



Effect of Curing Method on Properties of Lightweight Foamed Concrete

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Abstract

Lightweight construction is aimed to achieve a sustainable feature by reducing transportation frequency and construction materials usage during construction phase. Lightweight precast concrete may serve an alternative for the lightweight construction. There are rarely application can be found for structural members as lightweight panels always to be used for secondary or non-load bearing members. This paper presents an experimental study on properties (compressive strength, splitting tensile strength, water absorption) of lightweight foamed concrete (LFC) at two different curing methods. LFC with densities of 1500, 1700, and 1800 kg/m³, cement-sand ratio of 2:1 and water-cement ratio of 0.5 were investigated. The results showed LFC can be produced with the properties of density range of 1500 to 1800 kg/m³ and corresponding compressive strength of 10 to 39 MPa. The higher the density of LFC, the less the water absorption for all the curing method considered, the highest and the lowest water absorption was 11.3% and 2.0% for 1500 kg/m³ cured in water and 1800 kg/m³ cured in air respectively. Compressive strength of LFC increases with age and density while water cured LFC has high compressive strength. Splitting tensile strength increases with density of LFC, but air cured LFC has more splitting tensile strength than water cured of the same density. The highest splitting tensile strength recorded was 3.92 MPa for 1800 kg/m³ cured in air, which was about 16% of its compressive strength at 28 days of curing age. These properties are important and can be applied to LFC precast structural members with air or water curing method which have less references for LFC in structural usage.

Keywords: Lightweight; foamed concrete; curing; density; strength

1. Introduction

One of the advantages of lightweight concrete in construction projects is to reduce the self-weight of the concrete structure; thereby reducing the size of the structural members such as columns, beams, foundations and other load bearing members [1]. Foamed concrete is an aerated light-weight concrete produced by mixing cement, sand and water to form cement paste, the cement paste then mixed with pre-formed stable foam produced from foam generator. Foamed concrete can be designed to have any density within the range of 300 – 1850 kg/m³ dry density [2]. Lightweight foamed concrete (LFC) were commonly used for void filling, roof insulation, trench reinstatement, bridge abutment, thermal insulation, road and pavement sub-bases, precast blocks and panels [3]. Lightweight, ease of fabrication, durability and cost effectiveness are some of the advantages of LFC that attracts a lot of attention from industry [4].

Lim et. al. [5] presented other advantages such as excellent thermal and sound insulation, low density, self-compacting, and high flow ability made LFC commonly used for structural and non-structural purpose by construction industry. Mydin [6] studied the possibility of using LFC in load bearing composite wall panels for low rise structure. The result showed that it is possible to design composite walling system to resist floor loads using LFC in a low rise residential structure. Investigations on strength of composite sections with foamed and lightweight concrete was conducted on circular and square concrete filled steel tube columns and simply supported short beams. The result shows that LFC contribution to squash load

is insignificant, while its contribution to the flexural strength is significant [7].

A lot of studies were carried out on LFC and its application, but very few researches are available on structural LFC and its application; as such the properties of structural LFC need to be investigated thoroughly. The purpose of this paper is to presents the study on properties of structural light weight foam concrete at different curing method. When LFC is being used as an infill material in composite structures, in most cases, it is not possible to cure the LFC with water (for example in concrete filled steel tube columns). Therefore, LFC properties cured in water and Air need to be explored. Experimental investigations were carried out on 1500kg/m³, 1700kg/m³, and 1800kg/m³ LFC densities at 2:1 cement-sand ratio and water-cement ratio of 0.5.

2. Previous Investigation on Structural Properties of LFC

The amount of air content in LFC, resulting from mixing with foam, significantly affect the strength and other properties. LFC gained a lot of popularity in some countries like Japan, United Kingdom and Europe [8]. Lightweight concretes have been classified based on its properties [9], the classification is presented in Table 1.

Table 1: Classification of light-weight concrete based on concrete properties



Classification of light-weight concretes. Property	Structural	Structural / insulating	Insulating
Compressive strength [MPa]	>15.0	>3.5	>0.5
Coefficient of thermal conductivity [W/m.K]	-	<0.75	<0.30
Approximate density range [kg/m ³]	1600-2000	<1600	<<1450

Concrete must be subjected to appropriate environment at the early stages of hardening for achieving a good quality; curing is the procedures followed for promoting cement hydration. Generally, control of temperature and of the movement of moisture in to and from the concrete is termed curing procedures. They both affect the strength of concrete, temperature movement in to and from the concrete affect both strength and durability of concrete. Concrete curing procedures varies depending on the conditions on site and on the size, shape, and position of the concrete member considered. The effect on curing conditions on the strength of concrete is lower in the air entrained than non-air entrained concrete [10].

The properties of structural LFC have been investigated using fly ash, polypropylene fiber and silica fume [11, 12]. Sand was replaced by fly ash in the mix; silica fume and polypropylene fiber were added to enhance the properties of LFC. Compressive strength and splitting tensile strength were among the properties investigated. It was reported that a compressive strength of 10-50 MPa can be achieved with foam concrete density of 800-1500kg/m³ using silica fume and polypropylene fiber. Addition of silica fume and polypropylene fiber significantly enhanced compressive strength of LFC. Propylene fiber also improves the splitting tensile strength.

Experimental study was carried out to determine the effects on properties of foam concrete by replacing cement content up to 75% by weight with both classified and unclassified fly ash [13]. The results showed the porosity of the LFC cured for one year was dependent on dry density of the concrete, not on amount or type of fly ash used. Permeability of LFC was determined by water vapour permeability, water absorption, and the amount of water absorbed doubled that of corresponding cement paste; also it did not depends on the entrained air volume, amount or type of fly ash.

Properties of fresh and hardened foamed concrete were studied [5]. Various sand gradations ranging from 2.36 mm to 0.6 mm were used to produce the foamed concrete with density of 1300kg/m³, the specimens were cured in water and air. The results showed that the sample made with finer sand produced higher compressive strength, flexural toughness and flexural strength than the sample made with coarser sand. Also, for better compressive and flexural strength development, total water curing is required up to 56 days than curing in air.

The properties of LFC were investigated by replacing the cement and fine sand with silica fume and fly ash [14]. The study was carried out on 1300 to 1900 kg/m³ concrete density; among the properties studied are consistencies, mechanical and thermal properties. The results showed that 6 to 23 MPa compressive strength of foam concrete can be achieved by replacing some amount of the cement and sand with silica fume and fly ash.

Effects of various dimensions and profiles on the axial compressive strength of LFC were investigated [15]. The mixes with dry target density of 1250kg/m³ were prepared. Cubes, cylinders and prism of various dimensions were casted and cured for 7 and 28 days. All the samples were cured inside plastic sheet for curing duration. It was concluded that the cylinder specimen has a small change in compressive strength when length to diameter ratio change from 1.0 to 2.0 as compared to cube specimen. Cube specimens carried more load than cylinder specimen when all the dimension and volume were identical [15].

An experimental study was performed on compressive strength and tensile strength of LFC containing pulverized bone as partial replacement of cement [16]. Among the properties investigated are workability, testing and plastic density, compressive strength, and tensile strength at the designated density of 1600kg/m³; the pulverized bone used in the mix was varied from 0 to 20% at a constant interval of 5%. Workability of fresh foam concrete was obtained

from the slump test, 150mm cubes were used for the determination of compressive strength and testing density, 150 × 150 × 750 mm unreinforced beams were used to obtain flexural strength and 150 × 300 mm cylinders were used for splitting tensile strength. Foamed concrete samples were made with and without pulverized bone. All the samples were cured in water and air for 28 days. From the results, for all the pulverized bone replacement levels, air cured samples produced higher strength than the water cured samples. And there is no significant difference between the samples with and without pulverized bone replacement. The investigation was concluded LFC can be applied for structural applications.

An investigation was performed on LFC made with sand and without sand, targeted 1900 kg/m³ plastic density [17]. It was concluded that the density of foam concrete depends on the amount of foam added in the foam concrete mixture; the higher the foam in the mixture, the less the density of the foam concrete. Also fine aggregate effectively increase the compressive strength of foam concrete. Panels made of higher density foam concrete can be demoulded after 24 hours, but panels made of lower density foam concrete needs at least 3 days before demolding. Water absorption of light weight foam concrete is less than 5% by volume. Compressive strength of foam concrete increases with age, and the increase is virtually linear up to the first one year. The strength development of foam concrete is higher than in normal weight concrete, as such curing method must ensure moisture retention for long period in foam concrete panels and building blocks.

Applications of LFC in building and construction are on increase. Recently, they are been used as structural materials in building houses and schools in countries like Russia, Libya, Indonesia, Brazil, Egypt, Singapore, Saudi Arabia, and Mexico. SMART tunnel project in Kuala Lumpur was the first major applications of foamed concrete in Malaysia [18]. Foam concrete block with density of around 1800Kg/m³ with 28 days compressive strength of about 3 MPa were used. The foam concrete blocks serves as a protection to the diaphragm wall for tunneling machine [18]. The applications of LFC were summarized [19] and depicted in Table 2.

Table 2: LFC applications based on its density

Density (kg/m ³)	Application
300 – 600	Replacement of existing soil, soil stabilization, raft foundation
500 – 600	Currently being used to stabilize a redundant, geotechnical Rehabilitation and soil settlement. Road construction
600 – 800	Widely used in void filling, as an alternative to granular fill. Some such applications include filling of old sewerage pipes, wells, basement and subways
800 – 900	Primarily used in production of blocks and other non-load bearing building element such as balcony railing, partitions, parapets, etc
1100 – 1400	Used in prefabrication and cast-in place wall, either load bearing or non-load bearing and floor screeds.
1100 – 1500	Housing applications
1600 - 1800	Recommended for slabs and other load bearing building element where higher strength required

The versatile characteristic of LFC application were explained by many researchers, notably in [20, 21]: *Lightweight*: The density is about 50% to 80% of the normal weight concrete density. Due to its low density, it reduces the weight of a structural element by about 25%. These will results in total decrease in weight of a structure to about 30 to 40% when a normal weight concrete is substituted by LFC in construction; *Heat and Sound Insulation*: Because of the uniform pores present in the foam concrete, it prevents heat and cold exchange by controlling the air. It also has very low thermal conductivity of about 0.1 W K/m for common foamed concrete in practice, which is around 14 times less than that of normal weight concrete. Sound insulation is due to the presence of distributed closed pores in the foamed concrete, which make it to have very

good performance in sound movement; **Fire resistance:** The constituent materials of foamed concrete do not have chemical characteristic of spontaneous combustion and the presence of distributed pores in the foamed concrete make it to have good fire resistance; **Seismic performance:** Foamed concrete is light in weight, having less density and modulus of elasticity when compared to normal weight concrete. It can easily absorb the impact of load when it is subjected to earthquake wave; and **Frost resistance:** porous nature of light weight foamed concrete making it to resist frost action on concrete.

The possibility of using LFC in load bearing composite wall panels for low rise structure has been studied [22, 23]. LFC density of 1000kg/m³, 2:1 cement-sand ratio, and water-cement ratio of 0.5 were used for the research. The result shows that it is possible to design composite walling system to resist floor loads using LFC in a low rise residential structure.

3. Experimental Investigation

3.1. Materials

Ordinary Portland cement, river sand, tap water, silica fume and synthetic foaming agent were used for this study. Silica fume were used as additive in the mix. Silica fume can make a meaningful increase of foamed concrete compressive strength up to at most 25%. The increase in compressive strength depends on the volume of foam added. Therefore, with appropriate volume of foam added, foamed concrete strength can significantly be increased [12].

Ordinary Portland cement (Type I): ordinary Portland cement from Tasek Corporation Berhad was used for this research. The chemical composition of ordinary Portland cement used is presented in Table 3

Sand: Preferred sand is mostly from the river, for this research, river sand was used which is free from any contamination. Raw (unsieved) sand was used in this research, which was got directly from the river contains no impurities.

Water: potable water was used for the foam concrete mixing and curing. Water for concrete mix should be free from acids, oils, salts, organic matter and alkalis. The oil used in the mould will not have harmful effect on the foamed concrete, because the foams are already embedded in mortar.

Silica fume: The Silica fume used for this research was densified silica fume for high performance concrete manufactured by Greco Chem. Company. Its specific gravity ranges between 2.1 to 2.4 kg/lit and of bulk density 550 - 650 kg/m³. Typical dosage rates ranges from 5 to 10% by weight of cement. Chemical composition of the silica fume is presented in Table 3.

Foam: Foam agents are made to produce stable foam (air bubbles) that resist applied forces when mixing, casting and curing of foam concrete. Foam agent solution is made up of surfactant one part and 5 to 20 parts water.

Table 3: Chemical composition of ordinary Portland cement used.

S/N	Oxide	Composition (%)	
		OPC	Silica fume
1	SiO ₂	21.28	90
2	Al ₂ O ₃	5.60	1.2
3	Fe ₂ O ₃	3.36	2.0
4	CaO	64.64	1.0
5	MgO	2.06	0.6
6	SO ₃	2.14	0.5
7	Na ₂ O	-	0.8
8	K ₂ O	-	0.8
9	Total alkalis	0.05	-
10	Insoluble residue	0.22	-
11	Loss on ignition	0.64	6.0

3.2. Mix Design

Cement- sand ratio of 2:1 and water-cement ratio of 0.5 were used for all the LFC mix. The above ratios were found producing

comparatively good compressive strength and sufficient workability respectively [24, 25]. Properties of LFC samples of 1500 kg/m³, 1700 kg/m³ and 1800kg/m³ densities were investigated. All the samples were casted in structures and materials laboratory Faculty of Civil Engineering, Universiti Teknologi Malaysia. Table 4 presents details of mix proportions for the LFC. Silica fume was added as 10% of cement weight in each mix.

Table 4: Mix constituents for LFC

Target dry density, kg/m ³	Cement, kg/m ³	Sand, kg/m ³	Water, kg/m ³	Silica fume, kg/m ³
1500	750	375	375	75
1700	850	425	425	85
1800	900	450	450	90

Mortar mix was prepared in the concrete mixer before mixing with stable foam. Stable foam was prepared by diluting synthetic foaming agent in water at a ratio of 1:30 synthetic foaming agent to water ratio by volume. The solution was then compressed by pressurized air in the foam generator there by producing the stable foam at a density of 45kg/m³. Stable foam produced from the foam generator was weighed in a container of known volume. The density of cement mortar was then measured to obtain a guide for the accurate amount of stable foam to be added. Required amount of stable foam was then added to the cement mortar and mixed in the concrete mixer. The density of the fresh foam concrete was then measured and maintained within the range of ±50 kg/m³.

3.3. Properties of LFC Specimens

Cubes size of 70 × 70 × 70 mm and cylinder mould of size 100 mm diameter and 200 mm height were used throughout this research. Both the cubes and cylinders were cured in water and air for 7, 28 and 56 days. All tests were carried out in triplicates, and the average values were reported.

3.3.1. Density

Fresh density of mortar and LFC mix was measured prior to casting. Dry density of LFC samples cured in water and air for 7, 28 and 56 days were obtained in accordance with BS EN 12390- 7 [26].

3.3.2. Water Absorption

Cubes LFC specimen was used for water absorption test in accordance with BS 1881 – 122 [27]. Specimens were cured in water and air. The samples were oven dried for 72 hours at 105±5°C. It was then removed and cools for 24 hours in an air tight dry vessel. The cool sample was then weigh and immersed in water for 30 minutes, mass of the sample after immersion in water then recorded. The water absorption was calculated as Eq. 1. The water absorption test was carried out at 28 days of curing, and the samples were spaced for oven drying as shown in Figure 1.

$$\% \text{ water absorption} = \frac{\text{mass of Immersed sample} - \text{mass of oven dried sample}}{\text{mass of oven dried sample}} \times 100 \quad (1)$$



Fig. 1: Oven drying samples for water absorption test

3.3.3. Compressive and Splitting Tensile Strength

Total of 81 cubes and 18 cylinders of LFC were tested and cured for 7, 28 and 56 days in water and air. Samples was then removed

and tested for compression in accordance to BS EN 12390-3 [28]. Cylindrical specimen was used for this test in accordance to BS EN 12390-6 [29] as shown in Figure 2. The maximum fracture load was recorded, and the splitting tensile strength was calculated using the relation of Eq. 2.

$$F_{ct} = \frac{2F}{\pi LD} \tag{2}$$

where F_{ct} is the splitting tensile strength in MPa, F is the maximum load in N, L is the height of the specimen in mm, and D is the diameter of the specimen in mm.



Fig. 2: Splitting tensile test set-up

4. Results and Discussion

4.1. Fresh Density

It can be seen from Table 5 that the stability of LFC tends to unity for all the target densities. It shows that the foam was able to mix with mortar thoroughly without collapsing. Stability is the ratio of fresh density to hardened density of LFC. Therefore, stability of foam concrete depends on quality of foam used.

Consistency is the ratio of fresh density to the designated density. Consistency depends on the amount of foam added to the LFC mix. For this research, the consistency tends to unity. The density of LFC depends on stability and consistency of the mix, and the strength of LFC depends on density, as such stability and consistency of LFC mix affects the strength of LFC.

Table 5: Densities of LFC specimens at 28 days of curing

Targeted density, kg/m ³	Curing condition	Fresh density, kg/m ³	Hardened density, kg/m ³	Consistency	Stability
1500	Water	1545	1604	1.03	0.96
	Air		1589		0.97
1700	Water	1749	1793	1.02	0.98
	Air		1724		1.01
1800	Water	1850	1909	1.02	0.97
	Air		1874		0.99

4.2. Water Absorption

Water absorption of LFC samples cured in water is higher than that of LFC samples cured in air for all the densities investigated in this research. The water absorption of LFC with density of 1800kg/m³ is 4.0% and 2.0% for water and air cured LFC respectively, it is less than 5.2% and 2.9% water absorption at 1700kg/m³ for water and air cured respectively. LFC sample with 1500kg/m³ density has 11.3% and 9.0% water absorption for water and air cured respectively, which is higher than that of 1700k/m³ and 1800kg/m³ densities.

From the result in Figure 3, it can be shown that the higher the density the less the water absorption. Density of LFC depends on amount of foam added, the more the foam and the less the density and also the porosity, and the higher the porosity the more the water absorption.

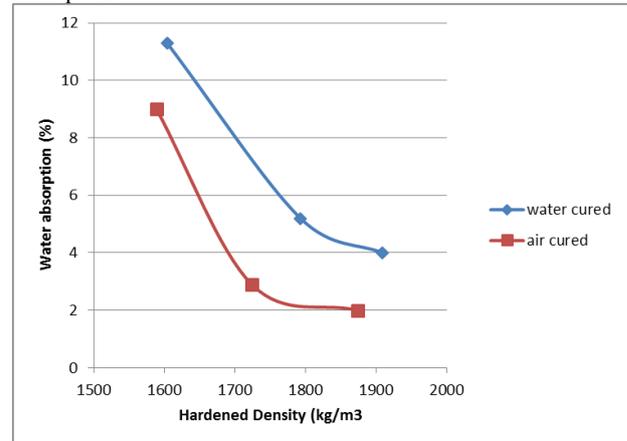


Fig. 3: Water absorption against hardened density of LFC cured in water and air

4.3. Compressive Strength

Compressive strength of LFC increases with increase in curing age for both densities and different curing condition of LFC as shown in Figure 4 and Table 6. The minimum compressive strength was recorded for LFC of 1500kg/m³ cured in air as 10.01 MPa, 12.67 MPa and 13.20 MPa for 7, 28, and 56 days respectively; the increase in strength is about 26.6% and 4% at 7 to 28 days and 28 to 56 days respectively. While the highest strength recorded for 1800 kg/m³ LFC cured in water was 27.11 MPa, 35.21 MPa, and 39.38 MPa for 7, 28, and 56 days respectively; which represent 29.9% and 11.8% increase in strength between 7 to 28 days and 28 to 56 days respectively. Foamed concrete compressive strength displayed continuous increase with age. The rate at which the compressive strength developed was initially greater and decrease with increase in age.

The compressive strength of LFC cured in water for all the densities considered is higher than that of the LFC sample cured in air at all the curing ages as shown in Figure 5. The increase in strength is high for when the density of LFC is also high. The compressive strength of LFC at 7, 28 and 56 days cured in water is 27.11, 35.21, and 39.38 MPa respectively; while that of LFC cured in air at 7, 28, and 56 days is 21.14, 24.05, and 25.05 MPa respectively.

Table 6: Compressive strength of LFC at different curing method for the densities considered

Design density, kg/m ³	Compressive strength, MPa					
	Air curing			Water curing		
	7d	28d	56d	7d	28d	56d
1500	10.01	12.67	13.2	10.40	13.51	16.35
1700	15.19	17.30	18.05	16.00	20.74	21.14
1800	21.14	24.05	25.05	27.11	35.21	39.38

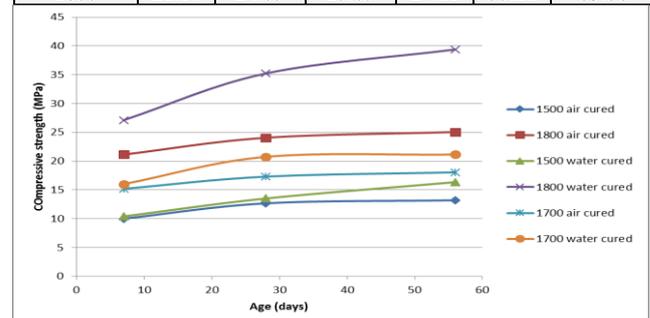


Fig. 4: Compressive strength against curing age of LFC

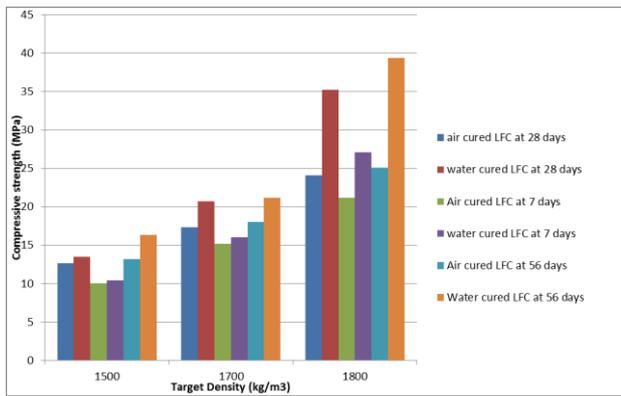


Fig. 5: Compressive strength against design density of LFC

4.4. Splitting Tensile Strength

Splitting tensile strength of LFC increases with increase in density for both water and air cured LFC specimen at 28 days curing. From Figure 6, it can be seen that the splitting tensile strength of LFC cured in air increases sharply with increase in density than LFC cured in water. The highest and the lowest splitting tensile strength recorded is 3.92 MPa and 1.32MPa for 1800 kg/m³ air cured and 1500kg/m³ water cured LFC respectively. The values recorded are above 0.17MPa minimum value as recommended by ASTM C869-91 [30] for lightweight concrete. From Table 7, splitting tensile strength ranges between 8 to 17% of the compressive strength of LFC at 28 days water and air curing.

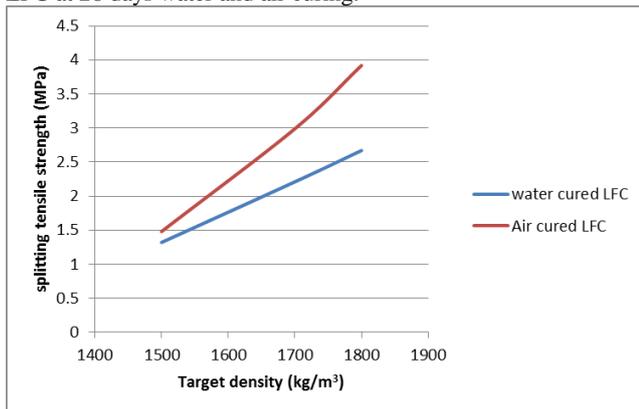


Fig. 6: Splitting tensile strength against target density at 28 days curing

Table 7: Comparison between Splitting tensile strength and Compressive strength of LFC at 28 days curing

Target density, kg/m ³	Curing method	Strength, MPa		Ratio, fs/fc
		Compressive strength, fc	Splitting tensile strength, fs	
1500	water	13.51	1.32	0.10
	air	12.67	1.48	0.12
1700	water	20.74	2.21	0.11
	air	17.30	2.99	0.17
1800	water	35.21	2.67	0.08
	air	24.05	3.92	0.16

5. Conclusions

This study presented the experimental investigation on LFC properties at different curing method. From the results, the following conclusions can be made:

- (i) The density affects other properties of fresh and hardened LFC. Air cured LFC is more stable than water cured sample for all the densities considered.
- (ii) It can be seen that the higher the density of LFC, the less the water absorption for both the water and air cured LFC. And water cured LFC has more water absorption than air cured LFC of the same design density.

- (iii) Compressive strength of LFC increases with age for both water and air cured LFC. But the strength of LFC cured in water is high than that of LFC cured in air of the same design density. Also, the higher the density of LFC, the more the compressive strength for both the air and water cured samples.
- (iv) Splitting tensile strength of LFC is proportional to its designated density. Air cured LFC has high splitting tensile strength than water cured LFC for all the designated densities considered at 28 days curing.

These information are important for the development of precast LFC in order to achieve structural behaviour towards sustainable construction system.

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