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Mechanical and Durability Properties of Fibre Lightweight Foamed Concrete

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Abstract: This paper describes the investigation of mechanical and durability properties of lightweight foamed concrete (LFC) with the inclusion of fibres. All the specimens were tested using the density of 1000 kg/m3. The cement, sand and water ratio used was 1:1.5:0.45. Polypropylene and kenaf fibre were used as additives by volume fraction and 30% of fly ash was replaced by cement. The experiment was setup to examine its mechanical and durability properties with accordance to standard method of testing. With reference to the result analyzed, fibres inclusion has least contribution in compressive strength or might also lessen the result but the integration of fly ash in the mic has the ability to enhance the compressive strength. The higher percentage of fibre inclusion is proven to have contributed more on flexural, tensile splitting and shrinkage properties of LFC.

Key words: foamed concrete, mechanical properties, durability, fibre, fly ash, strength.

INTRODUCTION

Lightweight foamed concrete (LFC) has been a popular approach for building material. It is a concrete product that consists of entrapped air bubble that acts as the aggregate which is lighter than the normal concrete aggregate. The LFC has been referred as lightweight material obviously because of the weight itself which is lighter in comparison to the normal weight concrete with a density in the region of 2400kg/m^3. The density of the LFC usually varies in the range of 300kg/m^3 to 2000kg/m^3. The LFC consists of slurry mortar with the addition of foam by dosage as a point-measure of controlling the density of the LFC product. The foaming agent can be classified in three types which are the polymer foam agent, protein foam agent and surface active agent. The slurry mortar is a cement based product consists of Portland cement, sand and water with specific determined ratio.

The density of the mortar usually varies between 2150 kg/m^3 to 2250kg/m^3. LFC is applicable to any kind of building material depending on its casting purpose. Slurry formation of LFC makes it viable for void filling, self-leveling, rapid installation for a cast in-situ project, thus cost saving. With LFC porous nature, it offers better thermal insulation and considerable amount of material will be saved. Fibres inclusion is well known to have contribution towards properties of concrete. 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 and Monteiro, 2006). Several studies have proven the effectiveness of adding fibres into concrete mixes where some of the studies resulted in encouraging enhancement of the mechanical and durability properties of concrete. There are mainly two types of fibres usually included in concrete which are the synthetic and natural type of fibres. Both synthetic and natural resource fibers have its advantages in the matrix proportioning of cement composites. Synthetic fibers are man-made fibers from researches and developments of textile industries. It was first reported to be a component of construction materials in 1965.

The types of fibers that have been tried in Portland cement concrete based are: acrylic, aramid, carbon, nylon, polyester, polyethylene and polypropylene. Consequently, the utilization of synthetic fiber reinforced concrete is presently exists worldwide due to its promising characteristic of optimizing the durability and mechanical properties of concrete. Furthermore, it is proven that synthetic fibers helped to perk up the post peak ductility performance, pre-crack tensile strength, and impact strength and eradicate both the temperature and shrinkage cracks (Brown *et al*., 2002). In comparison of synthetic fibers, natural fibers are believed to be more environmental friendly. That is why they are currently getting a lot of attention for replacing synthetic fibers (Thielemants and Wool, 2013). It has been reported that natural fibers have many advantages such as low density, recyclable and biodegradable compared to the synthetic fibers (Hatta *et al*., 2008). Even if compressive and tensile strength of natural fibers concretes are to some extent lower than the control concrete mix, their deformation behavior shows some improvement in ductility and reduce the shrinkage (Ramasmawy *et al*., 1983). Besides that, natural fiber exhibit many advantages properties and offer considerable reduction on the cost and benefit associated with processing compared to synthetic fiber (Toledo *et al*., 2003). Some investigations have been carried out on the properties of concrete using the natural fibers from coconut coir, sugar cane, bamboo, jute, elephant grass, akwata and sisal. These investigations have shown encouraging results.

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Fig. 1: Polypropylene fibre mega mesh

Fig. 2: Kenaf fibre (bast)

Materials:

Lightweight foam concrete is a mixture of slurry mortar and foaming agent. The slurry mortars are made of cement, sand and water in certain proportion. The cement used was Ordinary Portland Cement. A portable foaming generator is used to fabricate practically stable foam purchased from the Malaysian manufacturer, (www. portafoam.com). A protein based foaming agent namely, Noraite PA-1 was chosen to be used in the research. This is because the protein based surfactant has smaller bubble and the bonding structures of the bubbles are stronger and more stable compared to the synthetic based surfactant (McGovern, 2000). The weight of the foam used in this investigation varies in 60-80gram/liter. Class F fly ash was used to replace the cement. As for fibres used, polypropylene fibre was purchased from Timuran Engineering SDN BHD and the raw kenaf fibre was obtained from the state of Kelantan. The properties and characteristics of material used will be explained in detail in Table 1 to Table 4.

Table 1: Chemical composition of ordinary Portland cement

Constituent	Ordinary Portland cement % by weight
Lime (CaO)	64.64
Silica (SiO_2)	21.28
Alumina (Al_2O_3)	5.60
Iron Oxide (Fe_2O_3)	3.36
Magnesia (MgO)	2.06
Sulphur Trioxide (SO_3)	2.14
N_2O	0.05
Loss of Ignition	0.64
Lime saturation factor	0.92
C3S	52.82
C2S	21.45
C3A	9.16
C4AF	10.2

Table 2: Properties of fly ash class F

Properties	Percentage (%)
Silicon dioxide (SiO2) plus aluminum oxide (Al2O3) plus iron oxide (Fe2O3), min, %	70
Sulfur trioxide (SO3), max, %	5
Moisture Content, max, %	3
Loss on ignition, max, %	6

Table 3: Characteristics of kenaf fibre

Cellulose (%)	45-57
Hemicellulose (%)	21.5
Lignin (wt. %)	8-13
Pectin (wt %)	3-5
Tensile strength (MPa)	930
Young's Modulus (GPa)	53
Elongation at break (%)	1.6

Source : Akil et al (2011)

Table 4: Characteristics of polypropylene fibre

Composition	100% Polypropylene fiber
Configuration	Fibrillated/Multi-Filament
Fiber length	12mm, 19mm

Specific gravity	0.9
Melting point	160^0C - 170^0C
Tensile strength	45-60 ksi (0.31 – 0.42 kN/mm^2)
Thermal Conductivity	Low
Electrical Conductivity	Low
Absorption	None
Modulus of Elasticity	0.5 X 10 ksi (3.5kN/mm^2)

Experimental Program:

Principally, there are five tests were conducted for this investigation such as compressive strength, flexural strength, tensile splitting strength, water absorption and drying shrinkage. Each sample has the reading of 3 specimens in average. A total number of 9 samples including the control sample had been mixed as been outlined in Table 5. The compressive strength test was conducted using Autotest 3000 BS/ELE Compression Testing (Digital) Machine. The test procedure was according to BS 1881: Part 116: 1983 (BS1881, 1983) with specimen size of 100mm X 100mm X 100mm. The result was done up to 90th days of test. As for flexural strength test, it was conducted according to BS EN 1521:1997 (BS1521, 1997). The specimen size is 100mm x 100mm x 500mm with the result was covered up to 60th day of test. All the procedure and specimen tested in tensile spitting test was covered up to 28th day of test by referring to the ASTM C496 (2002). The specimen size used was 100mm x 200mm. Last but not least, the test for drying shrinkage is conducted according to BS 6073-1 (1981).

Table 5: Design mix proportion

Sample	Sample code	Composition of mixture			
		Cement (kg)	Fly Ash (kg)	Sand (kg)	Water (kg)
Normal foamed concrete	NF	29.59	-	44.38	12.29
0.25% Polypropylene fibre foam concrete	PF25	29.59	-	44.38	12.05
0.40% Polypropylene fibre foam concrete	PF40	29.59	-	44.38	11.25
0.25% Polypropylene fibre foam concrete with 30% fly ash cement replacement	PFA25	20.71	8.88	44.38	10.18
0.40% Polypropylene fibre foam concrete with 30% fly ash cement replacement	PFA40	20.71	8.88	44.38	11.13
0.25% Kenaf fibre foam concrete	KF25	29.59	-	44.38	11.31
0.40% Kenaf fibre foam concrete	KF40	29.59	-	44.38	12.66
0.25% Kenaf fibre foam concrete with 30% fly ash cement replacement	KFA25	20.71	8.88	44.38	11.26
0.40% Kenaf fibre foam concrete with 30% fly ash cement replacement	KFA40	20.71	8.88	44.38	12.30

Table 5 describes in detail on the mix design used in this research. There are two main mixes used were prepared which are lightweight foam concrete with polypropylene and with kenaf fibre inclusion. Essentially, the proportion for mortar is cement, sand and water with the ratio of 1:1.5:0.45. Two percentages of fibre were used; 0.25% and 0.4% out of total volume fraction. Kenaf fibres were treated with 0.1mol NaOH for a night before being included into mix to avoid any degradation of fibres. 30% of class F fly ash was added in certain mixes as cement replacement. Slump test was carried out for each mix design according to the standards for lightweight foam concrete slump testing method which varies between 25-27mm. The slurry mortar is then mixed with the foaming agent, Noraite PA-1 (protein based) with the variation of foam weight 60-80 gram/liter. The total quantity of foam added into each mix is different, depending on the target of wet density of the concrete. Target of dry and wet density is 1000kg/m^3 and 1130kg/m^3 correspondingly. All the mixes were left to dry in moulds in laboratory standard temperature with no rapid air flow for approximately 12 hours. After the demolding process, all the specimens were cured in plastic sheets raping according to days of the test. The specimens for compressive, flexural and tensile splitting test that has completely cured in accordance to days of test required will be oven dried for a night and tested. As for drying shrinkage specimen, it is left uncured in normal air room temperature and tested in accordance to days of test.

RESULT AND DISCUSSION

4.1. Compressive Strength:

Figure 3 shows the result of compressive strength test. There is an improvement of strength starting from day 7 to 90. It can be observed that the strength for all specimens in day 7 is lower than the control mix, NF and NFA. But almost all specimens show positive enhancement of strength starting from day 60 to 90. On the 90th day, all specimens have almost the same result with the control mixes. The highest strength increment can be seen in mixes with fly ash inclusion PFA25, PFA40, KFA25 and KFA40. However, those mixes resulted an increment of not more than 1% from the control mix. Both of the synthetic and natural fibre specimens seem to reach the strength of control specimen. It is known that the inclusion of fibres slightly decrease the average compressive strength of concrete (Elsaid *et al*., 2011). Nevertheless, it can be observed that both synthetic and natural fibres have almost the same result. There is no significance in adding these two fibres for the purpose of compressive strength but more on durability enhancement (Vikrant *et al*., 2012).

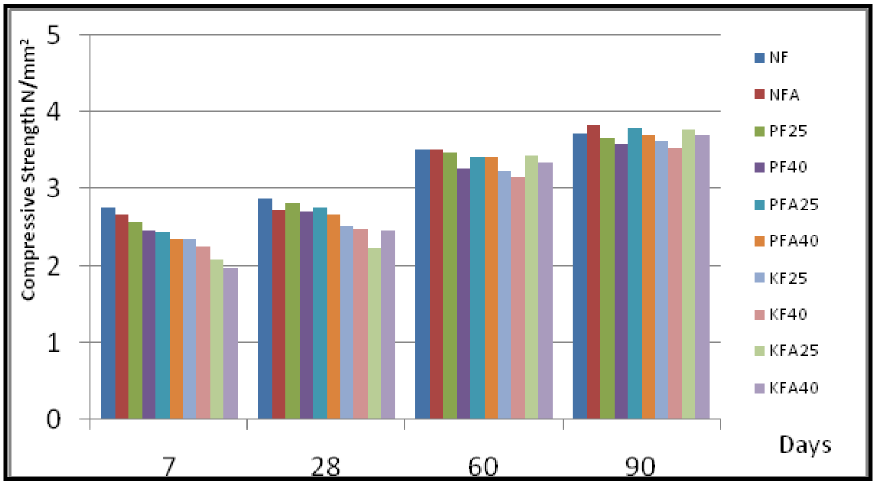

Fig. 3: Kenaf and polypropylene fibre concrete compressive strength

4.2. Flexural Strength:

The result of flexural strength of kenaf and polypropylene LFC is shown in Figure 7. In analyzing Figure 7, it can be drawn that both synthetic and natural fibres contributes to the enhancement of flexural strength of LFC. It can be observed that all the specimens resulted in positive increment from day 7 of test up to day 60. All of the specimens resulted higher flexural strength than the control specimen. At the early age, kenaf fibre seems to have average of lower flexural strength than the polypropylene. However, the strength of kenaf fibre LFC increases gradually at the age of 60. By comparing two different fibre percentages, it can be drawn that the higher percentage of fibre inclusion contributes more to flexural strength. The average of polypropylene and kenaf LFC strength increment compared to the control mix is 33.3% and 29.4% correspondingly. It has been analyzed that inclusion of these two fibres contributes to peak flexural strength and residual toughness of concrete as shown in Figures 4, 5 and 6 below. Figure 4 shown an immediate failure of concrete after the peak flexural strength had been achieved. As for specimen in figure 5 and 6, fibre acts as bridging component when a concrete cracks, preventing it to crack more or breaking into two parts (Roohollah *et al*., 2012).

Fig. 4: Complete failure of control specimen with the inclusion of fibre

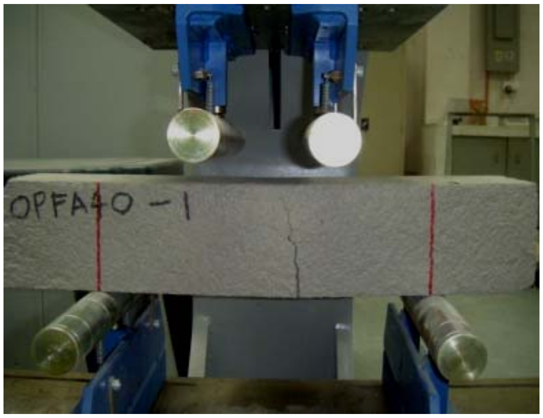

Fig. 5: Progress of 4 point bending test of specimen with fibre inclusion

Fig. 6: Enclosed concrete

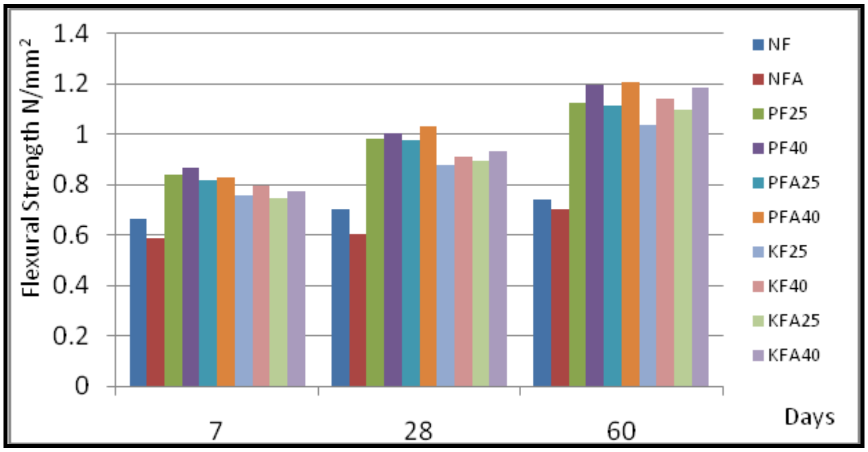

Fig. 7: Kenaf and polypropylene fibre concrete flexural strength

4.3. Tensile Splitting Strength:

The result of tensile splitting test is shown in Figure 8. By referring to Figure 8, all of the specimens resulted higher tensile splitting strength in comparison to the control mix. Both kenaf and polypropylene shown positive result but the highest result of all is polypropylene LFC. Both PFA40 and KFA40 have the result of 0.897 and 0.866 N/mm^2 respectively. This is higher than the control specimen by 23.1% and 20.4%. In average, tensile split strength of polypropylene fibre LFC is certainly higher than the kenaf fibre. The pattern of increment can be seen in Figure 8 with fly ash and the most fibre inclusion resulted as the highest in each group of fibre. It can also be stated that fly ash contributes in tensile splitting strength of LFC. As fly ash is included in the mix, the pozzolanic material of fly ash takes effect. The fineness of fly ash gets the filling rate of concrete increases. A more dense and impermeable structure occurs.Vikrant and Elsaid had proposed the same result in tensile splitting strength with the same pattern as polypropylene and kenaf fibres were included (Roohollah *et al*., 2012)

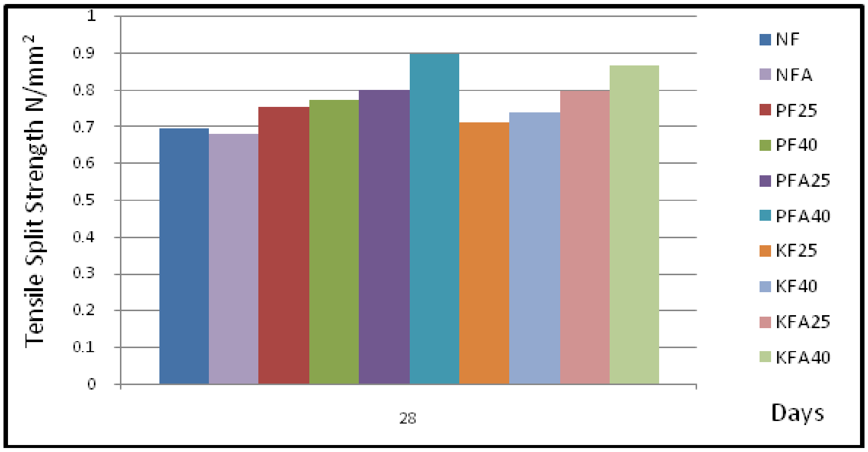

Fig. 8: Kenaf and polypropylene fibre concrete tensile splitting strength

4.4. Water Absorption:

The water absorption percentage of kenaf and polypropylene fibre LFC is presented in Figure 9. By analyzing Figure 9, it can be seen that overall, polypropylene fibre LFC resulted in the lowest result compared to control mix and kenaf fibre LFC. The pattern of water absorption rate for kenaf fibre LFC and polypropylene is almost the same which the inclusion of fly ash reduces the water absorption. PFA25 and PFA40 resulted in the lowest percentage of water absorption and KF25 and KF40 resulted in the highest peak of the graph. This is mainly due to the reason of polypropylene is a hydrophobic type of fibre which it does not absorb water or water repellant. Unlike kenaf fibre, it absorbs more water due to its surface morphology consists of more pores compared to polypropylene fibre. But the result of both kenaf and polypropylene fibre has not much difference. This is because of kenaf fibre had been treated with NaOH for it to be well blended in cement matrix which is rich of alkaline field to avoid degradation. This should be taken into account given that the degradation of natural fibres could lead to weak fibre's tensile

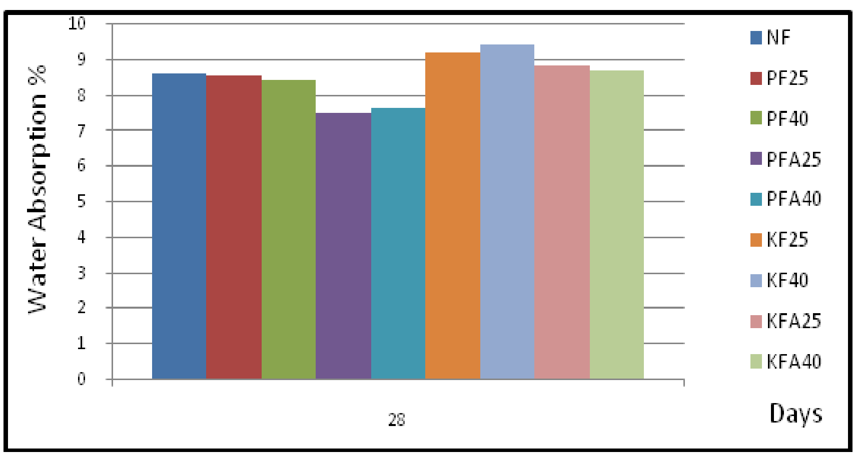

Fig. 9: Kenaf and polypropylene fibre concrete water absorption

4.5. Drying Shrinkage:

According to Figures 10 and 11, the control mix (NF) has the highest drying shrinkage which is 9.92%. This is followed by PF25 which shrinks 7.57% from the day of casting. Almost 31% of shrinkage difference compared to the highest specimen with fibre inclusion namely PF25. LFC has been known to have excessive shrinkage due to no present of aggregate. Fibre acts as the aggregate material to reduce the shrinkage due to its properties of filling voids. This has proven the effectiveness of fibre inclusion to resist drying shrinkage, thus saving it from the threat of cracking. There is not much difference comparing the result of kenaf and polypropylene fibre LFC. But the lowest drying shrinkage recorded is PFA40 with 2.42% of shrinkage. This is mainly due to the expansion of PFA40 starting at the age of 28 to 60. There are few specimens that begin to expand at the age of 14th to 60th. The enhancement of reducing drying shrinkage by inclusion of fibre has been a tremendous approach. It is supported by almost all researchers as a great action to counter cracking. This is supported by Roohollah *et al* . (2012) which stated that the increment of fibre resulted in reduction of the drying shrinkage

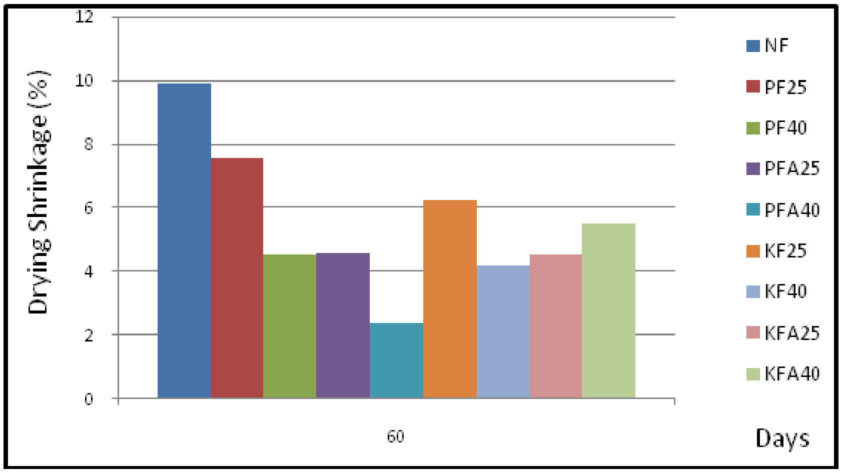

Fig. 10: Percentage of drying shrinkage of kenaf and polypropylene LFC up to 60 days

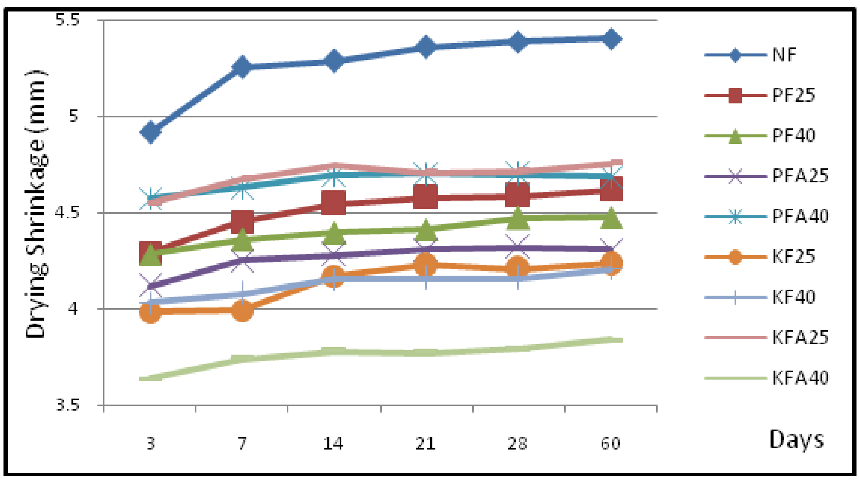

Fig. 11: Drying shrinkage of kenaf and polypropylene LFC by days of test

Conclusion:

Concluding all of the result discussed, it is proven that:

- Fibre inclusion is proven effective to improve the flexural, tensile splitting and drying shrinkage resistance as been supported by many researchers.
- Kenaf and polypropylene fibre has not much contribution in compressive strength. This has been quoted by Vikrant and Elsaid in their polypropylene and kenaf fibre studies which they quoted only minor increment in compressive strength has been observed.
- The quality of kenaf fibre is well-matched to the polypropylene fibre. This strengthens author's view in having synthetic fibre to replace the natural fibre for the purpose of cost saving and new material in the construction industry.
- The inclusion of fly ash is proven effective to overcome compressive strength reduction when fibres were added in the mix.

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