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Mechanical properties of kenaf fiber reinforced concrete with different fiber content and fiber length

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Abstract: The purpose of this paper is to discuss the findings of an experimental research conducted on the effects of fiber content and fiber length on the mechanical properties of kenaf fiber reinforced concrete (KFRC). The experimental results can be set as the foundation for the future research related to the development of KFRC as a sustainable and green construction material. In this study, compressive strength, splitting tensile strength, and flexural strength of KFRC are determined experimentally and the properties of plain concrete are used as a reference. The treated bast kenaf fibers with the alkaline solution of pH 13 is used as the reinforcement in concrete. The influence of five fiber contents (0.5%, 0.75%, 1.0%, 1.5%, and 2.0%) by volume of concrete and two fiber lengths (25 mm and 50 mm) to the KFRC are investigated. Concrete of Grade 30 strength is used and designed by using DOE method. This research is conducted according to British Standard (BS) and American Society for Testing and Materials (ASTM). The results indicate that the workability of KFRC is reduced compared to plain concrete. In terms of mechanical properties of KFRC, the results showed that the compressive strength decreased with increase in fiber content. However, the study also found that, by adding appropriate fiber content and fiber length in concrete, the flexural strength and indirect tensile strength of concrete can increase and, at the same time, the KFRC can have similar compressive strength to the plain concrete. Further, KFRC generally exhibits more resistance to cracking and toughness than the plain concrete.

Keywords: kenaf (Hibiscus cannabinus L.), kenaf fiber, natural fiber, mechanical strength, kenaf fibrous concrete.

1. Introduction

Concrete is undoubtedly the most widely used construction material in the world, and it is expected to be so in the future. Substantial research and development activities have been undertaken in the area of concrete engineering and technology to investigate and discover the characteristics of advanced materials, structure behaviour and applications, and the construction practices of concrete. However, one of the major challenge in construction industry is the high production of carbon dioxide during the manufacture of the Portland cement. Elsaid et al. [1] cited the work of Mohanty et al. [2] who studied the properties of natural fibers, biopolymers, and composites. Existing study results indicate that the kenaf plant had the best level of absorption of carbon dioxide among all of the plants studied, kenaf plant can absorbs 1.5 times of carbon dioxide by its weight. So, the use of kenaf fibers in concrete would reduce the amount of carbon dioxide in atmosphere. It may be one of the solution to overcome the problem of high carbon dioxide released during the manufacture of Portland cement. Therefore, KFRC is a green and sustainable material.

1.1 Kenaf plant and fiber

Kenaf (Hibiscus cannabinus L.) is a species of Hibiscus that can be found in southern Asia. Kenaf is a warm season annual fiber crop closely related to cotton and jute. The other names of kenaf are Ambary, Bimli, Deccan Hemp, Ambari Hemp, and Bimlipatum Jute [3]. Kenaf has a single, straight and branchless stalk. Kenaf stalk consists of two types of fiber, an inner woody core and an outer fibrous bast around the core. Bast is a coarser fiber in the outer layer while core fiber is a finer fiber in the core. Kenaf grows quickly and rise to heights of 4-5 m and 25-35 mm in diameter in a 4-5 month growing season. Historically, kenaf has been used as a cordage crop to produce twine, rope, and sackcloth. The reason why there are very high interests

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in kenaf cultivation in recent years are because kenaf has the ability to absorb nitrogen and phosphorus included in the soil and also can accumulate carbon dioxide at a high rate [4]. There are several studies conducted to identify the basic tensile properties of kenaf bast fiber [5,6]. The finding of the studies show that the average tensile strength of kenaf fibers ranges from 157 MPa to 600 MPa. The average ultimate tensile strain and elastic modulus of the fibers range from 0.015 to 0.019 and 12,800 MPa to 34,200 MPa respectively. The finding indicates that the tensile properties of kenaf fibers are comparable to those of other natural fibers, such as jute, flax, and bamboo, which have been previously used to produce natural fiber reinforced concrete.

1.2 Fiber surface treatment

The efficiency of the fiber-reinforced composites depend on the fiber-matrix interface and the ability to transfer stress from the matrix to the fiber [1]. However, the drawbacks in natural fibers like high moisture absorption lead to their low mechanical properties and poor fiber-matrix adhesion in composites, and limit their applications. Hence natural fibers need to be treated by physical and chemical methods to change their structural properties and improve its mechanical properties. Various chemical treatments have been used by many researchers in the past. The literature results show that the alkali treatment is a commonly used method to clean and modify the fiber surface and enhance interfacial adhesion between a natural fiber and a polymeric matrix [2,3]. Mohanty S. et al. [7] reported that fibers are treated with NaOH to remove lignin, pectin, wax substances, and natural oils that cover the surface of the fiber cell wall. Sgriccia et al. [8] confirmed that the alkali treatment removed the hemicellulose from the fiber. Mwaikambo and Ansell [9] have treated hemp, jute, sisal, and kapok fibers with various concentrations of NaOH solution. They found that 6% was the optimum concentration in terms of cleaning and fiber bundle surfaces and with high tensile strength. Besides that, from the findings of Edeerozey M. et al. [3], when the NaOH concentration was increased to 9%, the tensile strength of fibers exhibited a significant decrease. The intensity of 9% NaOH was too strong and might cause to damage the fibres, thus resulting in lower tensile strength. He also noted that 6% NaOH yields the optimum concentration of NaOH for the chemical treatment.

1.3 Natural fibrous concrete

According to ACI 544.1R-82 [10], fibrous concrete (FC) is defined as concrete made with hydraulic cement, containing fine or fine and coarse aggregate, and discontinuous discrete fibers. The fibers can be made from natural material or manufactured product. Fibrous concrete can be considered as material relatively short continuous fiber are randomly distributed throughout the matrix in order to overcome the problems brought about by the low tensile strength and strain capacity of a plain concrete mix. The properties of natural fibrous concrete are dependent on several numbers of factors including the type, length, and volume of fibers used. Previous research indicated that the fiber volume fraction required to provide significant improvement in the mechanical properties of cement composites was approximately 3% [11]. The study of jute fibrous concrete indicates that in general, compressive strength is not significantly affected by the additional of fibers, while tensile and flexural strength and toughness are all substantially increased [1].

Combining natural fiber with other resources provides a strategy for producing advanced composite materials that take advantage of the properties of both types of resources. The use of fibers in concrete was found to increase concrete strength and durability, and also to enhance the bond between fibers and matrix (cement binder) thus increasing the efficiency of fiber reinforcement [1]. Plain concrete is generally weak and brittle in tension compared to its capacity in compression, fiber reinforcing is a practical mean developed for a better control of the tensile performance as well as the tensile post-cracking and post-yield behaviors of concrete. Reinforcement by short and small diameter fibers to some extend can overcome these deficiencies. The randomly distributed fibers provide the material with significantly improved tensile strength, ductility, and toughness characteristics [12].

2. Experimental program

2.1 Materials preparation

2.1.1 Kenaf fiber

The kenaf fibers used in this study were obtained from National Tobacco Board at Kelantan, Malaysia. The bulk density of the fibers used was 1.2 g/cm^3. In order to modify and possibly improve the adhesion between the fibers and the matrix, the fibers were subjected to chemical treatment process involving soaking fibers in sodium hydroxide (NaOH) solutions of pH 13 for 3 hours before extracting the fibers. After decortications, the fibers were washed with distilled water until it reached pH

Fig. 1 – Kenaf fibers before treatment

Fig. 2 – Kenaf fibers after treatment

7 and then dried before chopping into lengths of 25 mm and 50 mm for incorporation into cement matrix. Chemical treatment was applied to enhance the bond between the organic fibers and the inorganic concrete matrix [1]. It also prevents degradation of the fibers in concrete and enhances the overall durability of the kenaf fibrous concrete. Kenaf fiber before and after treatment were shown in Figs. 1 and 2.

2.1.2 Cement

Holcim Top Standard brand of ordinary Portland cement - Type I cement conforming to ASTM C150 [13] was used. The cement has a specific gravity of 3.15, and initial and final setting time of 170 and 245 minutes, sulphate content of 2 % and chloride content of 0.01 %, respectively.

2.1.3 Aggregate

The coarse aggregate used in this study was granite. The maximum size required in this study was 10 mm. In order to obtain a quality mix of concrete, the aggregate used should be in dry condition. The fine aggregate used in this study was sand. It was a filler material in a sample of concrete mix to fill up all possible voids which appear in the mix. This may contribute to high compressive strength in a hardened concrete. Coarse and fine aggregate need to be sieved before added into concrete mix to ensure the uniformity of the particle size and to remove impurities. Sieve analysis of aggregate was conducted according to the ASTM C136 [14]. It wa sieved under air dry condition. The grain size distributions of the fine aggregate and coarse aggregate are shown in Figs. 3 and 4, respectively.

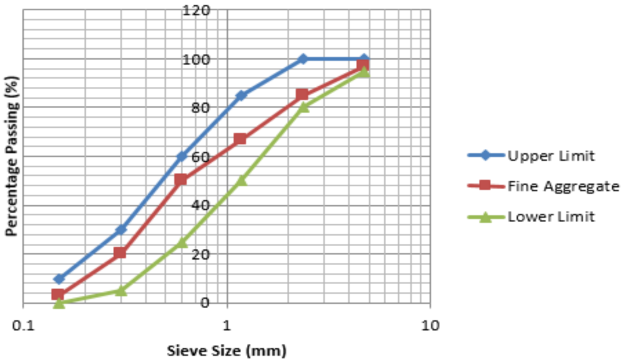

Fig. 3 – Sieve analysis for fine aggregate

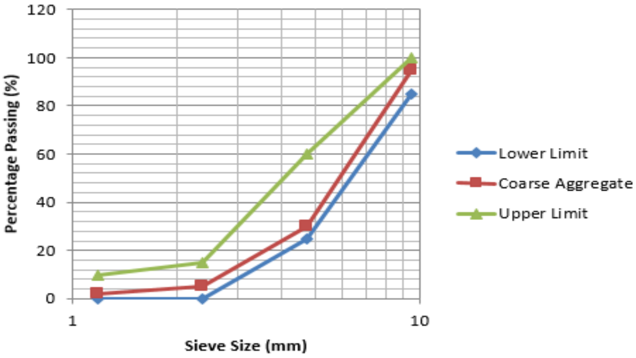

Fig. 4 – Sieve analysis for coarse aggregate

2.2 Specimens preparation

The concrete in this study was designed to achieve Grade 30 strength using DOE Method. Size of each cube was 100 mm x 100 mm x 100 mm. Cylinder mould size was 300 mm in height with 150-mm diameter, and rectangular beam mould size was 100 mm x 100 mm x 500 mm. Kenaf fiber was soaked in the water for 1 hour before it was added in the concrete, the amount of water used was determined from the absorption test conducted. The mix proportion for concrete specimens was listed in the Table 1. A total of 198 specimens were tested as outlined in Table 2. The mixing procedure adopted for all concrete mixes involve the following: (a) measure aggregate and cement and mix them thoroughly until homogeneous mix is achieved; (b) add measured quantity of water and mix the whole lot until a workable mix is obtained; and (c) add required quantity of fiber and mix carefully to a point of uniformity. All mixing and compaction were done by using the concrete vibrator. From each mix samples were taken for slump tests.

Before the casting, the mould was cleaned and grease was applied to the inner part of the concrete moulds before the fresh concrete was added into the mould to ease the removal of the hardened concrete. During the mixing process, the sand, aggregate, and cement were mixed with water before the kenaf

Table 1 – Kenaf fibrous concrete mixture proportions

Type of concrete	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)	W/C ratio	Kenaf fiber (kg/m^3)
Normal	418	710	1022	230	0.55	-
KFRC	418	710	1022	230	0.55	1200

fibers were added in to the concrete mix to avoid the kenaf fibers from absorbing the water.

The hardened concrete can be removed from the mould after one day from the casting date under room temperature. All samples were then soaked in the water for curing process. The curing process was conducted according to BS 1881, part 111 (1983) [15]. The curing age of the concrete in this research was set to be 7 days and 28 days. After the curing, the samples are then ready for different type of mechanical properties test. The specimens were tested in a surface dry condition.

2.3 Laboratory testing

In order to achieve the objective of the study, laboratory test were conducted. The test were conducted based on a range of tests such as slump test of fresh concrete and compressive strength test, flexural strength test, and indirect tensile strength test to investigate the mechanical properties of the hardened concrete.

2.3.1 Water absorption test

The water absorption study of kenaf fibers was done in accordance with ASTM D570-98 [16]. The water absorption was calculated as:

$$\text{Water absorption (\%)} = [(w_2 - w_1)/w_1] \times 100 \quad (1)$$

where, w_1 is the initial weight of oven dried kenaf fiber before water absorption and w_2 is the weight of kenaf fiber after water absorption.

2.3.2 Slump test

The test was conducted according to standard as stated in BS 1881 part 102(1983) [17]. This test needs mould in cone shape with dimension of 200 mm at bottom and 100 mm at the top and 300 mm of height. The cone with inside surface damped was placed on a smooth, flat, non-absorb surface and the cone was filled with fresh concrete in three layers where each layer took about one third of the volume of the cone mould. Every layer was tamped throughout its depth 25 times with a 16-mm diameter and 610-mm long tamping rod. When the cone was full with concrete, the mould was immediately removed by raising it vertically with a steady upward lift. The number of mm the original center of the cone sink or settle uniformly was measured.

If instead of slumping evenly all round, as in a true slump, one-half of the cone slides down an inclined plane, a shear slump was said to have taken place, and the test should be repeated. If shear slump persists, as may be the case with harsh mixes, this was an indication of lack of cohesion of the mix. Fig. 5 shows different types of slump.

2.3.3 Hardened concrete density

The density, expressed in kg/m^3, was the ratio between the weight (the mass) of a given sample of the concrete and its volume. The study was done in accordance with ASTM C642 -13 [18]. The density was expressed as:

$$\rho = m/v \quad (2)$$

where,
ρ = density, kg/m^3
m = mass of the specimen, kg
v = volume of the specimen, m^3

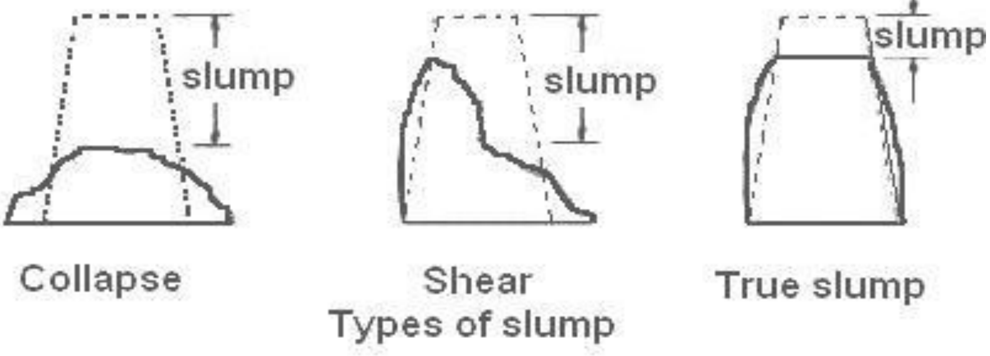

Fig. 5 – Types of slump

Table 2 – Specimen preparation for laboratory tests

Specimen	Fiber content (%)	Fiber length (mm)	Curing duration	Properties tested	Number of samples	Specimen ID
SP1	0	0	7 days	Comp.	3	SP1-7-CS-1~3
				Tens.	3	SP1-7-TS-1~3
				Flex.	3	SP1-7-FS-1~3
			28 days	Comp.	3	SP1-28-CS-1~3
				Tens.	3	SP1-28-TS-1~3
				Flex.	3	SP1-28-FS-1~3
SP2	0.50	25	7 days	Comp.	3	SP2-7-CS-1~3
				Tens.	3	SP2-7-TS-1~3
				Flex.	3	SP2-7-FS-1~3
			28 days	Comp.	3	SP2-28-CS-1~3
				Tens.	3	SP2-28-TS-1~3
				Flex.	3	SP2-28-FS-1~3
SP3	0.50	50	7 days	Comp.	3	SP3-7-CS-1~3
				Tens.	3	SP3-7-TS-1~3
				Flex.	3	SP3-7-FS-1~3
			28 days	Comp.	3	SP3-28-CS-1~3
				Tens.	3	SP3-28-TS-1~3
				Flex.	3	SP3-28-FS-1~3
SP4	0.75	25	7 days	Comp.	3	SP4-7-CS-1~3
				Tens.	3	SP4-7-TS-1~3
				Flex.	3	SP4-7-FS-1~3
			28 days	Comp.	3	SP4-28-CS-1~3
				Tens.	3	SP4-28-TS-1~3
				Flex.	3	SP4-28-FS-1~3
SP5	0.75	50	7 days	Comp.	3	SP5-7-CS-1~3
				Tens.	3	SP5-7-TS-1~3
				Flex.	3	SP5-7-FS-1~3
			28 days	Comp.	3	SP5-28-CS-1~3
				Tens.	3	SP5-28-TS-1~3
				Flex.	3	SP5-28-FS-1~3
SP6	1.00	25	7 days	Comp.	3	SP6-7-CS-1~3
				Tens.	3	SP6-7-TS-1~3
				Flex.	3	SP6-7-FS-1~3
			28 days	Comp.	3	SP6-28-CS-1~3
				Tens.	3	SP6-28-TS-1~3
				Flex.	3	SP6-28-FS-1~3
SP7	1.00	50	7 days	Comp.	3	SP7-7-CS-1~3
				Tens.	3	SP7-7-TS-1~3
				Flex.	3	SP7-7-FS-1~3
			28 days	Comp.	3	SP7-28-CS-1~3
				Tens.	3	SP7-28-TS-1~3
				Flex.	3	SP7-28-FS-1~3
SP8	1.50	25	7 days	Comp.	3	SP8-7-CS-1~3
				Tens.	3	SP8-7-TS-1~3
				Flex.	3	SP8-7-FS-1~3
			28 days	Comp.	3	SP8-28-CS-1~3
				Tens.	3	SP8-28-TS-1~3
				Flex.	3	SP8-28-FS-1~3
SP9	1.50	50	7 days	Comp.	3	SP9-7-CS-1~3
				Tens.	3	SP9-7-TS-1~3
				Flex.	3	SP9-7-FS-1~3

			28 days	Comp.	3	SP9-28-CS-1~3
				Tens.	3	SP9-28-TS-1~3
				Flex.	3	SP9-28-FS-1~3
SP10	2.00	25	7 days	Comp.	3	SP10-7-CS-1~3
				Tens.	3	SP10-7-TS-1~3
				Flex.	3	SP10-7-FS-1~3
			28 days	Comp.	3	SP10-28-CS-1~3
				Tens.	3	SP10-28-TS-1~3
				Flex.	3	SP10-28-FS-1~3
SP11	2.00	50	7 days	Comp.	3	SP11-7-CS-1~3
				Tens.	3	SP11-7-TS-1~3
				Flex.	3	SP11-7-FS-1~3
			28 days	Comp.	3	SP11-28-CS-1~3
				Tens.	3	SP11-28-TS-1~3
				Flex.	3	SP11-28-FS-1~3

2.3.4 Compressive strength test

The test was conducted with universal testing machine as specified in test method of BS 1881, Part 116 (1993) [19]. Increasing compressive load was applied on the sampling cube with size of 100 mm x 100 mm x 100 mm until the sampling cube no longer withstood the load and thus, the maximum compressive load of the sampling cube was obtained.

2.3.5 Flexural strength test

The test was done by testing on concrete rectangular beam samples. It was conducted following the procedures according to standard as stated in BS 1881, Part 118 (1993) [20]. The concrete rectangular beams with size of 100 mm x 100 mm x 500 mm were tested. The specimen was centered in the third-point loading apparatus. The load was continuously applied at a specified rate until rupture. If fracture initiated in the tension surface within the middle third of the span length, the flexure strength (modulus of rapture) was calculated as

$$R = Mc/I = PL/bd^2 \qquad (3)$$

where,

R = flexure strength, MPa (psi),
M = maximum bending moment =$PL/6$,Nmm,
$c = d/2$, mm,
I = moment of inertia = $bh^3/12$, mm^4,
P = maximum applied load, which is distributed evenly (1/2 to each) over the two loading points, N (lb),
L = span length, mm (in.)
b = average width of specimen, mm
d = average depth of specimen, mm

Note that the third-point loading ensures a constant bending moment without any shear force applied in the middle third of the specimen. If fracture occurred slightly outside the middle third, the results could still be used with some corrections. Otherwise the results were discarded.

2.3.6 Indirect tensile test

The test was done by testing on concrete cylinder samples. It was conducted with universal testing machine as specified in test method of BS 1881, Part 117 (1993) [21]. In this test, a 150-mm diameter and 300-mm height concrete cylinder sample was subjected to a compressive load at a constant rate along the vertical diameter until failure. Failure of the specimen occurs along its vertical diameter, due to tension developed in the transverse direction. The indirect tensile strength was computed as:

$$T = 2P/\pi Ld \qquad (4)$$

where,

T = tensile strength, MPa (psi)
P = load at failure, N (psi)
L = length of specimen, mm (in.)
d = diameter of specimen, mm (in.)

3. Results and discussions

3.1 Determining the properties of kenaf fiber

3.1.1 Water absorption

The results obtained from the study reveals that the moisture absorption capability of kenaf fiber increased after chemical treatment. From Figs. 6 and 7, it shows that the moisture content increased with time. When fibers were immersed, the water molecules penetrated and induced the weight gain. At the beginning of the curve, the weight increased sharply demonstrating the rapid moisture penetration into the fibers. It can be seen that the treated fibers absorb water very rapidly at the initial stage compare to untreated fibers and a saturation level is attained without any further increase

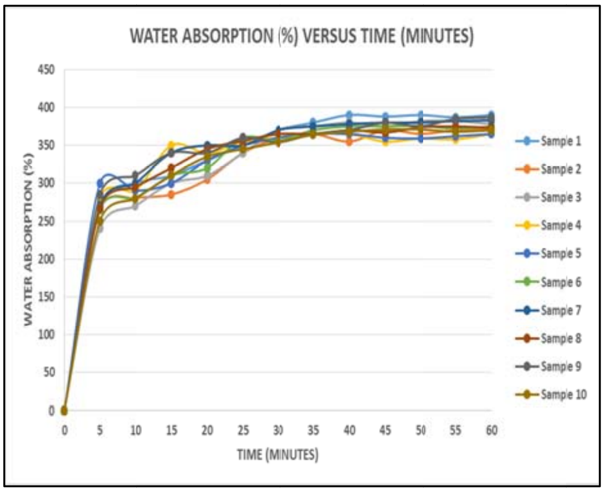

Fig. 6 – Untreated kenaf fiber

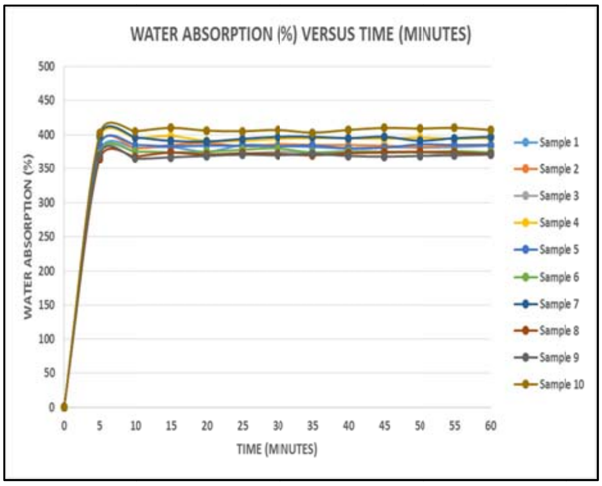

Fig. 7 – Treated kenaf fiber

in water absorption. This may be due to removal of lignin and hemicellulose component of fiber by alkali treatment, hence the fibers have high tendency to absorb moisture. Water absorption of untreated kenaf fiber is 376% but increases to 385% after alkaline treatment. The time for the untreated kenaf fiber to be fully saturated in water is 40 minutes but it reduces to 10 minutes after alkaline treatment.

3.2 Determining the properties of kenaf fiber reinforced concrete (KFRC)

3.2.1 Slump test

The workability of the fresh concrete was measured by slump test according to BS 1881 part 102(1983) [17]. The slump designed was 30-60 mm. Slump value, an index of workability of fresh concrete, was adversely affected by kenaf fiber content. As water soaked fibers were used there was no further water absorption by kenaf fiber from concrete mix and this makes the fresh concrete to have a good workability. However, the presence of kenaf fibers in fresh concrete makes the concrete higher the kenaf fibers content in concrete, the lower slump was observed. The factor to consider here is the surface area of the fiber. In addition to the coarse aggregate the mortar (sand and cement) must also coat the fibers. If the mortar fraction is insufficient, then the effect on the slump and workability will be greater. Therefore, it is mandatory to consider the quantity of fibers when determining the proportions of the conventional ingredients in a fiber reinforced concrete mix. More fibers require more mortar. Besides that, it has been found that longer fibers will reduce the slump to a greater degree than shorter fibers. A small reduction in workability was observed in the specimens with 50-mm fibers compared to 25-mm fibers. Long fibers hold the concrete and make the concrete more resistant to flow, hence reduce the slump value. It may also due to the orientation and contact surface area of fiber with concrete. The concrete becomes stiff and results in low slump values.

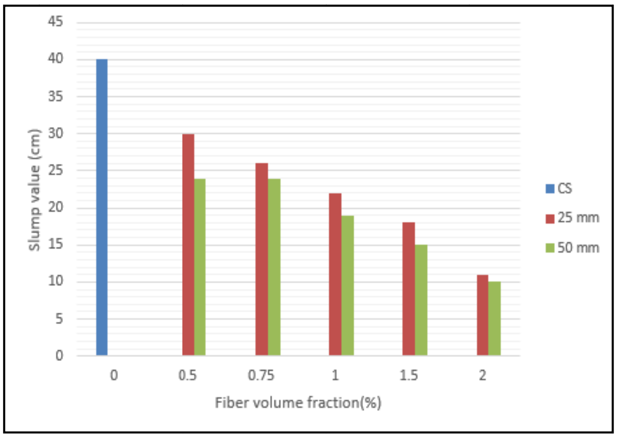

Fig. 8 – Results of slump test

3.2.2 Hardened concrete density

Increase in kenaf fiber content significantly decreases the density of the concrete. The reason might be due to the reduction of cement mortar (dense materials) in the specimens by the added light kenaf fiber. Besides that, the presents of kenaf fiber in concrete reduces the reaction between water and cement particle to take place vigorously to produce calcium-silicate-hydrate (C-S-H) gel and calcium hydroxide. The gel produced then fills up all possible voids in the sample which then increase the weight of each sample. Increment in weight under constant volume simply indicates that the density is increased.

3.2.3 Compressive strength test

The specimens with the ID of ###-#-CS-# were undergoing a series of compressive strength tests to evaluate the strength of specimen at 7 days and 28 days. The specimens

Fig. 9 – Control sample

Fig. 10 – KFRC

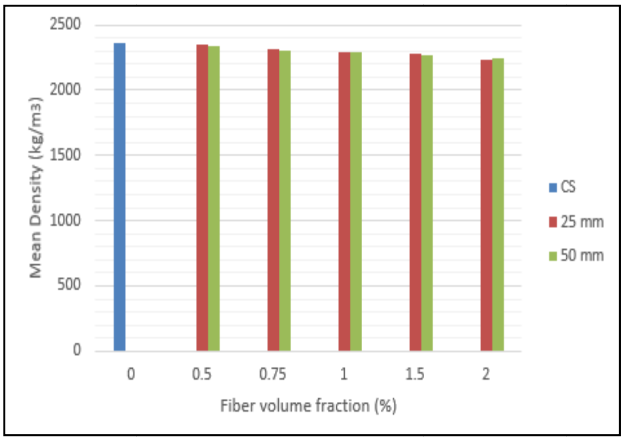

Fig. 11– Results of density test

of KFRC were compared to the control concrete (plain concrete). From Figs. 12 and 13, it is shown that plain concrete exhibited very little cracking prior to failure. Failure was occurred near the edges of the cube. For KFRC, it was clearly seen that specimen exhibited more ductile failure mode and formed multiple distributed cracks before failure. Mean compressive strength of 7 days and 28 days curing for each specimen are shown in Fig. 14. From the results obtained, it can be seen that the compressive strength of KFRC decreases with increasing fiber content and fiber length compared with the control concrete. The high amounts of fiber content also increased the ductility of the concrete. In addition, high fiber content increases the fiber agglomeration in concrete, hence makes the concrete become more porous and reduces its strength. The reduction of compressive strength are more significant for SP8 to SP10. This indicates that the fiber volume added in concrete exceeded the limit. High volume of fibers added reduces the concrete volume in specimen and hence reduces its compressive strength. The addition of kenaf fiber in concrete does not increase the compressive strength significantly and therfore the concrete still can achieve the design strength with the appropriate amount of fiber contents. This can be seen on SP2 to SP5. Although its early strength was low, it still achieved the target design strength (Grade 30) in 28 days. By comparing the specimen with the same fiber volume but different fiber length, it can be seen that the fiber length influences the compressive strength of KFRC. KFRC with the long fibers had higher compressive strength compared to those with short fibers. This was partly due to the fact that the decrease in length of the fiber increases fibre agglomeration in composite specimens. The fiber ball makes the specimen porous and leads to lower strength.

3.2.4 Flexural strength test

The specimens with the ID of ###-#-FS-# were undergoing a series of flexural strength tests to evaluate the strength of specimen at 7 days and 28 days.

Fig. 12 – Control cube failure

Fig. 13 – KFRC cube failure

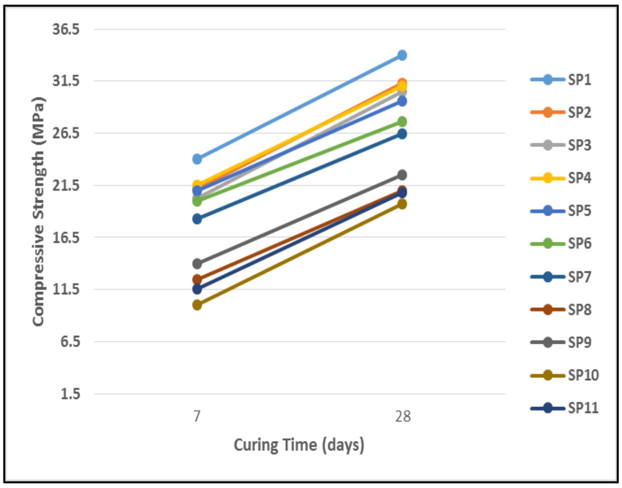

Fig. 14 – Compressive strength vs. curing time

The results of flexural strength test are shown in Fig. 15. Inspection indicates that the high fiber content in concrete reduced the flexural strength of KFRC. However, the addition of fibers with the appropriate amounts slightly increased the flexural strength of the KFRC prisms. This is shown by the specimen SP2 to SP5. From the results obtained, the fiber length affects only slightly the flexural strength of KFRC. From the Fig. 16, it can be found that failure of the control prisms occurred due to the formation of a single crack within the central one-third length of the prism which led to brittle failure of the prism. When a similar crack formed in the KFRC prisms, however, the presence of the kenaf fibers helped to bridge the crack and the crack is smaller, as shown in the Fig. 17, which led to a more ductile failure mode with greater toughness and residual strength.

3.2.5 Indirect tensile strength test

The specimens with the ID of ###-#-TS-# were undergoing a series of indirect tensile strength tests to evaluate the strength of specimen at 7 days and 28 days. The KFRC specimens were evaluated and compared to the behavior of corresponding control concrete. The mean indirect tensile strength of specimens is shown in Fig. 18. From the tests done, it can be found that KFRC cylinders exhibited a more ductile failure mode compared to the control concrete. The control concrete exhibited a brittle failure due to the formation of a single splitting crack along the vertical diameter of the cylinder. KFRC cylinders had a more distributed cracking pattern with clearly visible kenaf fibers bridging across the cracks. The results obtained indicate that high volume content of kenaf fibers in concrete caused the reduction of indirect tensile strength of concrete. This is shown by SP8 to SP11 where the indirect strength was much lower compared to the control concrete. This may be due to the high percentage of fiber presence in concrete reduced the aggregate and cement content, hence affect the strength of cylinders.

Fig. 16 – Control prism failure

Fig. 17 – KFRC prism failure

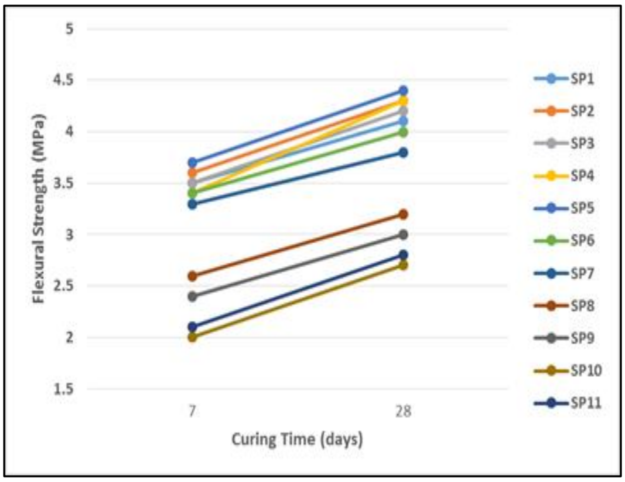

Fig. 15 – Flexural strength vs. curing time

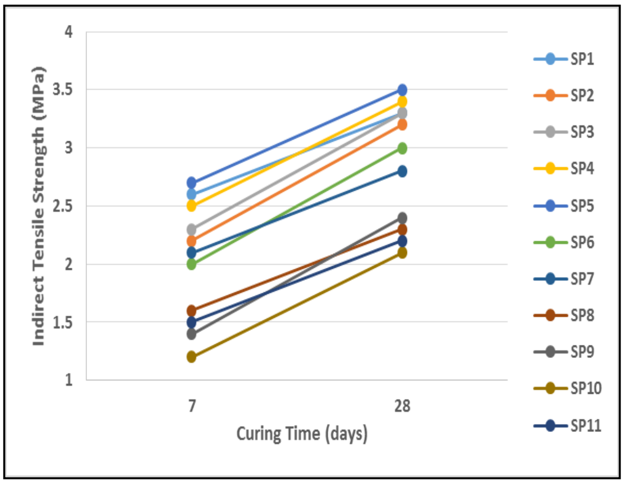

Fig. 18 – Indirect tensile strength vs. curing time

Fig. 19 – Control cylinder

Fig. 20 – KFRC cylinder

The mean indirect tensile strength for specimens with the fiber content of 0.75% (SP4 and SP5) is slightly higher from the control concrete. The reduction of indirect tensile strength of KFRC also affected by the fiber length. It was found that the different strength between the short fiber KFRC and long fiber KFRC are around 6 to 14 percent.

4. Conclusions

The main conclusions that can be drawn from this study are as follows:

(1) Addition of kenaf fiber in concrete resulted in a significant reduction of the slump of the fresh concrete. This may due to the fact that the presence of kenaf fibers in fresh concrete makes the concrete stiffer and reduces the workability.

(2) The compressive strength of KFRC decreased with the higher fiber contents and the use of short fiber. However, KFRC can achieve the required design compressive strength with the appropriate fiber contents and fiber length.

(3) Flexural strength and indirect tensile strength of KFRC are directly proportional to the fiber content and fiber length.

(4) The results of flexural strength and indirect tensile strength test indicate that KFRC exhibits a ductile failure mode compared to conventional concrete. Moreover, the observed improvement of the cracking behavior enhances the durability of concrete at relatively low cost compared to other types of fibers. Thus, KFRC could be used in the production of impact resisting members.

(5) From the findings of this study, it indicated that the volume and length of kenaf fiber to be added in concrete to improve its mechanical properties should be 0.75% or lower and 50 mm. Future study about the fiber content should be conducted.

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