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Kenaf Fibrous Concrete: Mechanical Properties with Different Fiber Volume Fraction

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Abstract— **Kenaf fiber comes from Kenaf plant which grows thrivingly in hot and humid temperature. The origin of Kenaf comes from a few different countries that have similar characteristics such as Africa, China, and India. Kenaf or its scientific name, hibiscus cannabinus is a beneficial crop where the seeds and stems can be used in various industries such as medicine, paper production and composite material. Kenaf core and bast fiber can reach up to 3 meters long and this is an essential reason to corporate Kenaf with other composite material like polymer and concrete. This paper indicates the investigation of finding an optimum value of Kenaf Fibrous Concrete with fiber volume of 0%, 0.5%, 0.75%, 1% and 1.5% in the mix proportions. The mechanical properties of fresh and hardened samples were tested during 7th and 28th day of curing in water. Compressive strength, splitting tensile and flexural strength tests were executed in accordance of BSEN 12390-3:2009, ASTM C496M-06 and BSEN 12390-5:2009 respectively, with different volume fractions in finding an optimum value of Kenaf Fibrous Concrete. The result shows that kenaf fiber has the hydrophilic characteristic that influences more water absorption in the mix proportions. The capability of this fiber improves the tensile strength and ductility because of the inclusion of fiber. However, it decreases the concrete compressive strength.**

Keywords— **kenaf fiber; kenaf fibrous concrete; strength; fiber volume fraction**

I. Introduction

Kenaf fiber comes from Kenaf plant which can grow thrivingly in hot and humid temperature. The origin of Kenaf comes from a few different countries that have similar characteristics to Africa, China, and India [1]. Kenaf or its scientific name, *hibiscus cannabinus* is a beneficial crop where the seeds and stems can be used in various industries such as medicine, producing papers and composite material. Kenaf core and bast fiber can reach up to 3 meters long, and this is the essential reason to corporate with other composite material like polymer and concrete.

Kenaf is one of the natural fibers that have been identified as biomass plant that can absorb unwanted gasses in the environment. The stems are 1–2 cm diameter, often but not always branched. It has variable shape and colors of white, yellow, or purple; petals and white or yellow plant leave. The fruit is a capsule 2 cm diameter, containing several seeds. The adaptation of Kenaf to climate, it can live in the different type of weather condition, 22 °C and 30 °C [2]. It was also reported that particleboard made from kenaf core has superior physical and mechanical properties than those of rubberwood [3]. Kenaf core particles can also be treated with fire retardants to produce particle boards that reduce the spread of flame and the release of heat when exposed to fire [4]. Table 1 shows the mechanical properties of some natural fibers.

The performance of biocomposites depends on the properties of the fibers used in them. However, there are some aspects need to be considered due to its properties. The ability of fiber somehow lower the elasticity, absorb more water, availability in an aggressive environment and also changes in mechanical and physical properties [5]. Fiber from the Kenaf plant can be divided into short and long fiber measured by aspects ratio. Different studies stated how fiber behavior in strengthening the composite, as kenaf fiber reinforced concrete can be used as strengthening materials for reinforced concrete (RC) beams [6]. The previous research and literature have already shown the mechanical and dynamic properties of kenaf fiber as an additive to improve the concrete properties, but somehow the results are not yet stable and transparent [5]. The objective of this paper is to find an optimum value of Kenaf Fibrous Concrete (KFC) by conducting an experimental study in different ratios of volume fraction and fiber length.

TABLE I
MECHANICAL PROPERTIES OF SOME NATURAL FIBERS [7]

Fiber	Density (g/m^3)	Length (mm)	Diameter (μm)	Elongation at break (%)	Tensile strength (MPa)
Cotton	1.21	15-56	12-35	2-10	287-597
Coir		0.3-3.0	7-30	15-25	
Flax	1.38	10-65	5-38	1.2-3	343-1035
Jute	1.23	0.8-6	5-25	1.5-3.1	187-773
Sisal	1.20	0.8-8	7-47	1.9-3	507-855
Hemp	1.35	5-55	10-51	1.6-4.5	580-1110
Henequen	1.4		8-33	3-4.7	430-580
Ramie	1.44	40-250	18-80	2-4	400-938
Kenaf (bast)	1.2	1.4-11	12-36	2.7-6.9	
Kenaf (core)	0.31	0.4-1.1	18-37		170-1627
Pineapple	1.5	3-8	8-41	1-3	20-290
Bagasse	1.2	0.8-2.8	10-34	0.9	
Southern Yellow Pine	0.51	2.7-4.6	32-43		
Douglas Fir	0.48	2.7-4.6	32-43		
Aspen	0.39	0.7-1.6	20-30		

II. EXPERIMENTAL STUDY

A. Materials

1) *Kenaf Fiber Plant and fiber treatment:* The raw material of Kenaf fiber was collected from Kelantan, Malaysia. National Kenaf and Tobacco Board conducted expandable research on properties and performance of Kenaf. They have been supporting research activities of Kenaf Fiber to develop data and reference of this beneficial fiber.

Fig. 1. Kenaf Fiber before and after treatment process

The raw Kenaf fiber is extracted from the plant by water retting process. The cellulosic fibril of Kenaf fiber contains lignin and hemicellulose components that may distract the compatibility of fiber and concrete mixture [8, 13]. Kenaf fiber needs to be treated to remove lignin, pectin, hemicellulose, and dust from its original condition. The hydrophilic behavior makes kenaf absorbs more water when mixed with concrete. The fibers were treated with 5% sodium hydroxide for 3 hours at room temperature [9, 10]. This chemical concentration was the optimum value to prepare a better condition of fiber. High chemical concentration will damage and break the fiber surface [11]. After chemical treatment, then the fibers were rinsed with water and immersed for 24 hours. After 24 hours the fibers were rinsed again until the brownish color of liquid fades out as shown in figure 1. The fiber needs to be dry about 2-3 days at room temperature.

The dried fiber will be cut into the desired length between 25mm and 50mm using cutter machine and ready to be used. The physical, mechanical properties and chemical characteristics will be determined at this time along with the same raw material.

2) *Cement:* Tasek Cement product used in this experimental study is an Ordinary Portland Cement (OPC) where the chemical composition stated that lime (CaO), silica (SiO2), alumina (AL2O3), iron (Fe2O3) and sulfur trioxide (SO3) that forms binder paste when mixing with water.

3) *Aggregate:* The coarse aggregate used in this experimental study is a crushed granite of 10mm of nominal size. The fine aggregate of sand passing through 4.75mm sieve and sieve test analysis was referred to ASTM C136-06.

B. Samples and mix proportions

The objective of this research is to achieve the mechanical properties in finding an optimum value of KFC. The specimens were compared to the ordinary concrete without kenaf fiber. The mix proportions were designed to achieve 30 MPa in 28 days of curing for KFC. The design of concrete mix used in the experimental studies is given in Table 2. The compressive strength was determined by using 100× 100×100mm cube mold. Meanwhile Splitting Tensile and Flexural Strength were determined by using 200 height, 100 diameters of cylinder and 100×100×500mm of prism mold respectively.

TABLE II
CONCRETE MIX PROPORTIONS USED IN THE STUDY OF KFC

Constituent material	Proportions (kg/m^3)
Cement	463
Fine aggregate	800
Coarse aggregate	867
Water	250
Kenaf Fiber 0.5%, 0.75%, 1%, 1.5%	6,9,12,15
Superplasticizer	4.63

The experiment using this fiber, the volume fraction ranges from 0.5% to 1.5 % in furtherance of finding an optimum value for KFC. Fiber needs to be treated using 5% of NaOH before mixed in the concrete. The treated fiber also needs to be soaked in 4.9% of water by weight one hour before casting started to ensure fiber will not absorb water while concrete mixing process carried out [12]. Cement and aggregates initially mixed in a drum mixer. Water and Rheobuild 1100 superplasticizer were added partially to increase the workability. The wet kenaf fiber then needs to be disassembled to obtain uniform mixing of KFC. Compaction of the vibrating table as an external vibrator was carefully taken to avoid honeycomb and segregation.

The fresh concrete properties of all the mixes were measured by using the slump tests by BS EN 12350-2:2009. There were three samples for each concrete mix proportions range 0.5%, 0.75%, 1% and 1.5% of fiber volume fractions with two different lengths of fiber 25mm and 50mm to indicate the effectiveness of fiber-matrix interactions. The control mixture was also prepared to compare the enhancement of fibrous concrete strength in different tests.

C. Test specimen and setup

The setup testing for mechanical properties was conducted by referring to the ASTM and British standard concerning achieving the objectives of this research. All 162 samples, from 3 samples each of every 7 and 28 days and different fiber volume fractions were tested according to British and ASTM standards. Fiber length indicated in this research are 25mm and 50 mm for all types of concrete mix proportions.

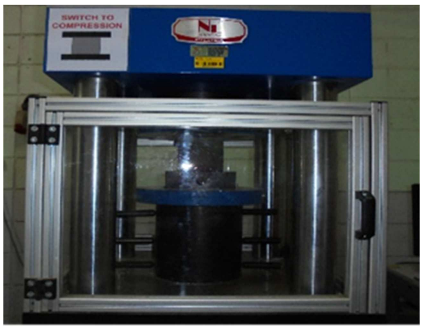

Fig. 2 Universal Testing Machine (UTM) used for Compressive Strength Testing Splitting Tensile Strength and Flexural Strength Testing

The initial testing is a fundamental property to investigate how the material will react to the physical force. Fresh concrete density and workability are indicated data to ensure the hardened concrete is compacted homogeneously without bleeding and segregation.

1) Compressive Strength Test

Compressive strength was executed using the following formula in accordance to BSEN 12390-3:2009.

$$f_c = \frac{F}{A_c} \quad (1)$$

Where:
f_c = compressive strength, in Mpa, (N/mm^2);
F = maximum load at failure, in N;
A_c = area of the specimen

2) Splitting Tensile Strength Test

Splitting tensile strength was calculated using the following formula in accordance to ASTM C496M-06. This test used the same method of compressive test. However, the load was applied to cylinder sample which is applied across its horizontal length [13].

$$T = 2P/\pi ld \quad (2)$$

Where:
T = splitting tensile strength, in Mpa, (N/mm^2);
P = maximum applied load indicated by the testing machine, in N;
l = length, in mm;
d = diameter, in mm.

3) Flexural Strength Test

Flexural strength test was conducted using the following formula in accordance to BSEN 12390-5:2009

$$f_{cf} = \frac{F \times I}{d_1 \times d_2^2}$$

(3)

Where:
f_{cf} = flexural strength, in Mpa, (N/mm^2);
F = maximum load, in N;
I = is the distance between the supporting rollers, in mm;
d_1 *and* d_2 = diameter, in mm.

III. RESULTS AND DISCUSSION

A. Properties of Kenaf Fibrous Concrete (KFC)

Fresh concrete slump test determined the workability of KFC. According to the design of 60-180mm, the inclusion of fiber reduced slump as stated in figure 3. The hydrophilic characteristics caused by the added fiber makes the concrete mix absorbs more water. Even though the fiber was treated and was soaked before concrete mixing process, yet its slump value still decreases caused by the outer surface of kenaf fiber. The concrete becomes stiff and dried when fiber volume fraction is increased.

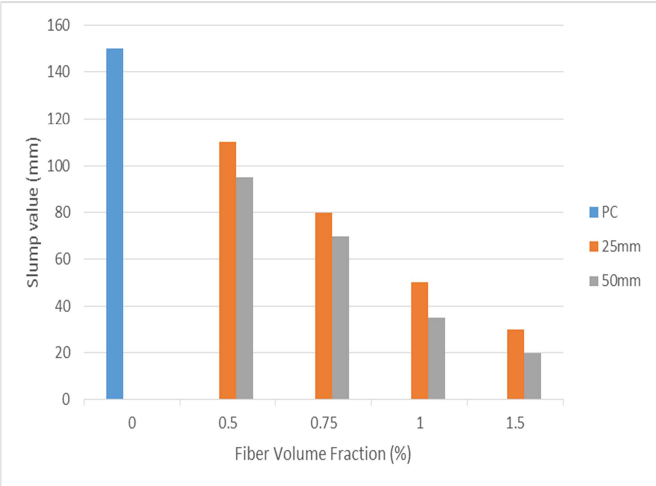

Fig. 3 Slump Test Result

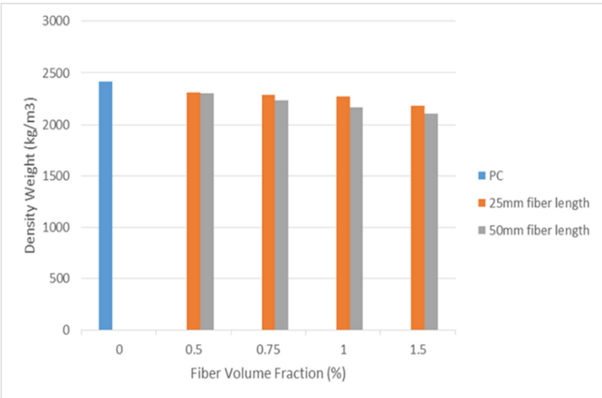

Fig. 4. Density Weight Result

B. Effect on concrete strength of Kenaf Fibrous Concrete

1) *The effect of Compressive strength*: Figure 5 shows that, the compressive strength of overall mix proportions. The compressive strength of KFC is slightly lower than normal concrete. 25mm and 50mm length of fibers were used to compare the performance of concrete. Based on design criteria of 30N/mm^2 the KFC-2 mixed (0.75% and 25 mm) achieved the strength required, however, lower than normal concrete. This is attributed to lower density and slump by addition of fiber. More water has been absorbed while mixing and less water for hydration process [18].

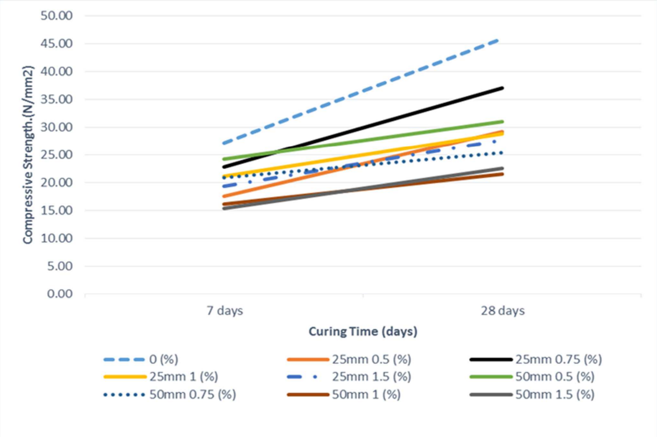

Fig. 5 Compressive Strength of Kenaf Fibrous Concrete (KFC)

2) *The Effect of Splitting Tensile strength:*

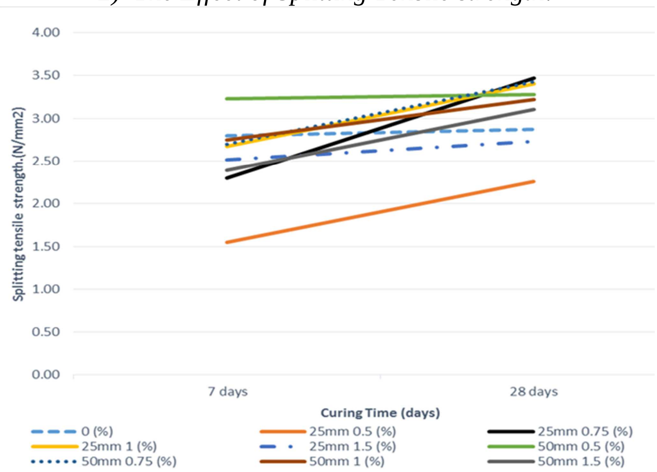

Fig. 6 Splitting Tensile Strength of Kenaf Fibrous Concrete (KFC)

Kenaf Fiber Reinforced Concrete increased the performance of tensile whereas the distribution of fiber in real influences the tension behavior [15, 19]. KFC-2 mixed (0.75% and 25mm) mix proportions stated the highest splitting tensile strength which is 3.47 N/mm^2 as shown in figure 6.

3) *Effect of Flexural Strength:* The flexural strength results in figure 7 also show the increment of KFC in all proportions, but the highest value of Kenaf Fiber with 0.75% shows better performance regarding bending properties compared to standard and other mix concrete proportions. The higher load on the KFC-2 (0.75% and 25mm) specimens restrained more load to deflect the specimens.

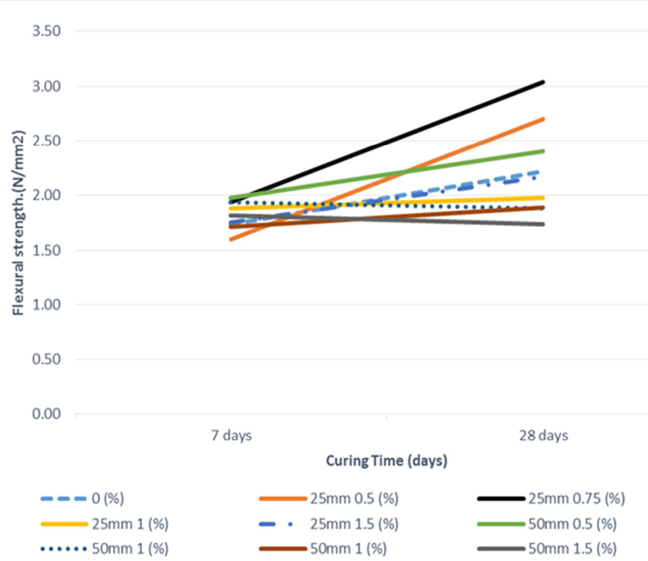

Fig. 7 Flexural Strength of Kenaf Fibrous Concrete (KFC)

The cracking pattern was shown in figure 8 and 9 using Universal Testing Machine (UTM). KFC expands time of cracking compared to normal concrete. The fiber reduces the microcracks in matrices and holds them together when receiving ultimate loading. This energy absorption by aggregates and fiber reduces the brittle manner of in normal concrete [19].

Fig. 8 Cracking failure of Control concrete

Fig. 9 Cracking failure of Kenaf Fibrous Concrete (KFC)

C. Fiber effect

The design criteria of mixing the concrete were referred to British Standard Mix Design Provisions (DOE) method based on various assumptions and requirements of water/cement ratio, workability and materials proportions. Figure 10 shows the scanning electron microscopic (SEM) of standard concrete with 100 times magnification. The C-S-H gel from cement is forming the bonding of cement and aggregates after the hydration process as shown in table 3 and figure 12. The EDX analysis showed a higher percentage of calcium, oxygen, and silica. The compressive strength of normal concrete relatively increases with time for 7 and 28 days. However, in the SEM micrograph shows that there are voids and pores in the mixture of normal concrete that indicate the brittleness of concrete. This weak characteristic influences the low tensile strength when it reaches an ultimate value.

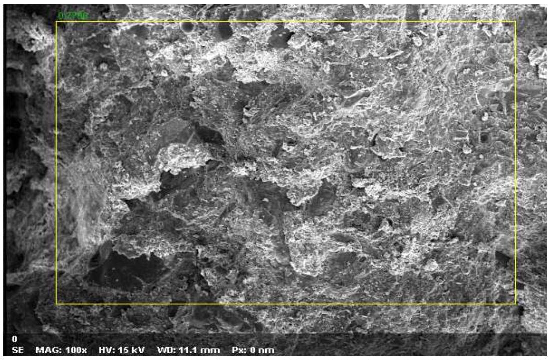

Fig. 10 SEM micrograph of normal concrete

The addition of other materials like natural fiber enhances values on some mechanical properties [19, 21]. The rough surface of the surrounding fiber explains the ductility of KFC when failed at maximum stress in figure 11 [6]. Fiber treatment serves a better surface modification and gives adhesion between fiber and concrete. However, to increase the workability of fiber, high water/cement ratio was used in the experimental study and for that reason, it reduces their strength. This is applied to the EDX analysis in table 4 and figure 13. The calcium and silica are slightly similar to standard concrete, but not the oxygen. The highest percentage of oxygen in table 4 explains high water absorption. This explains of few challenges while working with natural fiber are the adhesion of fiber-matrix and hydrophilic characteristic [22,23].

TABLE III
EDX ANALYSIS OF NORMAL CONCRETE

Element	At. No.	Netto	Mass (%)	Mass Norm. (%)	Atom (%)	Abs. error (%) (1sigma)	Rel. error (%) (1sigma)
Oxygen	8	3280	7.73	39.84	53.7	1.34	17.31
Calcium	20	12176	7.13	36.76	19.7	0.25	3.51
Silicon	14	6856	1.79	9.23	7.09	0.11	5.88
Carbon	6	755	1.68	8.65	15.5	0.44	26.05
Magnesium	12	426	0.40	2.07	1.83	0.06	14.75
Iron	26	122	0.35	1.78	0.69	0.06	17.43
Aluminium	13	974	0.32	1.67	1.34	0.05	14.10
Gold	79	5005	0.00	0.00	0.00	0.00	1.73
		SUM	19.4	100.0	100.0		

The process of preparations and execution may differ while concreting. Kenaf fiber is a natural fiber that needs a standard of operation and preparations before corporate with concrete as a biocomposite. Kenaf fiber needs uniformity of treatment and is handling particularly when mixing with concrete. A remarkable ‘green’ concrete and friendly to nature will be achieved if the extensive study of this concrete can be done [21].

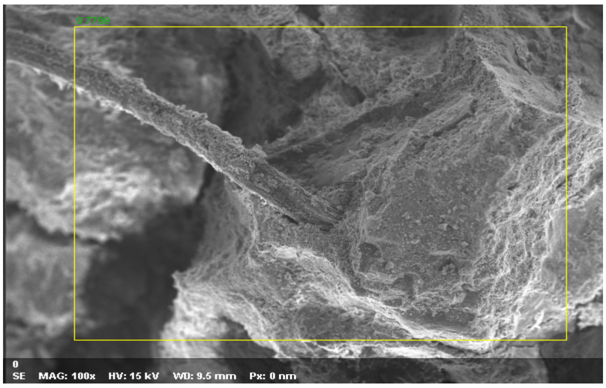

Fig. 11 SEM micrograph of Kenaf Fibrous Concrete (KFC)

TABLE IV
EDX ANALYSIS OF KENAF FIBROUS CONCRETE

Element	At. No.	Netto	Mass (%)	Mass Norm. (%)	Atom (%)	Abs. error (%) (1sigma)	Rel. error (%) (1sigma)
Oxygen	8	2357	7.73	42.08	55.33	1.36	18.58
Calcium	20	7255	6.11	34.99	18.36	0.23	3.69
Silicon	14	4612	1.67	9.58	7.17	0.10	6.12
Carbon	6	519	1.63	9.33	16.35	0.47	29.10
Aluminium	13	681	0.31	1.79	1.39	0.05	14.96
Magnesium	12	150	0.18	1.05	0.91	0.05	25.26
Iron	26	41	0.18	1.01	0.38	0.05	30.89
Chlorine	17	63	0.03	0.17	0.10	0.00	14.11
Gold	79	4329	0.00	0.00	0.00	0.00	1.73
		SUM	19.47	100	100.00		

D. Fiber Length and Volume Fraction

The fiber length used in the experimental research was 25mm and 50mm while the aggregate used is 10mm in diameter. The short fiber was capable of exhibiting aggregates and reducing shrinkage. The fiber length indication is two times of the size of coarse aggregate to ensure the binding of fiber and aggregate was enough in the concrete matrix. Kenaf fiber is easily to clump each other. Hence long fiber is not acceptable. The tensile strength of 50mm fibrous concrete however still comparable with 25mm with very minimal reduction. The length and high-volume fraction comparative each other somehow decreases when the optimum value was achieved.

E. Ductility of Kenaf Fibrous Concrete

The results from the flexural strength testing in figure 8 show that Kenaf Fibrous Concrete carries tension efficiently compared to regular concrete. The brittleness of plain concrete is relatively taking less energy. KFC absorbs more energy after cracking failure. The distribution of fiber disseminates extensibility of cracking when received the high load and absorbed more strength. Lower load structure of KFC can be applied in building construction since its ductility characteristics [21].

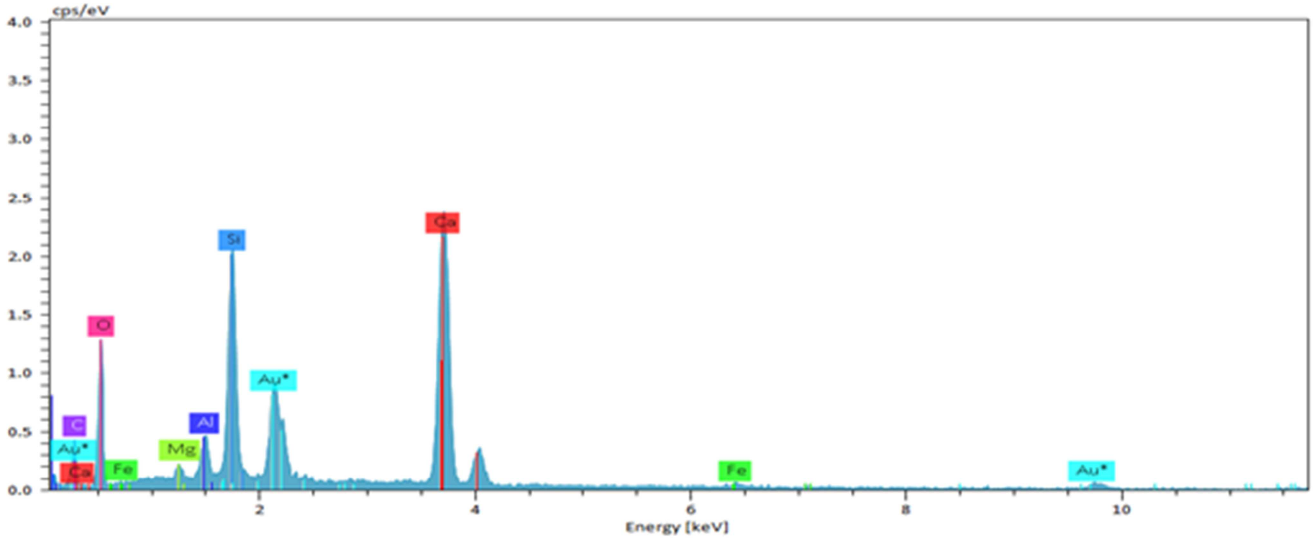

Fig. 12 EDX spectrum analysis of Normal Concrete

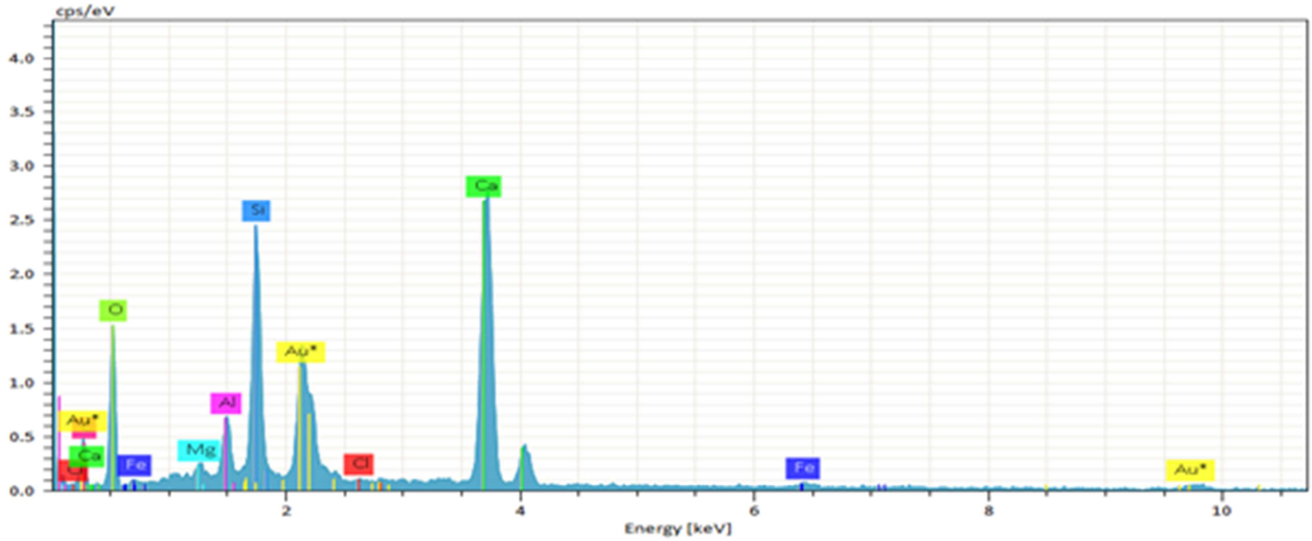

Fig. 13 EDX spectrum analysis of Kenaf Fibrous Concrete (KFC)

IV. Conclusions

According to experimental results discussed above; Fiber volume fraction of 0.75% was observed to hold the highest value in carrying tensile properties rather than 0.5% and 1%. However, the volume fraction range between of 0.5% to 1% was appropriate indication of optimum values. The addition of fibers caused relatively reduced slump and lower density concrete. Kenaf Fibrous Concrete disseminates extensibility of cracking and failure. 25 mm and 50mm of fiber somehow gives the minimal difference in performance. In this experimental study, the 25mm of fiber length indicated as the best additional mix to enhance durability and performance in further testing.

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