11	0.91	2289
KBFCC-3	25	1.0	40	16	0.90	2222
KBFCC-4	25	1.5	15	40	0.87	2212
KBFCC-5	25	2.0	10	58	0.85	2138
KBFCC-6	50	0.5	70	12	0.91	2350
KBFCC-7	50	0.75	55	15	0.90	2345
KBFCC-8	50	1.0	25	33	0.87	2280
KBFCC-9	50	1.5	10	52	0.83	2230
KBFCC-10	50	2.0	5	73	0.77	2248

Effect of fibre treatment on Water Sorptivity of natural Kenaf fibre

Water absorption curves showing the sorption behaviour of untreated and treated Kenaf fibre at room temperature in distilled water are given in Figure 4, where percentage of water absorbed is plotted against the square root of the soaking time. Each data point denotes the mean of three samples. The spongy structure of Kenaf fibres leads to an initial capillary sorption which results in the large initial uptake in all cases.

Treatment considerably reduces the overall water uptake of the Kenaf fibre. The initial uptake due to the capillary action is also reduced. The equilibrium % water uptakes for the untreated and treated fibres in distilled water at room temperatures are given in Table 4. The treated fibre has a decreased water uptake value of up to 13.8% compared to the untreated fibre. However, there are irregularities observed for different treated systems. The decrease in uptake value for treated fibres will be attributed to the physical and chemical changes that occurred on the fibres as a result of the alkali treatment. The reduced sorption observed is also due to the decreased capillary action that had occurred on the treated fibre. The process is also supported by the studies of Sreekala *et al.* (2002), Sreekala and Thomas (2003) that mercerization treatment on oil palm cellulose fibres leads to decreased water uptake. The interstices between the groups of microfibrils of the fibre would be blocked by the linked agents that reduce water accessibility. The chemical bond formed on the fibre surface during treatments is presented in a schematic form as shown in Figure 5.

Properties of Hardened Concrete

In this study, some important supplementary test to determine the mechanical properties of KBFCC was investigated. The following are the strength tests carried out; compressive strength, splitting tensile strength and flexural strength. The results obtained for all categories of strength investigation are presented in Figures 6 to 17. Alongside the strength tests, ultrasonic pulse velocity of the concrete specimen was also studied to examine its relationship to compressive strength of concrete.

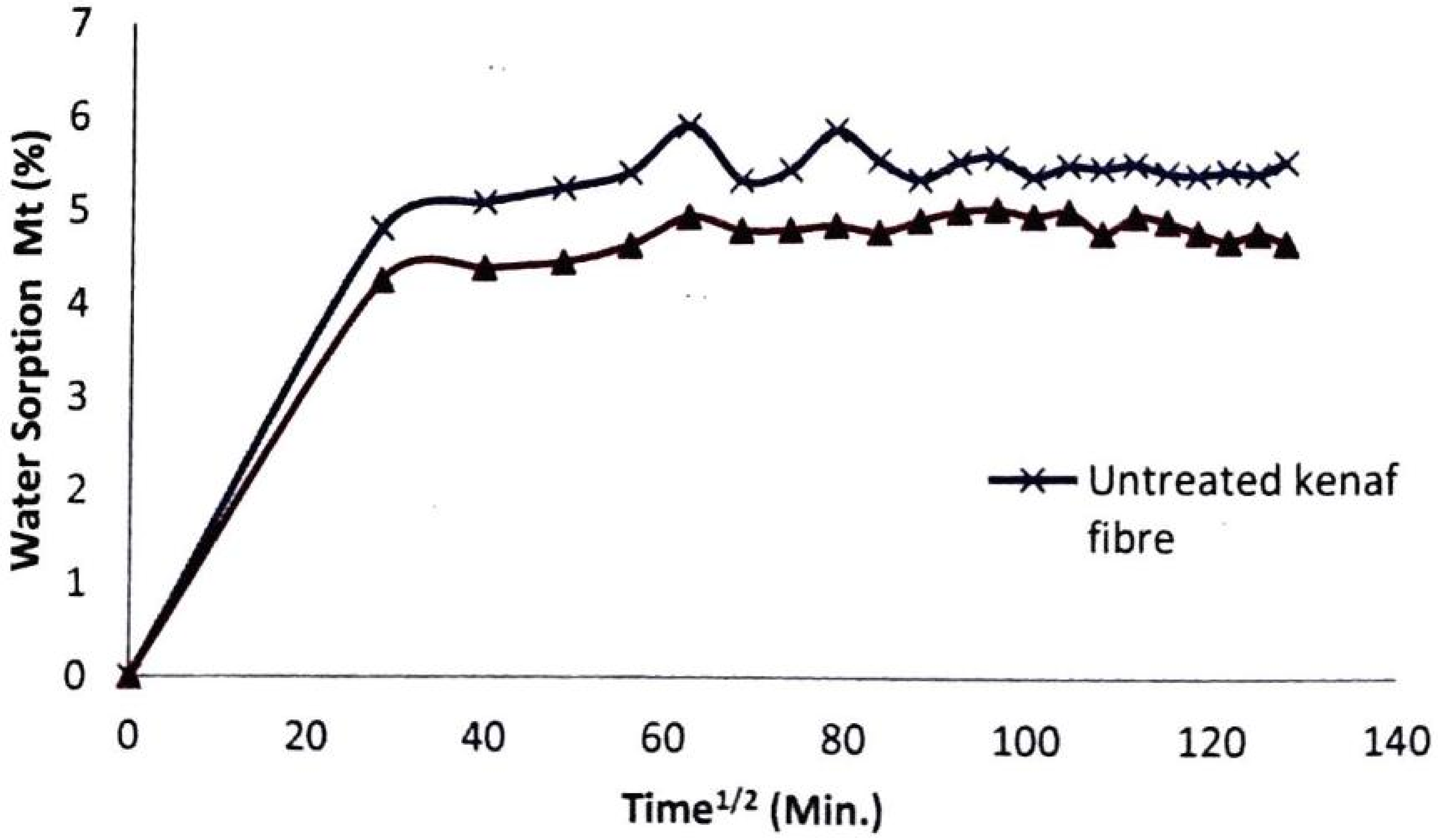


Figure 4: Water sorption curves for distilled water/treated and untreated Kenaf fibre.

Table 4: Values of M_∞ for the treated and untreated Kenaf fibres in distilled water

Treatment	M_∞ (%)
Untreated	5.38
Treated	4.64

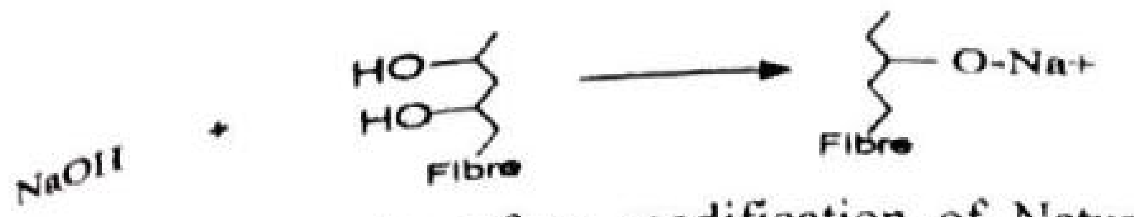
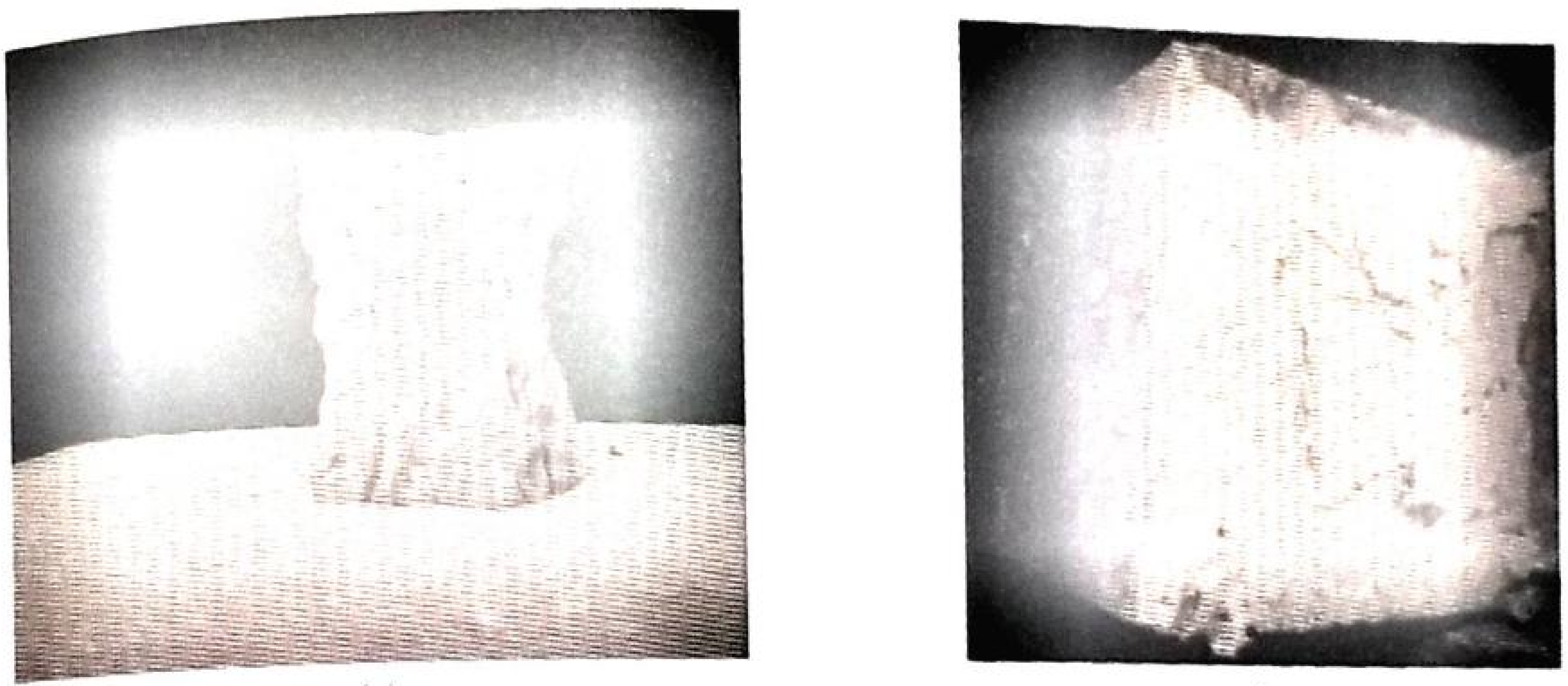


Figure 5: Chemical surface modification of Natural (cellulose) fibres using Alkali treatment.

Compressive Strength

Figure 6, 7 and 8 presents the influence of fibre content and fibre length on compressive strength. Compressive strength decreased with higher fibre content and increased with longer fibres. Because of increase in fibre content, compressive strength reduced up to 66% when compared to that of PC. This may be caused by creation of air voids because of fibres with relatively high fibre content. Although the compressive strength of KBFCC was much affected by the presence of fibre, the failure mode, however, exhibited a considerable change from fragile to ductile state. Due to bridging effect of the fibre, the cubic specimens did not crush but held their integrity up to the end of the test. Figure 6(a&b) illustrates the typical failure mode of plain concrete and KBFCC.



(a) (b)

Figure 6: (a) Failure mode of PC (b) Failure mode of KBFCC

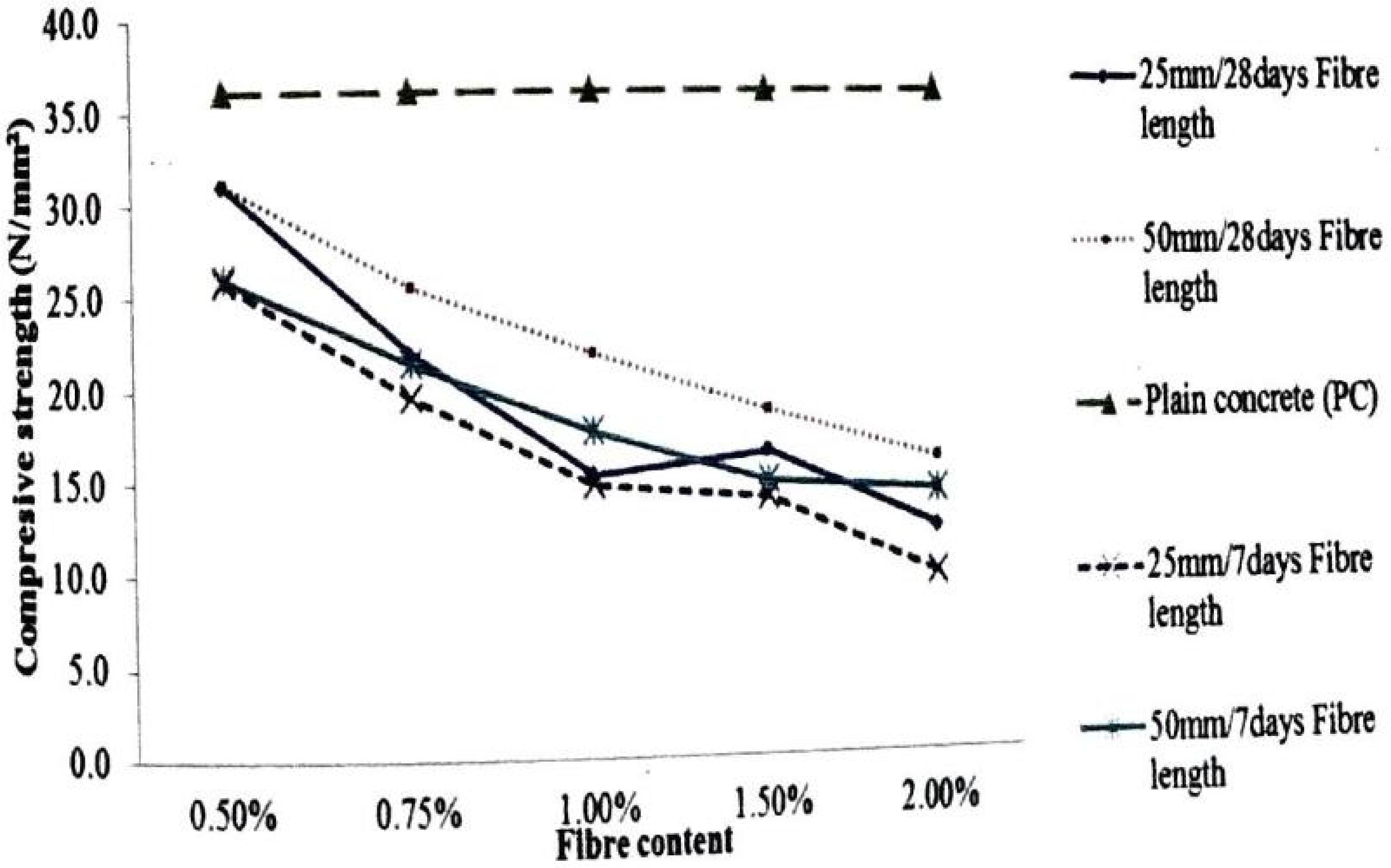


Figure 7: Influence of fibre content on the Compressive Strength

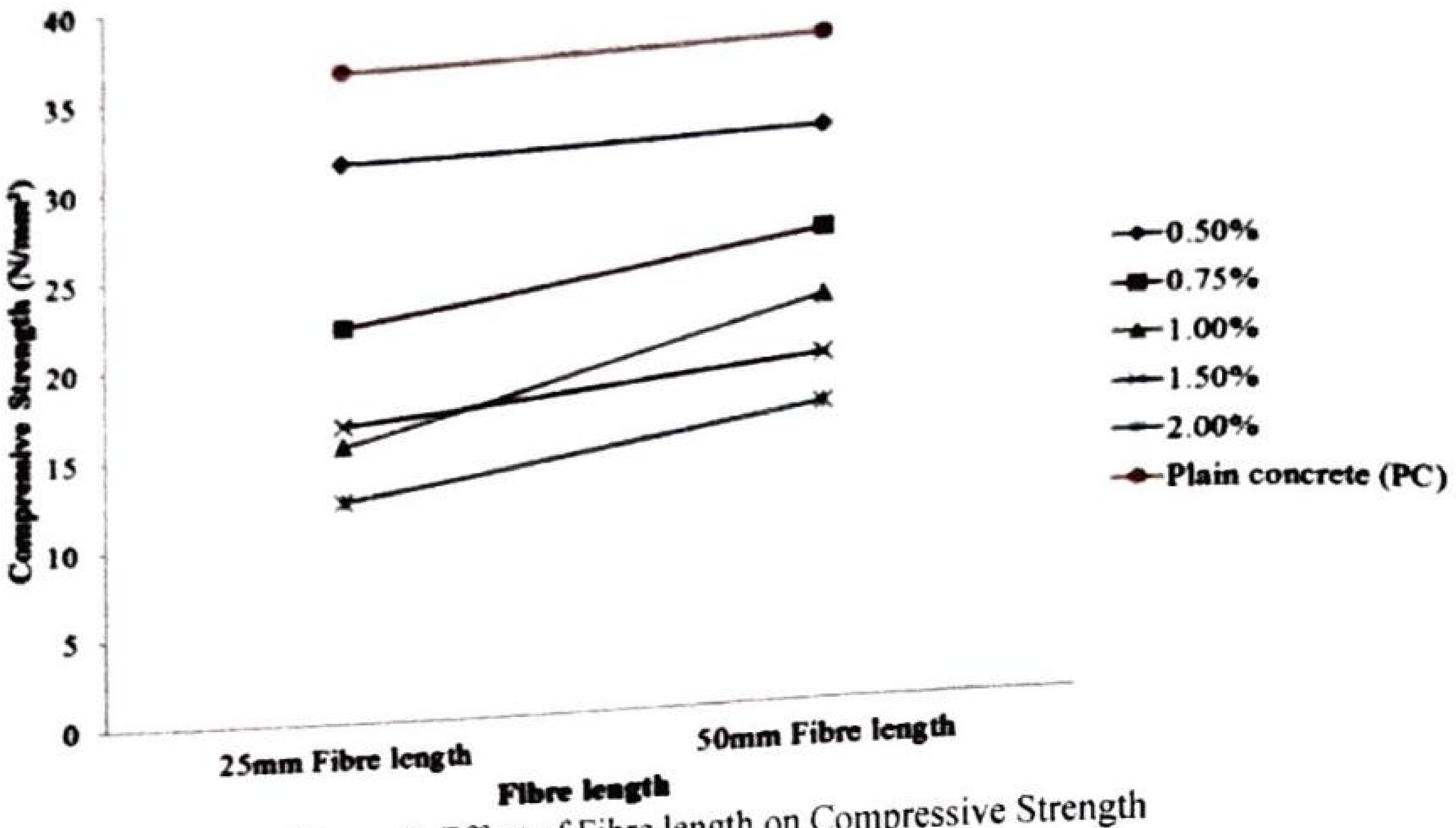


Figure 8: Effect of Fibre length on Compressive Strength

Ultrasonic Pulse Velocity

Figure 9 illustrates the Setup of the UPV test and the Operational sequence for obtaining UPV measurements of PC and KBFCC conducted at 7 days and 28 days for both 25 mm and 50 mm length fibre at varying fibre volume (0%-2%). It was observed that as the fibre content increases the value of UPV decreases (Figure 10). Though the UPV value of the PC and the KBFCC are within the range of 3798 - 4452 m/s, which is considered good based on the classification quality Criteria for Concrete on the basis of pulse velocity, as provided in BS 1881, 1983 standard.

Figure 11(a-d) illustrates the co-relation between the UPV value as a function of compressive strength of PC and the KBFCC. Compressive strength was used as a response parameter with the UPV as their predictor parameter. A positive relationship between the strength and UPV values of concrete can clearly be observed in these figures. A linear regression method was used to correlate the experimental data resulting in the equations shown in the figures, with a coefficient of determination R^2 lying between 0.90-0.99, which represents a good confidence relationship. The experimental data fitted well to the proposed equations as indicated by the coefficient of determination of R^2 lying in the region of 0.904-0.995. The correlations obtained are useful to determine the compressive strength of concrete containing Kenaf fibre using without necessarily undertaken compressive strength test in a laboratory. There appears to be a good correlation between compressive strength and ultrasonic pulse velocity of PC and concrete containing Kenaf fibre.

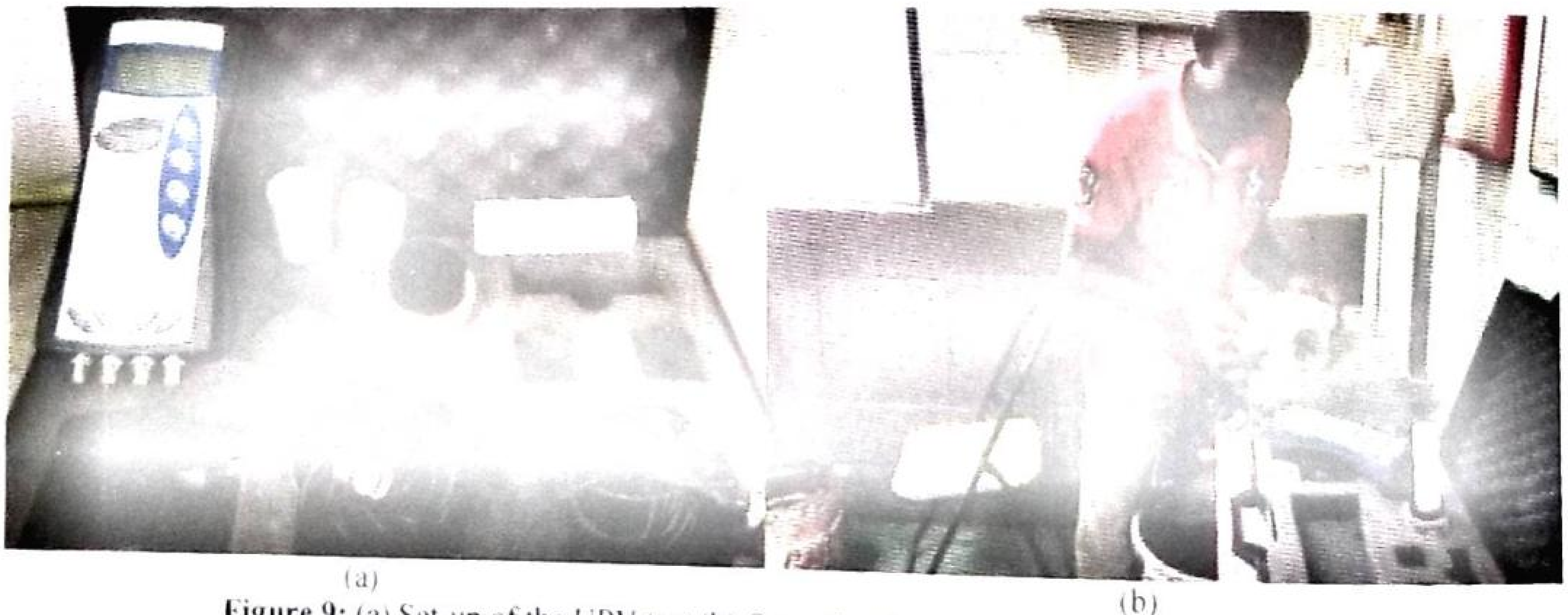

(a) (b)

Figure 9: (a) Set-up of the UPV test (b) Operational sequence for obtaining UPV

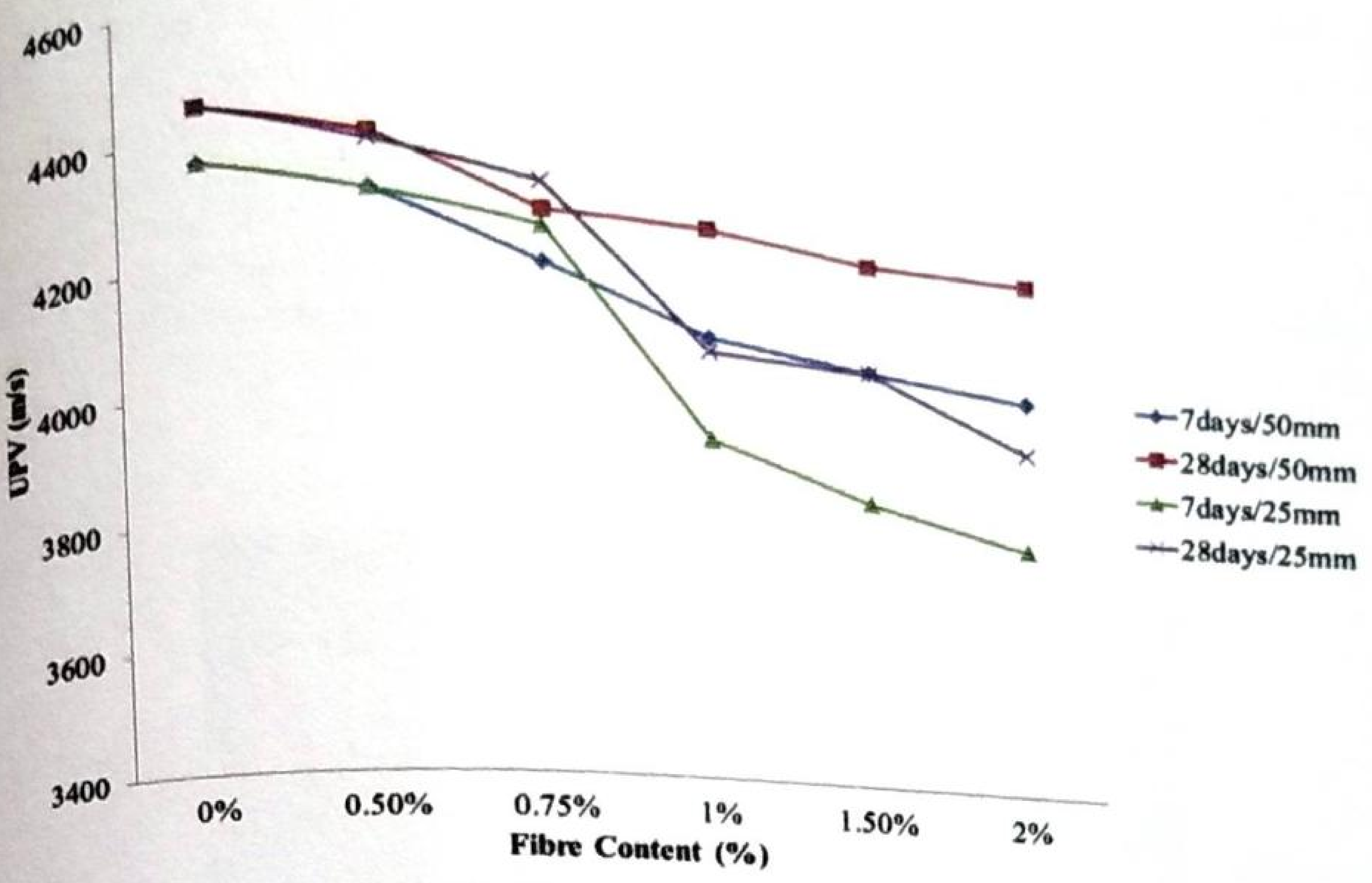


Figure 10: Effect of Fibre content on UPV of KBFCC

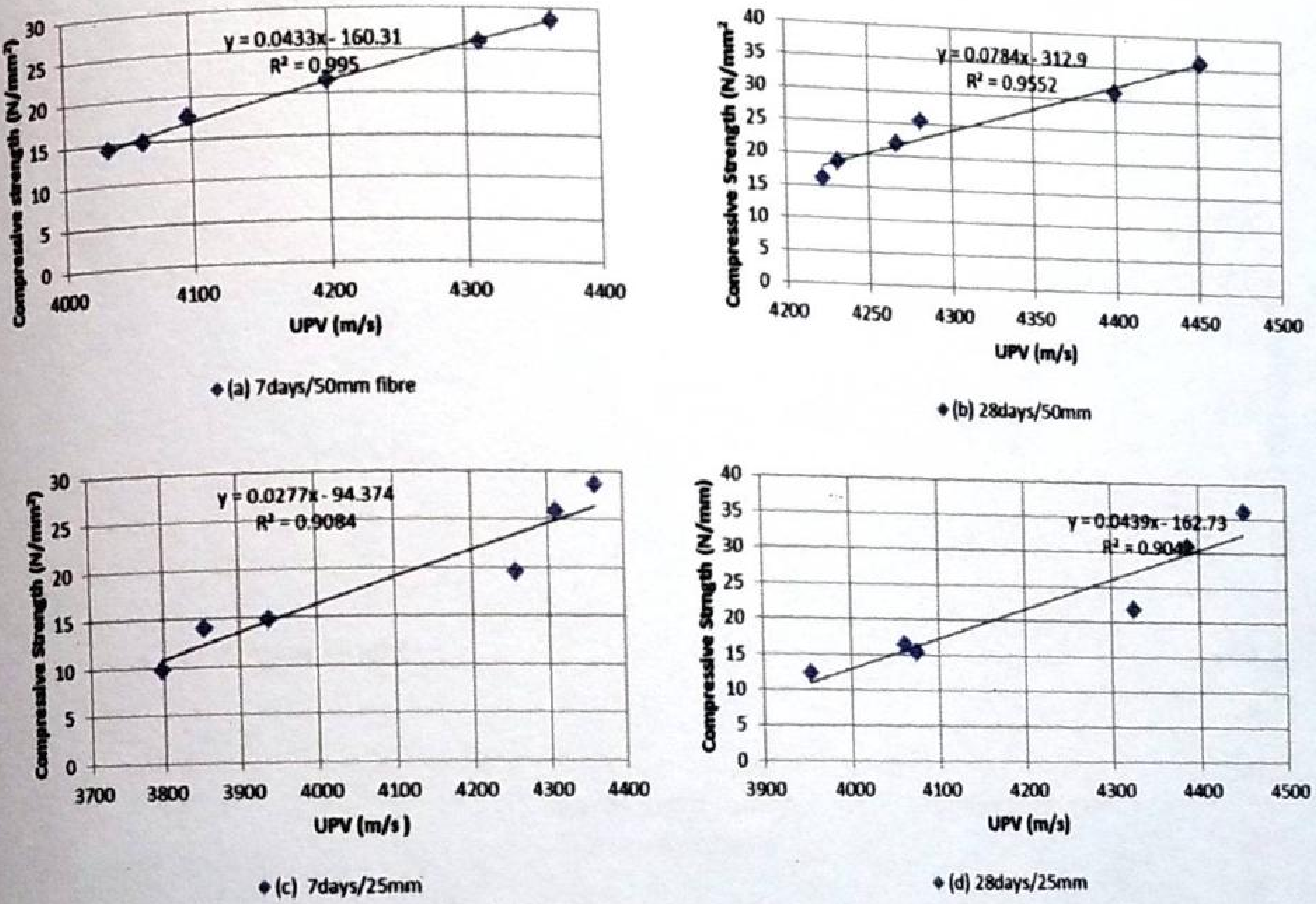


Figure 11: Correlation between UPV and Compressive strength of PC and KBFCC

Splitting Tensile Strength

The maximum load obtained from the test is taken for the calculation of splitting tensile Strength (STS). PC cylinders were broken into two halves at maximum load, while KBFCC cylinders were held together after cracks and even when the test was continued up to its maximum failure load for all KBFCC cylinders in order to observe the post peak load behaviour. The two pieces were held together up to the end of the test. One of the tested PC and KBFCC cylinder specimens are shown in Figure 12a and b. Figure 13 and 14 shows the influence of fibre content and length on STS of KBFCC. STS decreases with higher fibre content, however it first increases 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 fibre. Compared to the STS of PC, an addition of fibres can increase the splitting tensile strength 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. Hence, in all mixes, concrete with fibres volume fraction of 0.5%, fibre length of 50 mm (KBFCC-6) showed the maximum strength gain. The test results indicated that splitting tensile strength of KBFCC is about 2-5% higher than the control mixture. This showed a slight improvement in the splitting tensile strength of concrete as compared to compressive strength. The results obtained in this study are consistent with previous studies (Lam & Jamaluddin, 2015; Ali *et al.*, 2012; Hasan *et al.*, 2015).


(a) (b)

Figure 12: After splitting tensile test (a) PC specimen and (b) KBFCC specimen.

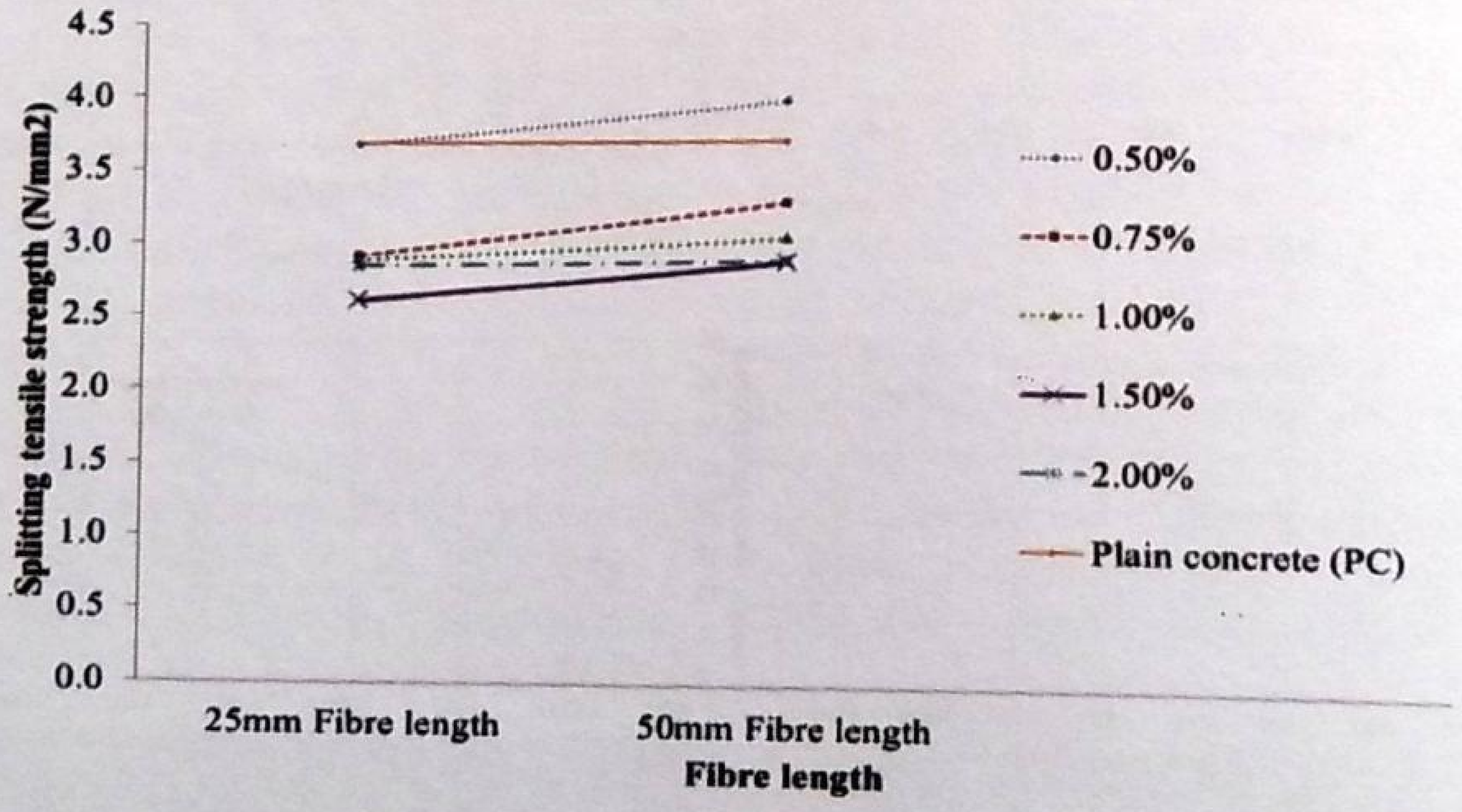


Figure 13: Effect of Fibre length on splitting tensile strength.

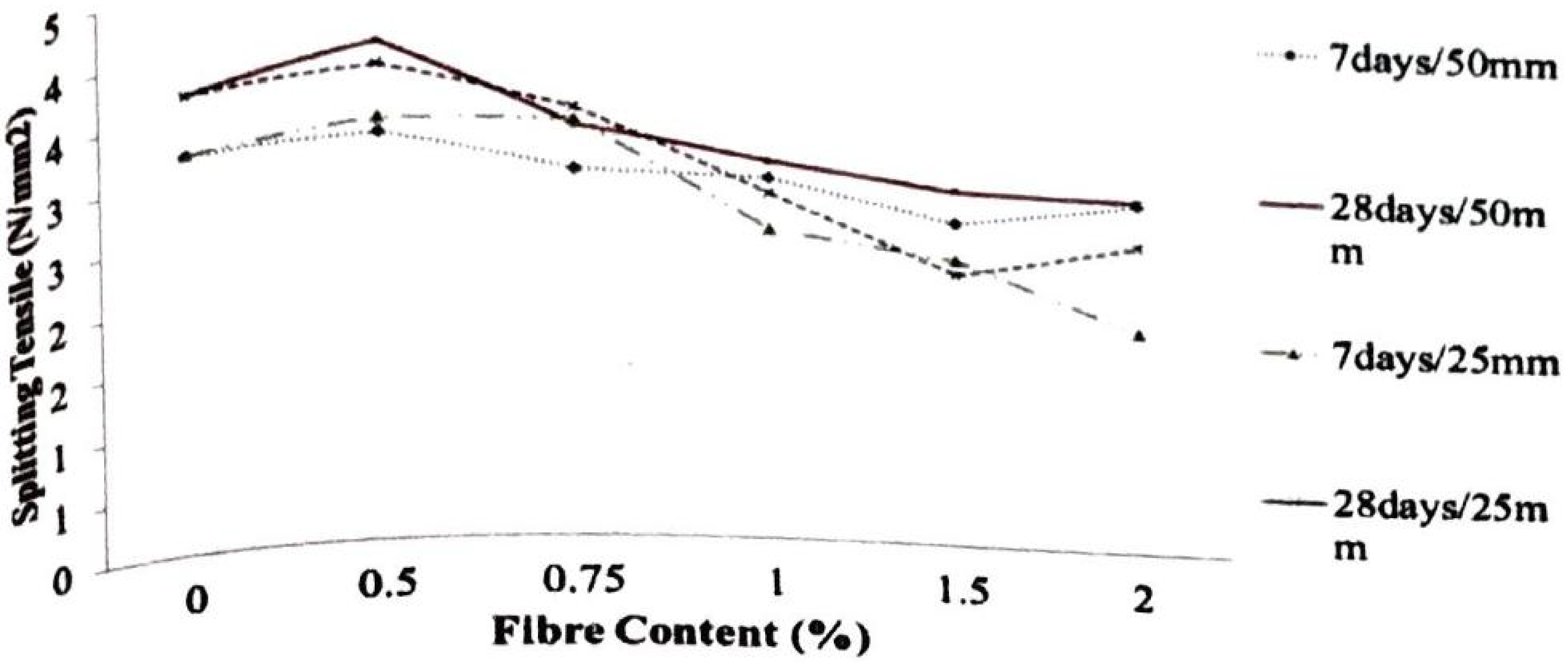


Figure 14: Influence of Fibre content on splitting tensile strength.

Flexural Strength

Fibres are added to concrete to inhibit the propagation of cracks which occurs due to concrete low tensile strength. PC specimens was observed to fail catastrophically by a single crack and parting into two pieces (Figure 15a). But on the contrary, the fibrous concrete specimens made of Kenaf fibre, even those with small fibre volume fraction were seen to retain post cracking ability to carry loads. Few short and narrow cracks were observed on almost all the KBFCC samples (Figure 15b). The maximum load obtained from the Flexural strength tests on PC and KBFCC is taken for the calculation of modulus of rupture (MOR). Figure 15c shows the spread of Kenaf fibre bridging the cracked space. Figure 16 and 17 displays the influence of hydration days, fibre content and length on Modulus of Rupture (MOR). Compared to PC, the value of MOR of KBFCC with 0.5% fibre content and 50 mm long fibres increased slightly up to 7%.

Time dependent Properties

Figure 18 illustrates the compressive creep strain for plain and Kenaf biofibrous concrete composite subjected to a load intensity of 40% of their compressive strength. From the test results obtained, it can be seen that the presence of fibres could significantly change the compressive creep behaviour of concrete. In the case of the specimen with a fibre volume fraction of 0.5% (KBFCC-6), the strain deformation was considerably lower than that of the plain concrete specimen (PC) with a reduced value of 23.1% at 86 days of sustained loading.

It was also observed that the KBFCC sample also exhibited improved ductility deformation behaviour when compared to the PC sample that had crack on its surface after the loading days.

Figure 15: Failure mode of prism in Flexure (a) PC specimen (b) KBFCC specimen (c) Kenaf fibre bridge across the crack space

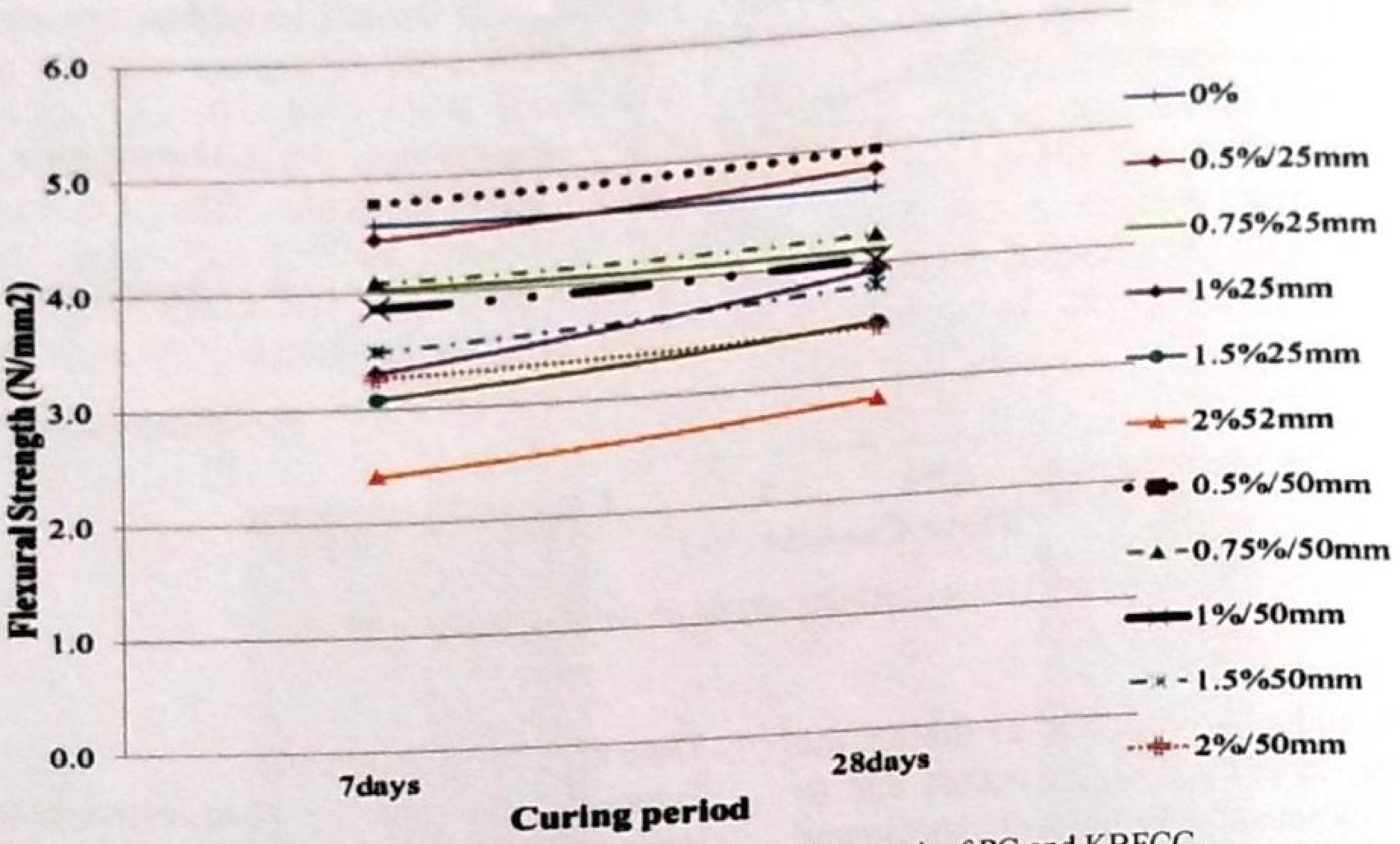


Figure 16: Effect of curing age on the flexural Strength of PC and KBFCC.

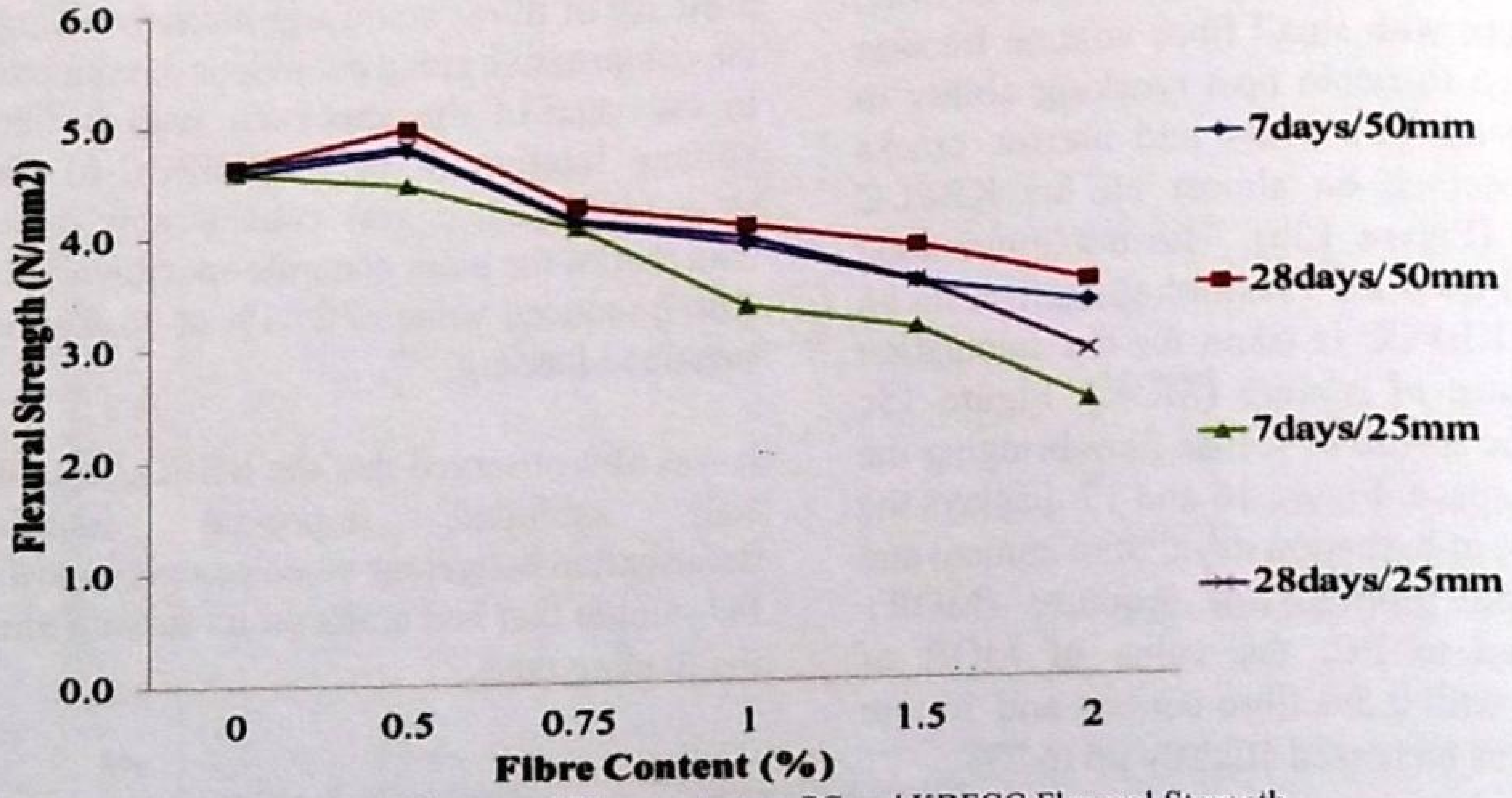


Figure 17: Influence of Fibre content on PC and KBFCC Flexural Strength.

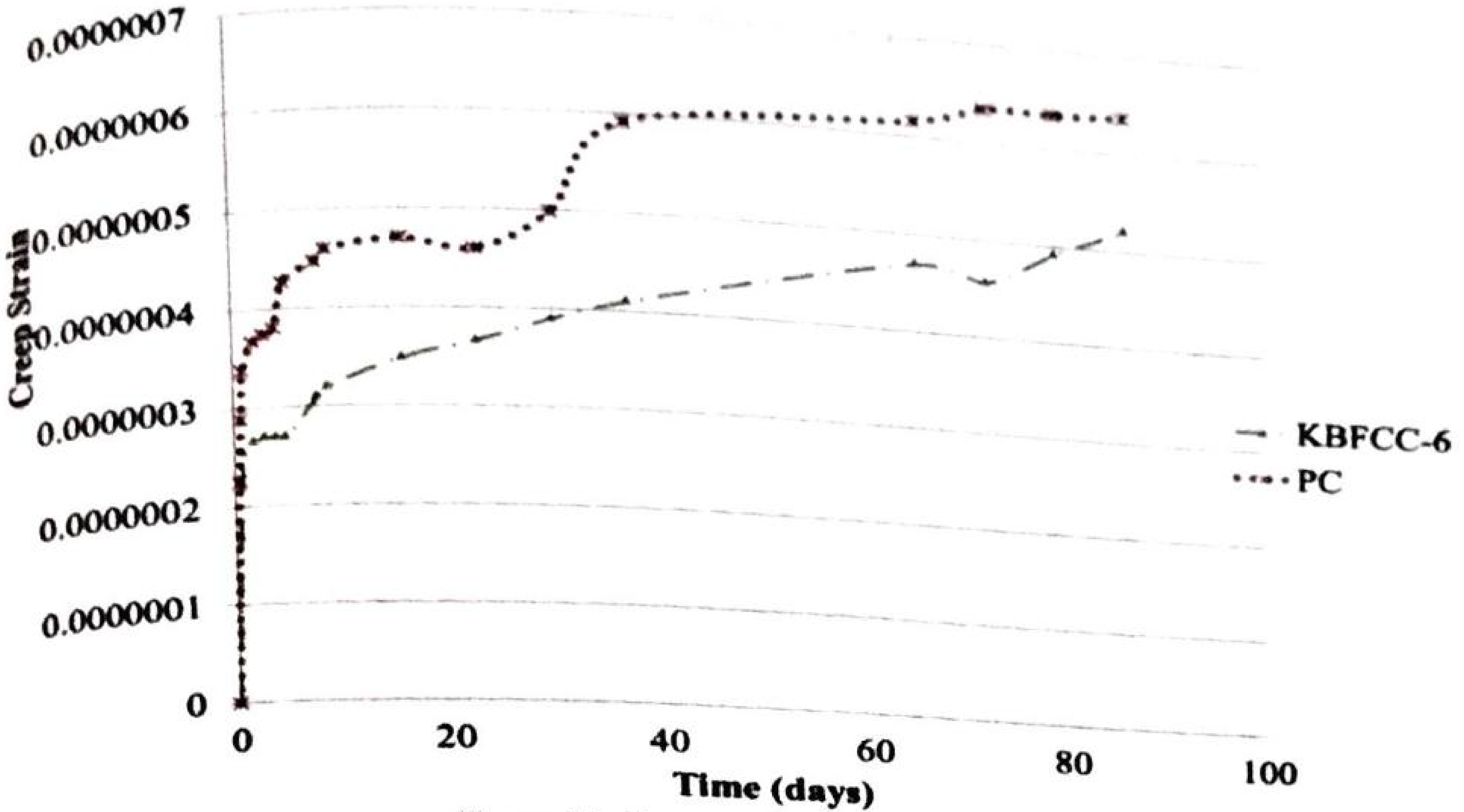


Figure 18: Compressive creep strain profile

Conclusions

In conclusion, the inferences drawn from the results and observations in this study are stated below:

1. Kenaf fibre inclusion in PC, significantly affects the workability of concrete. The workability of concrete mixes decreased with the increase in fibre length and volume fraction (V_f) of fibre.
2. Kenaf fibre has been found to improve the tensile strength of concrete. This improvement has been shown to be prominent in case of splitting tensile and flexural strength as compared to that of compressive strength. Generally, the 50mm length fibre and 0.5% V_f gave the optimum performance and strength development.
3) There has been a good co-relation between compressive strength and ultrasonic pulse velocity of concrete. Like that in other reinforced concrete, the ultrasonic pulse velocity of this concrete was found to increase with the increase of compressive strength and vice versa.
4) The overall findings in this study suggest that the Kenaf fibre has a good potential as reinforcing material.
5) In terms of Long-term investigation (time dependent properties) including deformation behaviour and durability aspects of concrete, KBFCC has proved sustainable and performed well under sustained compressive load.
6) This study offered valuable data that can be used to evaluate performance with respect to strength properties and creep coefficient (compressive creep,) of structural concretes made from KBFCC.

References

Agrawal, R., Saxena N.S., Sharma, K.B., Thomas S. & Sreekala, M.S. (2000). Activation energy and crystallization kinetics of untreated and treated oil palm fibre reinforced phenol formaldehyde composites. *Materials Science and Engineering*. 277, 77–82.

Amar K.M., Manjusri M. & Lawrence T.D. (2005*). Natural fibres, biopolymers, and biocomposites*. UK: Taylor and Francis Group.

Awal A.S.M.A., Mazlan, D. & Mansur, M.L. (2011) Utilisation of Soft Drink Can as Reinforcement in Concrete. *Proceedings of 3rd International Conference of EACEF (European Asian Civil Engineering Forum)* Universitas Atma Jaya Yogyakarta, Indonesia, September 20-22, B15-B20.

Awal A.S.M.A., Yee, L.L., & Hossain, M.Z. (2013). Fresh and Hardened Properties of Concrete Containing Steel Fibre from Recycled Tire. *Malaysian Journal of Civil Engineering*, 25(1), 20-32.

Balaguru P. & Shah S.P. (1992). *Fibre reinforced cement composites*. McGraw-Hill, USA.

Bentur A. & Mindess S. (1990). *Fibre Reinforced Cementitious Composites*. New York: Elsevier Applied science.

Bicanic N., Borst, R., Mang, H., & Meschke, G. (Eds). (2011). *Computational Modelling of Concrete Structures.* Balkema: CRC Press.

Bilba K., Arsene, M.A., & Ouensanga, A. (2007). Study of Banana and Coconut Fibers Botanical Composition, Thermal Degradation and Textural Observations. *Bioresource Technology*, 98, 58–68.

Buratti N. & Mazzotti, C. (2012). Effects of different types and dosages of fibres on the long-term behaviour of fibre-reinforced self-compacting concrete. In *Proceedings of the 8th RILEM Symposium on Fibre Reinforced Concrete: Challenges and opportunities (BEFIB 2012)*, Guimarães, Portugal, September 2012, Barros Ed.

Buratti N., Mazzotti, C. & Savoia, M. (2011). Post-cracking behaviour of steel and macrosynthetic fibre-reinforced concretes. *Construction and Building Materials*, 25(5), 13–22.

Elie A., Bilal, H., Mounir, M., & Helmi, K. (2010). Sustainable Construction materialUsing Hemp Fibres–Preliminary Study. *Second International Conference on Sustainable Construction Materials and Technologies*, June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.

Elie A., Mounir, M, Bilal, H., & Helmi, K. (2011) Preliminary Studies on the Use of natural Fibres in Sustainable Concrete. *Lebanese Science Journal*, 12(1), 109-117

Elsaid A., Dawood, M., Seracin, R., & Bobko C. (2011). Mechanical properties of Kenaf fiber reinforced concrete. *Construction and Building Materials*, 25(4), 1991–2001

Hannant D.J. (1987). *Fibre Cements and fibre Concrete*. Chichester: Wiley

Hasan N.S., Sobuz H.R., Auwalu, A.S., & Tamanna, N. (2015). Investigation into the suitability of Kenaf fiber to produce structural concrete. *Advance Material Letters*, 6(8), 731-737

Hatta M., Nasrul, M., Akashah, M. & Akmar, N. (2008). Mechanical properties of polystyrene/polypropylene reinforced and jute fibre, In: CUTSE International Conference.

Lam T.F. & Jamaludin M.Y. (2015). Mechanical properties of Kenaf fibre reinforced concrete with different fibre content and fibre length. *Journal of Asian Concrete Federation*, 1(1), 11- 20.

Mehta P.K. & Monteiro, P.J.M. (2006). *Concrete: Microstructure, Properties and Materials*, UK: The McGraw-Hill Companies Inc.

Mobasher B., Ouyang, C. & Shah, S.P. (1991). Modeling of fibre toughness in cementitious materials using an R-curve approach. *International Journal of Fracture*, 50, 199–219.

Mobasher B. & Shah, S.P. (1990). Interaction between fibres and the matrix in glass fibre reinforced concrete Thin-Section Fibre Reinforced Concrete and Ferrocement, Am. Concr. Inst., SP, 124, American Concrete Institute, Detroit, MI, 137–156.

Mohd H.A.B., Arifin A., Nasima J., Hazandy A.H. & Khalil A. (2014). Journey of Kenaf in Malaysia: A Review. *Scientific Research and Essays*, 9, 458–470.

Najafi S. K. & Kordkheili H. Y. (2011). Effect of sea water on water absorption and flexural properties of wood-polypropylene composites. *European Journal of Wood and Products*.

Ogunbode E.B., Jamaludin M.Y., Ishak M.Y., Masoud R. & Meisam R. (2015). Potential of Kenaf fibre in bio-composite production: A review. *Jurnal Teknologi (Sciences and Engineering)*, 77, 23-30.

Ogunbode E.B., Jamaludin M.Y., Ishak M.Y., Hazlan A.H., Azmahani A.A. & Masoud R. (2016). Compressive creep of Kenaf bio-fibrous concrete composite under one dimensional stressing. *Malaysian Journal of Civil Engineering*, 28 SI (3), 279-289.

Ogunbode E.B., Egba E.I., Olaiju O.A., Elnafaty A.S. & Kawuwa S.A. (2017).Microstructure and mechanical properties of green concrete composites containing coir fibre, *Chemical Engineering Transactions*, 61, 1879-1884.

Ogunbode E.B., Egba E.I., Olaiju O.A., Johnson C.N., Amusuk D.J. & Dodo Y.A. (2018). Determining the properties of green laterized concrete with fly ash for sustainable solid waste management. *Chemical Engineering Transactions*, 63, 649-654.

Ogunbode E.B., Jamaludin M.Y., Hazim A., Azmahani A.A., Ishak M.Y. & Hazlan A.H. (2019). An evaluation of the interfacial bond strength of Kenaf fibrous concrete and plain concrete composite. *International Journal of Built Environment and Sustainability*, 6(1), 1-6.

Oh B.H., Kim, J.C. & Choi, Y.C. (2007). Fracture behaviour of concrete members reinforced with structural synthetic fibres. *Engineering Fracture Mechanics,* 74, 243–357.

Oh B.H., Park, D.G., Kim, J.C. & Choi, Y.C. (2005). Experimental and theoretical investigation on the postcracking inelastic behaviour of synthetic fibre reinforced concrete beams. *Cement and Concrete Research,* 35. 384–392.

Ramaswamy, G.N., Craft, S. & Wartelle, L., (1995). Uniformity and softness of Kenaf fibres for textile products. *Textile Research Journal*, 65(12), 765.

Soroushian, P., Khan, A. & Hsu, J.W. (1992). Mechanical properties of concrete materials reinforced with polypropylene or polyethylene fibres. *ACI Mater. J.*, 89 (2), 535–540.

Sreekala M. S., Kumaran M.G. & Thomas S. (2002). Water sorption in oil palm fibre reinforced phenol formaldehyde composites. *Composites Part A: Applied Science and Manufacturing*, 33,763-777

Sreekala, M. S. & Thomas S. (2003). Effect of fibre surface modification on water-sorption characteristics of oil palm fibres. *Composites Science and Technology*, 63(6), 861-869.

Suji D., Natesan S.C. & Murugesan R. (2007). Experimental study on behaviour of polypropylene fibrous concrete beams. *Journal of Zhejiang Univ Sci A*, 8(7), 101–19.

Tan, K. L. (1996). Long Term Deformation of Portland Blast furnace slag cement concrete. Unpublished Master of Engineering thesis, National University of Singapore.

Tan K. H., Paramasivam P. & Tan, K. C. (1994). Creep and shrinkage deflections of RC beams with steel fibres. *Journal of Materials in Civil Engineering*, 6(4), 474-494.

Tejchman J. & Kozicki J. (Eds). (2010). *Experimental and Theoretical Investigations of Steel-Fibrous Concrete*. Verlag Berlin Heidelberg: Springer.

Thielemants W. & Wool R.P. (2013). Butyrated Kraft lignin as compatibilizing agent for natural fibre reinforced thermoset composites. *Composite Part A: Applied Science and Manufacturing*, 35, 327-338.

Toledo R.F., Ghavami K., England G.L. & Scrivener K. (2003). Development of vegetable fibre-mortar composite of fibre-mortar composites of improved durability. *Cement and Concrete Composite*, 25, 185-196.

Udoeyo F.F. & Adetifa, A. (2012). Characteristics of Kenaf Fibre-Reinforced Mortar Composites. *International Journal of Research and Reviews in Applied Sciences*. 12(1), 18-26.

Zabihzadh M. S. (2010). Flexural properties and orthotropic swelling behaviour of bagasse/thermoplastic composites. *Peer reviewed article*, 5(2), 650-660.

Zollo R.F. (1997). Fibre-reinforced concrete: an overview after 30 years of development. *Cement and Concrete Composite*, 19(2), 107–122.