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Effect of additives on mechanical and thermal properties of lightweight foamed concrete

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ABSTRACT

This paper reports the results of experimental works that have been performed to investigate the mechanical and thermal properties of lightweight foamed concrete (LFC) with different additives. LFC with three different densities of 600, 1000 and 1400 kg/m^3 were cast and tested. Fly ash, lime and polypropylene fiber were incorporated with the LFC at different proportions. Compressive, flexural and drying shrinkage tests were carried out up to 180 days to evaluate the mechanical properties. The Hot Disk Thermal Constants Analyzer was used to establish different thermal conductivity values of LFC of different densities and additives. Scanning electron microscopy was used to give a detail view on each of particles produced by the reaction of additives in hydration process. The addition of additives in LFC showed no contribution on compressive strength but improvement in the flexural and shrinkage test results. LFC integrating various additives only contribute slight increase for thermal properties. Experimental results show that lower density LFC translates to lower thermal conductivity. The density of LFC is controlled by the porosity where lower density LFC signifies greater porosity hence thermal conductivity changes notably with the porosity of LFC because air is the poorest conductor compared to solid and liquid due to its molecular structure

Keywords: Foamed concrete, mechanical properties; thermal properties; additives and hydration process; microstructure

INTRODUCTION

Currently, the utilization and demand of LFC is becoming privileged where this material has increased many folds in modern years owing to its intrinsic economies benefits over conventional concrete in a range of structural and semi-structural applications. LFC is a cementitious material having a minimum of 20**%** by volume of mechanically entrained foam in the mortar slurry wherein air-pores are entrapped in the matrix by means of an appropriate foaming agent. With LFC, there is a reduced demand on primary aggregates thus enhancing sustainability, given that no coarse aggregate is essential in its fabrication and the fine aggregate fraction can be partly or fully replaced with recycled or secondary materials, e.g. fly ash, coir fibres, rice hush ash as well as air itself. LFC could be produced anywhere in any shape or building unit size on a small scale, even at site level, and it is comparatively trouble-free to place and finish devoid of heavy or costly equipment.

LFC has an outstanding thermal conductivity, low self-weight, high impact resistance and good freeze thaw resistance. Through proper control in amount of foam and methods of fabrication, an extensive range of densities of LFC could be formed thus providing flexibility for application such as structural elements, partition, insulating materials and filling grades. On the other hand, LFC has a self-levelling and self-compacting nature physically where it fills the smallest voids, cavities and seams within the pouring area.

Earlier, strength was not the major subject when using as it was normally used in void filling, highway reinstatement and other underground works. The typical strength value for LFC of densities between 800 kg/m^3 to 1000 kg/m^3 is in the range of 1 N/mm^2 to 8 N/mm^2 [1] which was sufficient for its purpose in underground works. With a minimum strength of 25 N/mm^2, LFC has the potential to be used as a structural material [2]. The compressive strength of LFC reduces with decreasing density. For mixes with similar constituents, the density-strength relations should be reasonably comparable. But, because the constituents in LFC mixtures can differ widely, density is not necessarily a dependable indicator of the compressive strength of LFC. The other main factors that influence the strength of LFC are cement-sand ratio, water-cement ratio, type of cement and content, pore size and distribution, type of foaming agents and curing regime [3].

The ratio of flexural strength to compressive strength of LFC is in the range of 0.06–0.10 and this ratio was also found to reduce with increasing water-cement ratios and decreasing densities. The splitting tensile strengths of LFC mixes are higher for mixes with sand than those with fly ash. This is attributed to the improved shear capacity between sand particles and the paste phase [4]. Cement-sand mixes had higher splitting tensile strengths compared to the cement-fly ash mixes [5]. This difference is possibly due to the strength contributed by interlocking aggregates. The introduction of polypropylene fibers in LFC mix has been reported to improve the tensile and flexural strength of LFC, provided this does not affect the fresh concrete behavior and self-compaction [6]

The thermal conductivity of LFC typically is 5 to 30% of that of normal weight concrete and range from between 0.1 and 0.7 W/mK for dry density values of 600 to 1600 kg/m^3 respectively [1]. In practical terms normal weight concrete would have to be 5 times thicker than LFC ones to achieve similar thermal insulation [7]. The thermal conductivity of LFC with 1000 kg/m^3 density is reported to be one-sixth the value of typical cement-sand mortar [8]. Since LFC is produced by injecting air into a cement based mixture, the density of LFC is directly a function of the air inside LFC. Expectedly, the density of LFC should play an important role in determining its thermal properties.
Up to now, mechanical and thermal properties have been one of the most significant topics to be studied but there is lack of research to look into the effect of additives on the mechanical and thermal properties of LFC. Detailed investigation will be done to examine the mechanical and thermal properties of LFC. This paper reports the results of an experimental investigation on mechanical and thermal properties of LFC with different densities and additives.

MATERIALS AND METHODS

LFC was produced under controlled condition from cement, water and a liquid chemical that is diluted with water with a ratio of 1:33 by water volume and aerated to form foaming agent.

2.1 Portland cement SEM1 and fine sand

Portland Cement SEM1 was used for the experiment. The cement is classified as MS 522, as well as BSEN 196. The fine sand used was natural sand that was obtained from a local riverbed. A sieve analysis was carried out to see the suitability of the sand to be used and the percentage passing 5 mm sieve size. The sand falls in zone 3 in accordance with British Standard BS 882: Part 2: 1973. Norizal (2000) mentioned that the appropriate size of fine aggregate used should be between 0 to 2 mm. In addition, 20% of the total quantity of sand used should preferably be of size less than 0.5 mm. Table 1 shows the cement quality that was used in this study while Figure 1 shows the particles sizes distribution of the river sand used in this study

Table 1. Properties of cement

Item	Clinker %	Cement %
Oxide composition		
SiO_2	21.04	19.98
Al_2O_3	5.24	5.17
Fe_2O_3	3.41	3.27
CaO	63.31	63.17
MgO	0.85	0.79
SO_3	0.41	2.38
Total Alkalis	0.9	0.9
Insoluble residue	0	0.2
LOI	0.5	2.5
Modulus		
Lime saturation factor	0.93	0.96
Silica modulus	2.39	2.37
Iron modulus	1.9	1.58
Mineral composition (%)		
C_3S	55.4	59.9
C_2S	18.53	12.71
C_3A	8.59	8.18
C_4AF	10.36	9.94
Free CaO (lime)	1.9	0

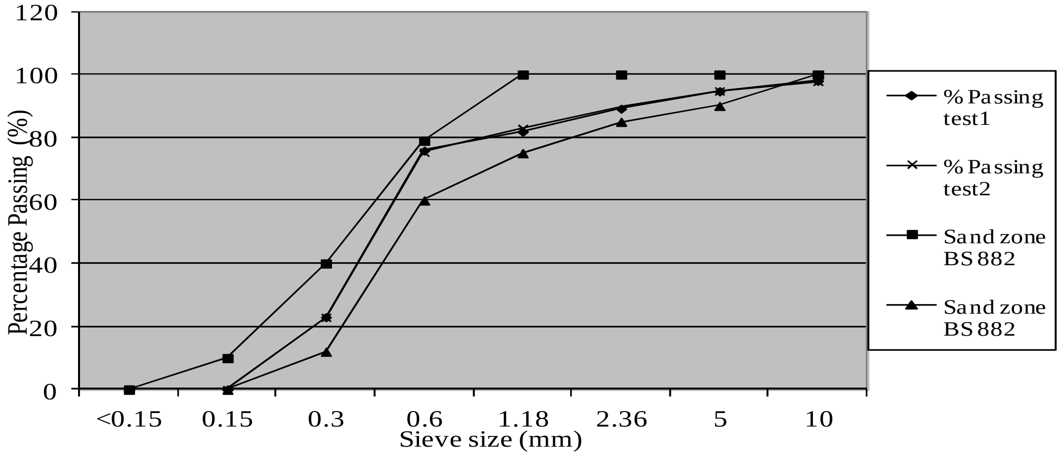


Figure 1. Particles size distribution of sand

2.2. Stable Foam

The stable foam used was protein-based (Noraite PA-1) surfactant with unit weight of between 70 to 80 gram/litre. The foaming agent was diluted in water with a ratio of 1:33 by water volume. Flow ability times are also calculated as the time will be used as a reference to add the required amount of foam into the mix. The density of LFC was determined by the volume of foam added for certain mixes. The stability of the foam is important in producing LFC. A foaming generator will act as a medium to transfer the chemical into stable foam.

2.3. Additives

Fly ash (FA), lime and polypropylene fibre (PF) with different percentages has been used in this study. Details properties and specifications of different additives used is shown in the Table 2.

Table 2. Properties of material used

	Fly ash	Lime	Polypropylene fibre
Size	5µm to 100µm	-	19mm length
Specific gravity	2.3	1.9	0.90 kg/dm^3
Material	Waste from electricity	Form quarry or mines	100% virgin polypropylene
E- modulus	-	-	3900 N/mm^2
Chemical composition	SiO_2 Al_2O_3 Fe_2O_3 CaO MgO SO_3 Na_2O	SiO_2 Al_2O_3 Fe_2O_3 CaO MgO R_2O LOI	C-33% H- 67%
Classification	Class F -ASTM C618	-	-

2.4 Mixture proportions

LFC with different densities and additives were prepared. Table 3 gives details mix proportion of LFC that will be used in this experiment. LFC samples of three densities of 600, 1000 and 1400 kg/m^3 were cast and tested for mechanical and thermal properties test. Only a constant cement-sand ratio of 1:1.5 and water-cement ratio of 0.45 were used for all bathes of LFC. A constant of cement to sand ratio of 1: 1.5 was used for all bathes of LFC.

The dry mix (cement and sand) was blended with water which had been fixed using a water-to-cement ratio of 0.45. The 0.45 water cement ratio was found acceptable to achieve adequate workability [9]. A 1:1.5 cement-sand ratio was chosen to achieve better compressive strength and 0.45 water-cement ratio was found acceptable to achieve adequate workability. It is important to achieve slump in a range of 23 to 27mm [10]. From each LFC mixture, tests were conducted on the fresh concrete to determine slump. The polypropylene fiber of the volumetric fractions 0.2 and 0.4% of the mixes were used in preparing mixes PF20-A, PF20-B, PF20-C, PF40-A, PF40-B and PF40-C respectively. The 15 and 30% of lime and fly ash were adopted for the LFC mixtures, respectively.

Table 3. Mix proportion of LFC with different density and additives

Sample	Remark	Mix ratio (cement: sand:water)	Composition of mixture Cement (kg)	Sand (kg)	Water (kg)	Dry density (kg/m^3)	Wet density (kg/m^3)	Foam volume (m^3)	Slump (mm)
600 kg/m^3									
Normal LFC	NF-A	1:1.5:0.45	15.32	22.97	6.89	600	700	0.050	25
0.20% PF	PF20-A						700	0.048	25
0.40% PF	PF40-A						710	0.046	25
15% lime	RL15-A						700	0.048	25
30% lime	RL30-A						720	0.046	26
15% FA	FA15-A						720	0.050	25
30% FA	FA30-A						710	0.051	25
1000 kg/m^3									
0.20% PF	NF-B	1:1.5:0.45	25.15	37.73	11.32	1000	1105	0.037	23
0.40% PF	PF20-B						1085	0.035	26
15% lime	PF40-B						1070	0.032	25
30% lime	RL15-B						1100	0.033	25
15% FA	RL30-B						1090	0.031	25
30% FA	FA15-B						1120	0.037	23
0.20% PF	FA30-B						1130	0.037	25
1400 kg/m^3									
0.20% PF	NF-C	1:1.5:0.45	42.49	63.73	19.12	1400	1500	0.029	25
0.40% PF	PF20-C						1480	0.028	25
15% lime	PF40-C						1510	0.029	25
30% lime	RL15-C						1500	0.025	25
15% FA	RL30-C						1510	0.017	25
30% FA	FA15-C						1530	0.030	25
0.20% PF	FA30-C						1530	0.029	25

3. EXPERIMENTAL SETUP

3.1 Mechanical Properties

To investigate the compressive and flexural strength of LFC, a total of 21 mixes were tested in the laboratory. An average of three samples was used for each mix to test the named parameters. The flow test for the mixes was carried out according to ASTM C230 with a targeted slump in a range of 23 to 27 mm. The slump test results are presented in Table 3. 100 mm cubic specimens were cast for the determination of compressive strength at the ages of 7, 28, 60 and 180 days. The test of compressive strength was achieved according to BS EN 12390-3:2009. Prism with size of 100 x 100 x 500 mm was used for the four-point flexural strength tests. The prismatic samples were tested for the flexural strength test at 28 days of curing age according to BS 12390-5:2009. The test specimens were left to stand for 24 hours, after which they were demould. After demolding, the specimens were immersed in the water till the age of test.

3.2 Thermal Properties

Thermal properties of LFC were investigated by using hot disk thermal constant analyzer. This machine is one of precise and convenient techniques to study the thermal properties by using Transient Plane Source (TPS) method. Censor was used between the samples to determine the thermal conductivity. The sensor is sandwiched between two samples. Size of sample is 25mm x 50mm with 10mm of thickness. The sample needs to be dried in oven to achieve dry state condition. The size of sample also needs to be larger than the diameter of the hot disk sensor in order to allow for not too short a transient recording. All the required data such as probing depth, time and power used need to be set until constant and allowable rate was accepted. All the data such as thermal conductivity (w/mk), thermal diffusivity (mm^2/s) and specific heat (MJ/m^3 K) were recorded. In this experiment, the samples tested were composite disks with a diameter, D of 6.4 cm and a thickness, x of 3.2 mm. Figure 2 shows the arrangement of Hot disk thermal constant analyzer for thermal conductivity test.

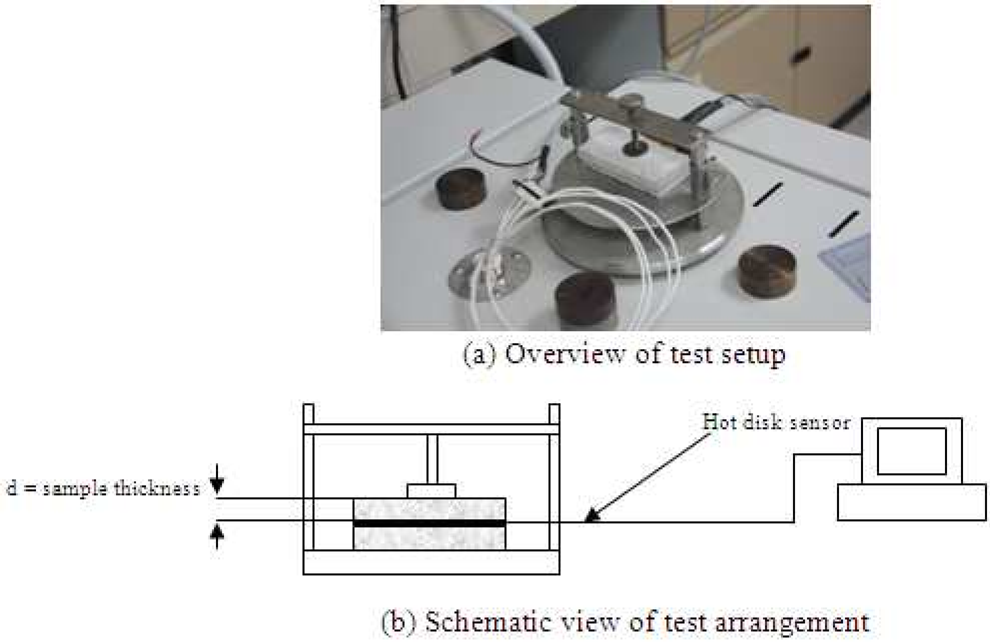


Figure 2. Set-up of Hot disk thermal constant analyzer for thermal conductivity test

3.3 Measurement of Porosity

Porosity value of LFC was determined through the Vacuum Saturation Apparatus for all densities considered for this study. The measurements of porosity were conducted on slices of 68mm diameter cores cut out from the centre of 100mm cubes. The specimens were dried at 105°C until constant weight had been attained and were then placed in a desiccator under vacuum for at least 3 hours, after which the desiccator was filled with de-aired, distilled water. The porosity was calculated using the following equation:

$$\varepsilon = \frac{(W_{sat} - W_{dry})}{(W_{sat} - W_{wat})} \times 100$$ ……………..(Eq. 1)

where ε is the porosity (%), W_{sat} is the weight in air of saturated sample, W_{wat} is the weight in water of saturated sample and W_{dry} is the weight of oven-dried sample.

3.4 Measurement of Void Size

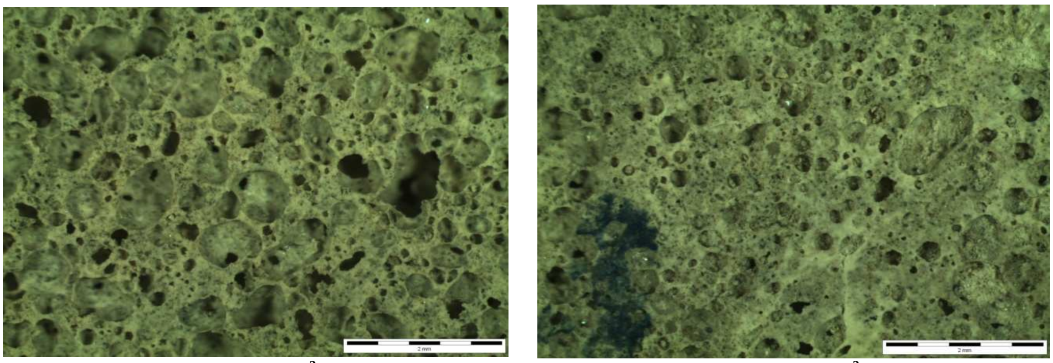
In sequence to examine the effect of pore size on thermal conductivity of LFC, it is necessary to establish the void size for each density. Mixtures from this study do not contain any coarse aggregate but consist of high amounts of air (foam). All specimens were vacuum-impregnated with slow-setting epoxy. To ensure consistency in results, all the specimens were prepared using similar techniques under the same environmental conditions. Foremost, the specimens of 45 x 45 mm size with a minimum thickness of 15 mm were cut from the centre of two randomly selected 100 mm cubes using a diamond cutter. The face of the specimen was cut perpendicular to the casting direction. Sized specimens were saturated in acetone to stop further hydration reaction before drying at 105 °C. To ensure the stability of the air-pore walls during polishing, the dried and cooled specimens were vacuum impregnated with slow-setting epoxy. The impregnated specimens were polished as per ASTM C 457. After polishing and cleaning, the specimens were dried at room temperature for 1 day. At last, an effective size 40 x 40 mm was considered for void size measurement.

RESULTS AND DISCUSSION

The properties of LFC can be influenced by the density and type of additives used. The densities are affected by the volumes of foam, water and filler used. Based on this statement, those factors could give different results that will affect the microstructure of LFC. Below are detailed studies on the investigation of LFC with different densities and various types of additives.

4.1 Compressive strength

Table 4 shows the results of compressive strength with different densities. The compressive strength tests were carried out up to 180 days.



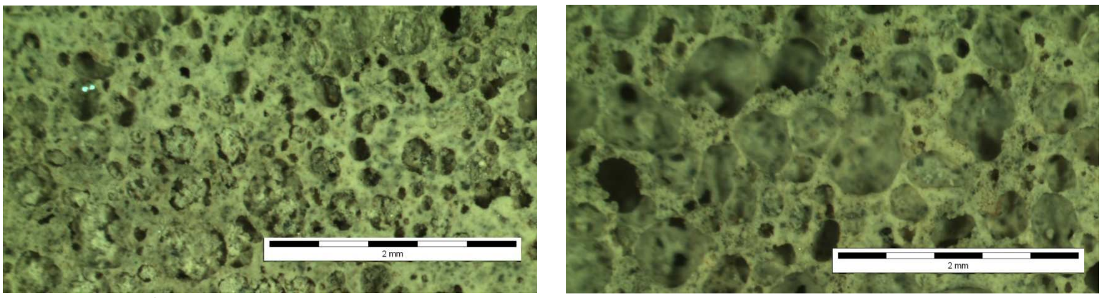
(a) 600 kg/m^3 **(b) 1000 kg/m^3**

Figure 3. Different formations of voids with different densities of LFC

Table 4. Compressive strength of LFC with different densities and additives

	Compressive strength (N/mm^2)				Porosity *(%)*
	7 days	*28 days*	*60 days*	*180 days*	
600 kg/m^3					
NF-A	0.4	0.5	0.5	0.6	69
FA15-A	0.2	0.5	0.7	0.6	69
FA30-A	0.1	0.3	0.7	0.6	70
RL15-A	0.3	0.4	0.7	0.6	72
RL30-A	0.5	0.5	0.7	0.6	70
PF20-A	0.3	0.5	0.7	0.6	70
PF40-A	0.4	0.6	0.8	0.7	71
1000 kg/m^3					
NF-B	2.6	2.9	3.1	4.5	49
FA15-B	2.2	3.2	3.3	3.8	50
FA30-B	1.6	2.8	3.8	4.6	51
RL15-B	1.9	2.8	3.1	4.0	56
RL30-B	2.0	2.9	3.1	3.6	55
PF20-B	1.8	2.2	2.4	3.0	54
PF40-B	1.6	2.1	2.5	2.7	55
1400 kg/m^3					
NF-C	6.3	8.1	10.1	10.1	36
FA15-C	8.2	11.4	11.8	12.2	35
FA30-C	7.9	11.8	12.1	13.2	35
RL15-C	7.5	9.5	11.2	11.1	36
RL30-C	6.9	10.3	10.9	11.2	37
PF20-C	5.4	8.3	8.3	8.6	36
PF40-C	6.7	8.3	8.3	9.7	35
Mortar					
Mortar	32.4	40.6	46.2	44.9	-

The amount of foam will result in different structure and formation of pore, void and matrix that interrelated with microstructure formation. Investigation in this study shows that density of LFC influences the mechanical properties due to the production of pores. The pores produced with each density differ in term of amount and size of pores. More pore and voids were produced with low density of LFC as more foam was added into the mix. It can be seen that more and large size of pores were produced with 600 kg/m^3 density compared to density of 1000kg/m^3(Figure 3). Based on Table 4, it can be concluded that density of LFC is governed by the porosity or amount of air content inside the material. Lower density of LFC indicates larger porosity value or greater amount of air contained (larger pore size). The pores merge with each other thus creating large size of pores. This will lead to weak cell structure between pores and matrix as there was insufficient surface area that connects the pore and matrix. As a result, the compressive strength of LFC was also reduced. The study also shown that, fly ash as a cement replacement gives the highest compressive strength results compared with other additives. The early development strength of fly ash was low due to the slow reaction of pozzolanic. Based on the data gathered shown in Table 4, 15% fly ash slightly increased compressive strength after 28 days. Whereas, with 30% fly ash, the strength increased after 60 days. It can be concluded that fly ash as a cement replacement needs a longer curing period as more fly ash is added. Yet, it was noticed that, there is a tendency for the strength to be reduced at 180 days. Fly ash that have small particle of size will react as filler and gives compact composition of structure thus providing additional strength. Based on Figure 4, fly ash that reacts as filler also will produce more uniform distribution of pores and prevents bubbles from merging with each other. A study done by Narayanan and Rammamuthy [11] shows that, pozzolanic reaction between cementitious material of fly ash and calcium hydroxide will form calcium silicate hydrate. The reaction result in small pore produce as the reaction complete. Hydration process of fly ash required longer curing period to react completely. Hydration process transform complex particle from different size and shape to another form with different phase. Different phase of hydration is the reason that affects the properties of LFC for longer period. Figure 5 shows phase transformation of particle by fly ash reaction as cement replacement. Encapsulation of spheres happens due to the hydration products of cement that precipitated on the surface of some of the particles of fly ash [11]. This rough texture of sphere particles shapes and size that occurred in hydration process is believed to affect the early strength [12]. Narayanan and Ramamurthy [13] claims that reaction of fly ash in hydration completed after 150 days. The sphere particle is then transformed to some prismatic members with semi crystalline gel.



(a) fly ash as cement replacement **(b) normal LFC**

Figure 4. Different formations of pore and voids with different additives

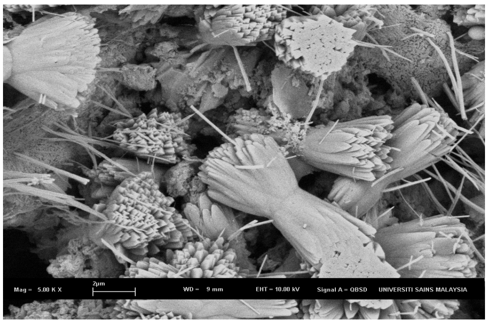
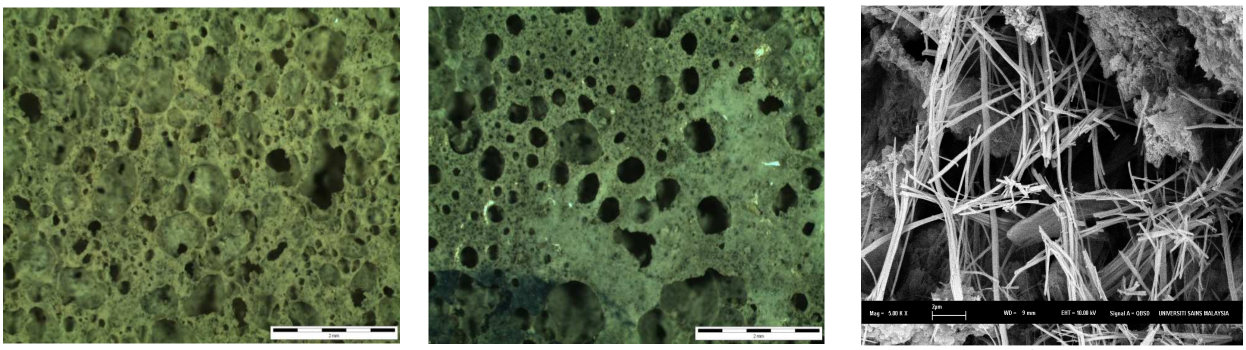


Figure 5. Transformation of complex particle by reaction of fly ash in hydration process

Lime as a sand replacement is a good binder but does not contribute to the strength of the concrete. Table 4 shows that lime only contributes to strength in the early age of LFC. Quicklime's release of heat during the hydration process is the reason why the lime contributes to the early developmental strength of LFC. The use of lime did not contribute more to strength as only a slight increase happens later in the age of LFC. Lime gives good results in the early development of strength and this is consistent with a study done by Barbhuiya et al. [14]. Figure 6(c) shows the microstructure formation with prismatic form of needles which cause low strength of LFC. Observation done using SEM shows that there was prismatic form of needles in hydration process that did not completely react. This happens due to insufficient hydration agent to react as most of it reacts quickly early in the process of hydration

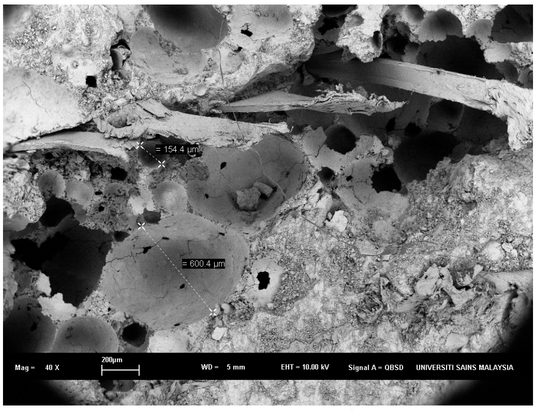


(a) normal LFC **(b) lime as aggregate replacement** **(c) microstructure formation by reaction of lime**

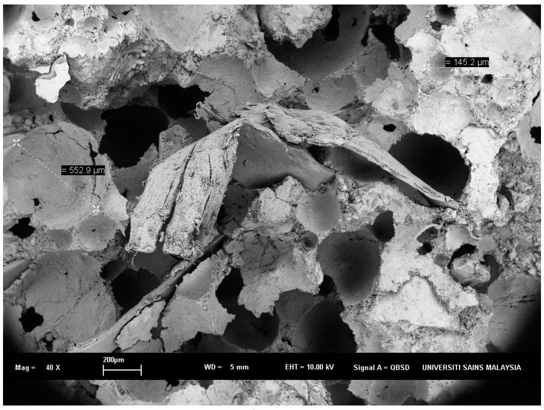
Figure 6, Different formations of voids

The present of fibres does not contribute to the strength development of the LFC at higher density. Based on the results, polypropylene fibre gives good results in compressive strength for low density of LFC. Adding polypropylene fiber to the LFC of lower densities (600 kg/m^3) gives good results in compressive strength compared to the higher densities (1000 kg/m^3 and 1400 kg/m^3 respectively). The compressive strength of LFC (density of 600 kg/m^3) with 0.2% and 0.4% fibre has increased by 17% and 35% respectively at 28 days. The compressive strength continuously increased by 44% and 54% at 60 days, after which there is a tendency for the strength to be reduced at 180 days. On the other hand, at the higher densities, fibres do not contribute to the strength of LFC.

The compressive strength obtained has been observed to decrease by 15-25%, due to the characteristics of polypropylene fibre as hydrophobic material, which retains water. Water that has been retained in the mix will affect the strength as it will create more voids. Amount of fiber will obstruct the voids which will cause weak bonding between the matrix. More addition of fiber will increase porosity and voids thus lowered the density of LFC slightly. Figure 7 shows microstructure formation of LFC with different percentage of fibre. It can be observed that pore and cavities surround the area of fibre that cause weak bond thus affect the strength of LFC.



(a) 0.20% fibre



(a) 0.40% fibre

Figure 7. Addition of fiber which results in production of pore and cavities that surround area of fiber

4.2 Flexural strength

Table 5. Flexural strength of LFC with different densities and additives

Mix	Flexural strength (N/mm^2)			
	7 days	28 days	60 days	180 days
	1000 kg/m^3			
NF-B	0.70	0.72	0.75	0.74
FA15-B	0.69	0.78	0.80	0.86
FA30-B	0.62	0.81	0.99	1.13
RL15-B	0.65	0.71	0.89	0.90
RL30-B	0.67	0.77	0.91	0.97
PF20-B	0.80	0.85	0.90	0.89
PF40-B	0.90	0.95	1.00	0.97
	1400 kg/m^3			
NF-C	1.82	2.00	2.13	2.17
FA15-C	2.12	2.31	2.49	2.61
FA30-C	2.06	2.60	3.11	3.29
RL15-C	2.23	2.51	2.79	2.90
RL30-C	2.35	2.75	3.01	3.18
PF20-C	2.09	2.19	2.30	2.36
PF40-C	2.30	2.49	2.68	2.71

Table 5 shows the flexural strength development from day-7 to day-180 for all the mixes having densities of 1000 kg/m^3 and 1400 kg/m^3. It is observed that the results have similar trend of development with the compressive strength result for most mixes. Flexural strength tests indicated that the fibres were capable to resist bending stress, which was influenced by inter-particle bonding characteristics in the microstructures. Table 5 shows mixes that ultimate flexural strength is obtained in the vicinity of 0.7 MPa to 3.29 MPa

4.3 Thermal Properties
4.3.1 Effect of density on thermal properties
LFC can be produce with a wide range of density. Each density gives different effect on the properties of LFC. Density of LFC influenced by the amount of foam added into the mix. In this study, different densities of LFC were cast and tested. The results show that the thermal conductivity of all LFC samples is positively proportionate with

the density (Table 6). For instance, the thermal conductivity for LFC reduced from 0.59 to 0.43W/mK and further reduced to 0.19W/mK for corresponding densities of 1400, 1000 and 600 kg/m^3, respectively.

This happened due to formation and size of pore that consist inside LFC. The thermal conductivity gives a better result as the density decrease. This is due to different formations and size of pores on the microstructure formation of LFC.

Table 6. Thermal properties of control LFC of different densities

Density (kg/m^3)	Thermal conductivity (W/mK)	Thermal diffusivity (mm^2/s)	Specific heat (MJ/m^3 K)	Percentage of porosity (%)	Moisture content (%)		
					7 days	28 days	60 days
600	0.19	0.35	0.54	69	15.3	14.8	13.3
1000	0.43	0.54	0.81	49	12.8	8.3	11.2
1400	0.59	0.60	0.98	36	11.6	10.1	10.1
Mortar	1.40	0.96	1.47	-	-	-	-

As been shown in Figure 3, it can be seen that more and large size of pores were produced with 600 kg/m^3 density. Taking mortar as a reference, all the sample porosities were calculated. Based from Table 6, it can be concluded that density of LFC is governed by the porosity or amount of air content inside the material. Lower density of LFC indicates larger porosity value or greater amount of air contained (larger pore size). As a result, thermal conductivity changes significantly with the porosity of LFC because air is the poorest conductor compared to solid and liquid due to its molecular structure. It should be pointed out that moisture is another factor that will influence the thermal properties of LFC. In this experimental study, all specimens were tested under dry state condition. Moisture content in each sample with different ages in the hydration process was shown in Table 6. Moisture content for 600 kg/m^3 density gives higher percentage of moisture compared with other densities. Based on the literature, moisture content changes the thermal conductivity. As LFC classified as porous material and characterized as hygroscopic, the thermal conductivity cannot be measured with specific moisture content. In this study, LFC with 600 kg/m^3 density contributes to thermal properties even with higher moisture content. Hygroscopic characterization of material is important to study as it will explain the behavior of porous material for thermal properties.

Table 7. Thermal properties of LFC with different densities and additives

Mix	Thermal conductivity (W/mK)	Thermal diffusivity (mm^2/s)	Specific heat (MJ/m^3 K)	Percentage of porosity (%)	Moisture content (%)		
					7 days	28 days	60 days
600 kg/m^3							
NF-A	0.19	0.35	0.54	69	15.4	14.8	13.3
FA15-A	0.17	0.38	0.46	69	14.0	12.4	11.7
FA30-A	0.16	0.39	0.42	70	13.9	12.5	11.5
RL15-A	0.16	0.34	0.49	72	16.6	16.4	15.5
RL30-A	0.20	0.48	0.48	70	17.2	16.6	15.3
PF20-A	0.18	0.32	0.56	70	14.2	13.0	12.2
PF40-A	0.18	0.30	0.59	71	16.5	14.2	13.4
1000 kg/m^3							
NF-B	0.43	0.54	0.81	49	12.8	8.3	11.2
FA15-B	0.38	0.49	0.79	50	14.7	10.9	12.6
FA30-B	0.36	0.52	0.69	51	13.1	12.1	12.0
RL15-B	0.31	0.46	0.67	56	12.4	14.8	14.4
RL30-B	0.31	0.44	0.71	55	11.8	15.8	15.5
PF20-B	0.31	0.43	0.73	54	13.4	12.0	12.5
PF40-B	0.32	0.42	0.75	55	14.1	14.8	13.1
1400 kg/m^3							
NF-C	0.59	0.60	0.98	36	11.6	10.1	10.1
FA15-C	0.58	0.62	0.95	35	12.4	11.1	10.3
FA30-C	0.61	0.65	0.93	35	11.8	10.7	9.3
RL15-C	0.59	0.60	0.99	36	13.5	11.0	11.0
RL30-C	0.53	0.54	0.99	37	15.5	14.1	14.0
PF20-C	0.60	0.66	0.91	36	13.4	10.9	10.1
PF40-C	0.56	0.64	0.89	35	12.2	10.9	9.9
Mortar							
Mortar	1.4	0.97	1.47	-	-	-	-

4.3.2 Effect of additives on thermal properties

Fly ash, lime and polypropylene fiber were used with different densities and percentages. Table 7 shows the result of thermal properties of LFC with different additives. Figures 8, 9 and 10 show the effect of different admixtures on thermal conductivity for 600 kg/m^3 , 1000 kg/m^3 and 1400 kg/m^3 density respectively. Fly ash and lime were used as cement and aggregate replacement. Both additives can be classified as fillers. Fly ash and lime react chemically in the hydration process. There is some complex particle produced that will have an effect on the microstructure formation of LFC. This will result in different thermal properties. Polypropylene fiber used as an addition to the mix will affect the formation and size of pores and does not react chemically. Lime as additives gives a better results on thermal properties of LFC compared with other additives. Principally, each additive used will give different reaction and result in different thermal value. This happened due to several factors, which will be investigated and explain in the next sections.

Fly ash as cement replacement can improve the properties of LFC. For this study, class F fly ash based from ASTM C618 was used. Fly ash characterized as pozzolan material improves the strength with a longer curing period. The utilization of fly ash also will reduce green house emission effects that are produced by the cement hydration process. Fly ash will react as filler which will result in compact microstructure and also will produce a good binder. Due to compact composition of microstructure, closed-cell structure was deformed. Addition of fly ash will reduce the heat created as the hydration process goes on.

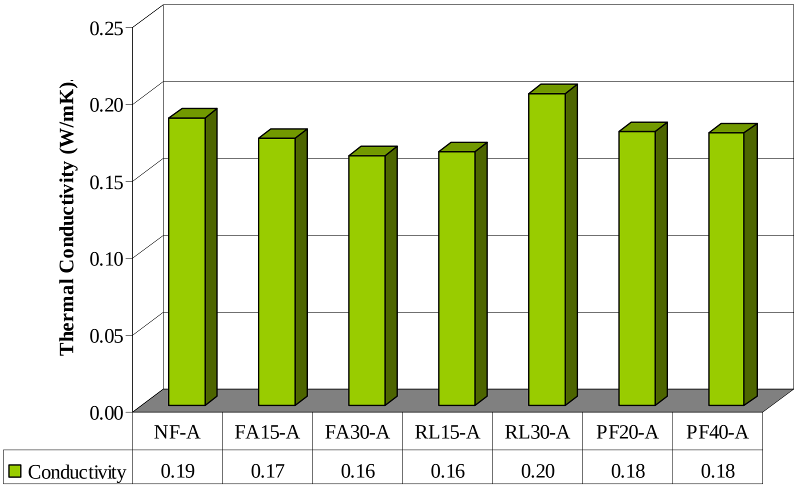


Figure 8. Effect of different admixtures on LFC thermal conductivity for 600 kg/m^3 density

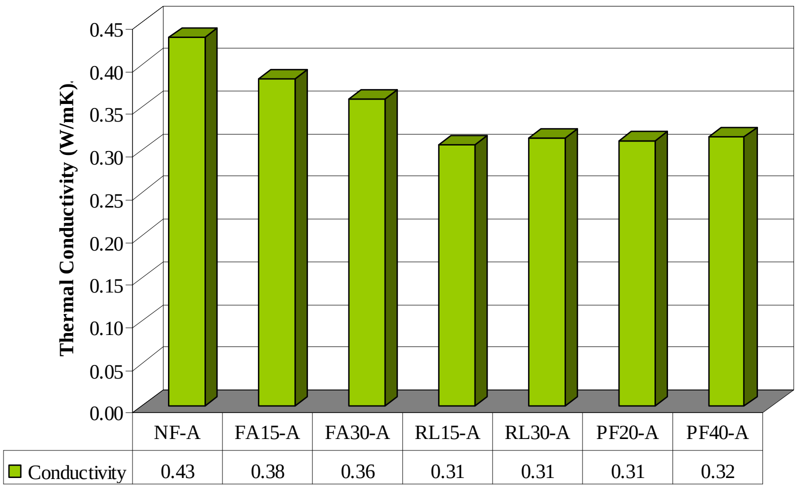


Figure 9. Effect of different admixtures on LFC thermal conductivity for 1000 kg/m^3 density

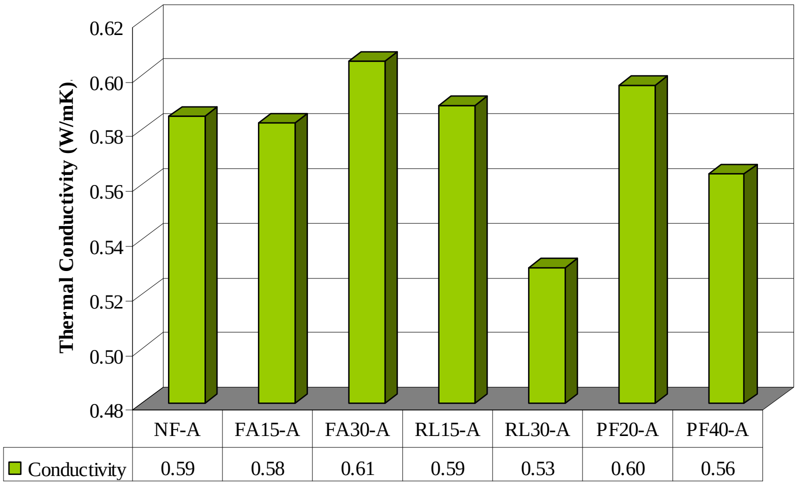


Figure 10. Effect of different admixtures on LFC thermal conductivity for 1400 kg/m^3 density

High amount of fly ash will reduce the usage of cement thus reduce the heat. The result shows that high percentage of fly ash results in good thermal conductivity as fly ash reduces and controls the heat of temperature. Fly ash as additives also reduces the amount and size of pores. Fly ash as filler prevents the bubbles from merging with each other and gives uniform distribution of pore. As been shown in Figure 4, it can be noticeably seen from both figures that incorporating fly ash in LFC mix reduced the size and amount of pore. This will influence the thermal properties of LFC as well. It should be pointed out that there are some particles produced in the hydration process as shown in Figure 5. The particle produced is another factor to be considered in determining the thermal properties of LFC as it changed the microstructure formation. By using fly ash, it could be assumed that it only contributes in slender enhancement of thermal properties of LFC. The heat and temperature control is the main reasons that assist LFC performing better thermally. Detail investigation on the complete formation of microstructure will lead to better perceptive on how thermal properties were affected by adding fly ash. On the other hand, lime was also used as an aggregate replacement for this investigation. It is classified as filler due to its finer size, and it reacts chemically during the hydration process. Lime also will contribute to closed-cell structure formation of LFC. Addition of lime causes a decrease in porosity (Barbhuiya et. al, 2009). Figure 6 proved that the pore size decrease compared with normal LFC. This will reduce the effectiveness of thermal conductivity for LFC as well. Figures 11, 12 and 13 show the effect of different admixtures on thermal conductivity for 600 kg/m^3, 1000 kg/m^3 and 1400 kg/m^3 density correspondingly. It can be seen from these figures that lime as aggregate replacement gives a higher percentage of porosity compared with other additives.

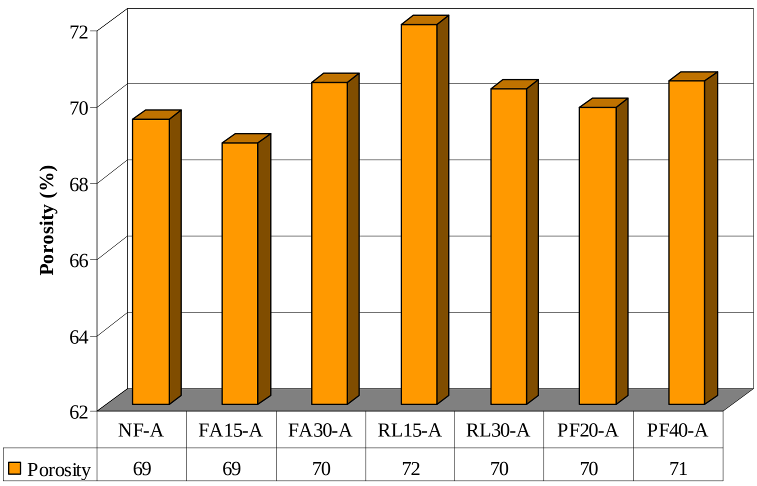


Figure 11. Effect of different admixtures on LFC porosity for 600 kg/m^3 density

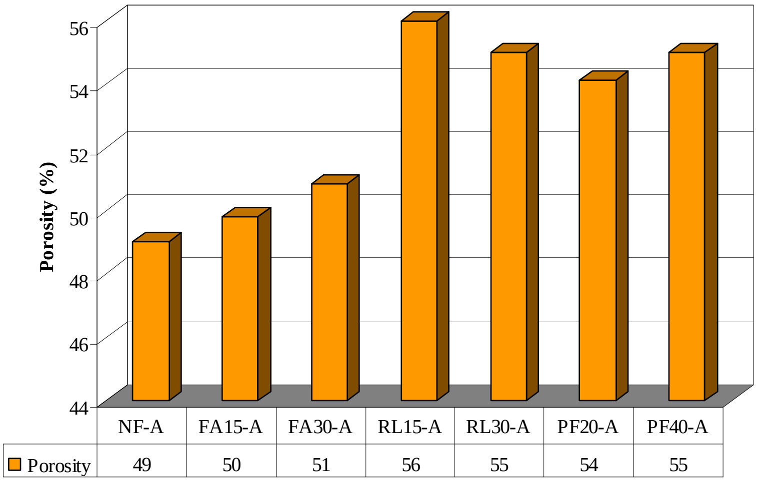


Figure 12. Effect of different admixtures on LFC porosity for 1000 kg/m^3 density

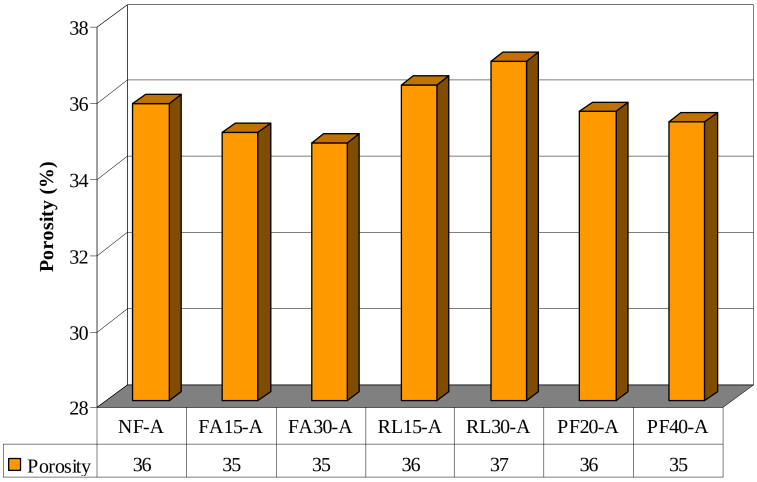


Figure 13. Effect of different admixtures on LFC porosity for 1000 kg/m^3 density

As been mentioned earlier, polypropylene fibers with 19mm long were also employed at a 0.20% and 0.40% by volume in this study. Polypropylene fiber characterized as hydrophobic will retain water. Air will be retained during mixing process leading to more voids and high porosity. In this experimental investigation, higher addition of fiber results in higher percentage of porosity. The result from Table 7 clearly shown that LFC with 0.40 percent of fiber gives better thermal properties compared with LFC with 0.20 percent of fiber. Therefore, higher addition of fiber will create more pores thus lead to better thermal properties. Even though the moisture content is slightly higher compared with normal LFC, it still gives better thermal conductivity value.

CONCLUSION

Both mechanical and thermal properties of LFC were investigated in this experimental study. It can be summarized that formation of microstructure plays an important role in determining the mechanical and thermal properties of LFC. Some complex particles produced will affect the microstructure formations that are interrelated with pore, void and matrix. Weak connection between pore, void and matrix cause low mechanical strength. Fly ash as cement replacement contributes most for mechanical properties of LFC. Based on discussion, below are conclusions on mechanical and thermal properties of LFC integrating various additives.

1) Different densities give different mechanical properties of LFC. Low density of LFC gives low mechanical properties but good in thermal as it was influenced by the production of pores. Large size and number of pores cause weak bonding of matrixes thus affect the mechanical properties of LFC at low density

2) Fly ash as cement replacement contributes to the mechanical properties of LFC. Both compressive and flexural strength increased with longer curing period as slow pozzolanic reaction takes place. Fly ash helps in producing

small size and uniform distribution of pore. This will aid to provide better strength as each pore and void are well connected.
3)Lime as aggregate replacement did not contribute much on mechanical but good in thermal. Acceleration of pozzolanic reaction in the presence of hydrated lime causes good early development strength for LFC. The prismatic form of needle produced in hydration process causes lack interlocking between each microstructure element thus affects the mechanical properties.
4) Polypropylene fibre produces more pore and void as it has hydrophobic characterization. Higher addition of polypropylene fiber in the mix produced more pores. This will affect the compressive strength as more pore and void are created. The present of fibres does not contribute to the strength development of the LFC at higher density but gives good results in compressive strength for low density of LFC.

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