Journal of Materials and Environmental Sciences
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2018, Volume 9, Issue 5, Page 1405-1410

https://doi.org/10.26872/jmes.2018.9.5.153

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Preliminary Study of Low Densities Lightweight Foamed Concrete Brick for Non-Load-Bearing Wall System

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Received 21Jul 2017,
Revised 08Sep 2017,
Accepted 14 Sep 2017

Keywords
- ✓ Foamed concrete;
- ✓ Lightweight Brick;
- ✓ Wall panel;
- ✓ Flexural Strength;
- ✓ Drying Shrinkage

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Abstract

This research focuses on experimental study to determine the mechanical properties of lightweight foamed concrete (LFC) brick in wall system. Three different densities of LFC of 600, 800 & 1000kg/m^3 were cast and tested. Three parameters will be evaluated such as compressive strength, flexural strength and drying shrinkage. The cement, sand and water ratio that used was 1:1:0.45 was fixed at each of the different density. The compressive strength of the LFC shows the positive result in which the results for the compressive strength increase with the duration of the ages of the specimen. From the experimental verification, it can be seen that the compression test result for the all of the LFC also within the range from 1-3N/mm^2. The tensile strength indicates that the relationship between the density and the strength are the same. The low density described that the tensile strength is weak because of the porosity of the concrete that do not bind together, that easily torn apart the concrete and the void in the concrete is the main trigger for the crack to pass through and fragmented the concrete into two.

1. Introduction

Lightweight Foamed Concrete (LFC) is one of the types of lightweight concrete which can be defined as a cementitious material that contains a minimum of 20% by volume of mechanically entrained foam in mortar in which air-pores are entrapped in the matrix by means of a suitable foaming agent [1]. Lightweight concrete can be defined as a type of concrete which includes an expanding agent in that it increases the volume of the mixture while giving additional qualities such as nailbility and lessened the dead weight. It is lighter than the conventional concrete.LFC is produced by the mixing of ordinary portland cement (OPC), sand, water and preformed stable foam. The foam is engendered with the aid of a foam making machine, by means of foaming solution with 1:33 ratio to water. The air content is generally between 40 to 80 percent of the total volume. LFC is diverse compared to aerated concrete, where the foam is chemically formed by means of reaction of aluminium powder with calcium hydro oxide and other alkalizes unconfined by cement hydration and, air entrained concrete, which a much lower volume of entrained air is used in concrete for durability purpose.

The air-pores are initiated by agitating air with a foaming agent diluted in water; the foam then carefully is mixed together with the mortar to form or produce LFC. Due to the air-pores inside the matrix, concrete with properties of low self-weight, high workability, excellent insulating values, but lower strength compared to normal concrete is produced. Moreover, the use of LFC can contribute many advantages such as rapid and relatively simple construction, economical in terms of transportation and reduction in main power, reduce structural weight with a minimum number of frame and piles, better nail-ability and saving properties than heavier and stronger conventional concrete [2].

There are two approaches used to formulateLFC. The first method is by injecting the gas into the mortar slurry during its plastic condition by means of a chemical reaction and the second method is by introducing the air, either by mixing-in stable foam or by whipping-in air, using an air-entraining agent. The first technique is typicallyutilied in prefab concrete factories where the precast units are consequently autoclaved in order to produce concrete with a rational high strength and low shrinkage. On the other hand, the second technique is usually used for in-situ concrete which is appropriate for insulation of roof screeds component and also pipe lagging.

The minimum strength of the compression of crushing strength of the normal brick is ranging between 3-15N/mm^2. The application of lightweight foamed concrete in civil engineering works is very broad as it can be used in almost every parts of building from the superstructure right down to the substructure, including wall panels and roofing [3].

2. Raw materials

2.1 *Cement*

The cement used for the study is an Ordinary Portland Cement (OPC) from Phoenix Ordinary Portland Cement as been shown in Figure 1. Phoenix is the brand name of specifically blended bagged Portland-composite cement. It is manufactured by Portland Cement Clinker and other carefully selected secondary constituents (pozzolanicmaterials, fly ash and other constituents permitted under BS EN 197-1:2000). Under an effective system of testing controlling and monitoring by Lafarge Malayan Cement, Malaysia's leader in clinker and cement manufacturer. Phoenix is the 1st cement in Malaysia to be accredited with Singapore Green Building and Green Label by the Singapore Environmental Council. Phoenix cement is produced under stringent quality control and environmental management systems that are certified under ISO9001, ISO14001 and OHSAS 18001.

Figure 1. Sieve Analysis Grading Result

2.2 *Fine Aggregate*

The fine aggregate used was natural sand obtained from a local distributor. A sieve analysis has been carried out to identify the suitability of the sand to be used according to British Standard BS 882: 1992. The result of sieve Analysis shows in Table 1 and the grading curve of sieve analysis shows in Figure 2.

Table 1. Result of Sieve Analysis

Sieve Size Range (mm)	Mass Retained (g)	Cumulative Retained (g)	Cumulative % mass Retained	Cumulative % mass passing through
10.00-5.00	0	0	0	100
5.00-2.00	3.8	3.80	0.76	99.24
2.00-1.18	38.30	42.10	8.42	91.58
1.18-0.600	135.00	177.10	35.42	64.58
0.600-0.300	160.60	337.70	67.54	32.46
0.300-0.150	114.30	452.00	90.40	9.60

From the results, it was found that the sand provided by the local distributor can be considered as very fine sand. This is due to the fine modulus of the sand is equal to 2.02 instead of ranging between 2.2 to 2.6 as required for fine sand. Furthermore, the sand fell in the zone 4. However, the sand was accepted to be used in this research because more than 20% of the total quantity of the sand has a size less than 0.5mm as per requirement.

2.3 Water

The clean water is used for mixing and curing shall be clean and free from any debris and other organic materials. This is because if water used is not clean, it can affect the performance of concrete. Otherwise, cleaned water is needed to mix together with the protein to create good foam agent that free from debris. Basically, the water cement ratio that has been used for this research is 0.45 because most of the previous studies used this ratio to achieve reasonable workability of foamed concrete.

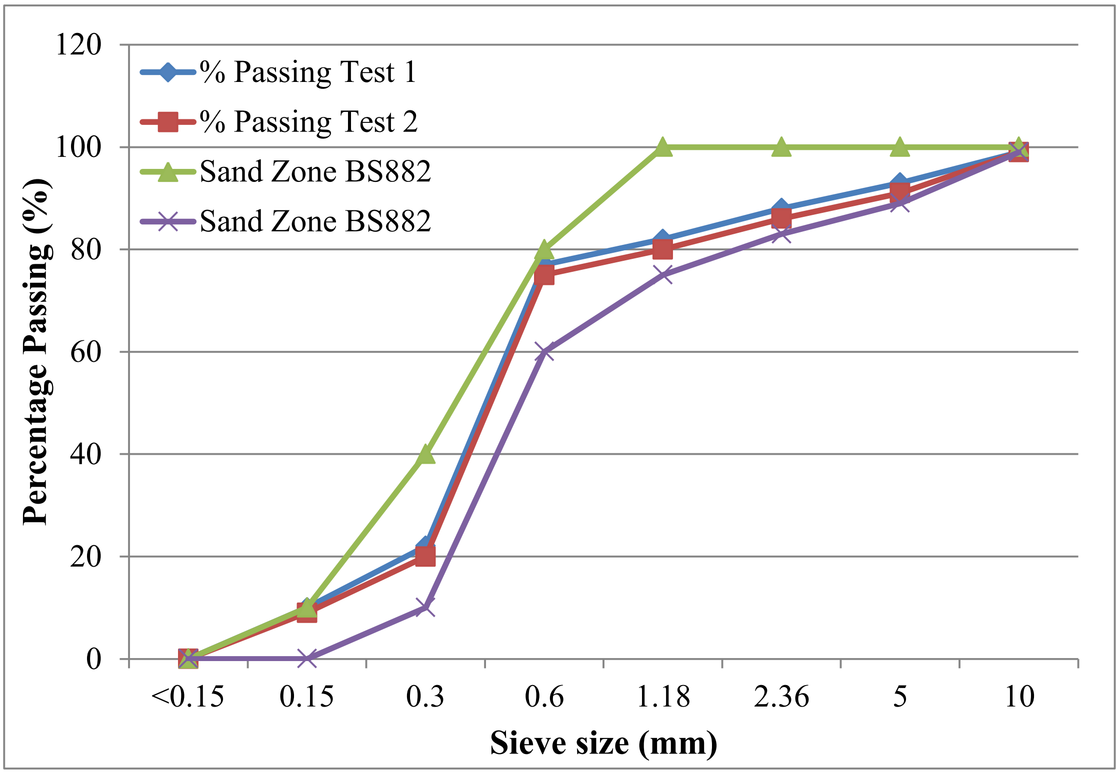

Figure 2. Sieve Analysis Grading Result

2.4 Surfactants

The type of foaming agent used for this research was a protein based type (PA-1). The reason of using a protein based foaming agent because it is more stable compared to other types. The protein is made of organic protein that not acidic type that can be contact on skin. Generally, protein based surfactants may produce a tiny bubble size, which can contribute to a more stable and a stronger closed bubble structure [4]. Portable foaming generator (Portafoam) is the name of the foam generator machine used for this research. The surfactant was diluted in water at a ratio of (1:29) and then aerated using the Portafoam generator to produce stable foam with a density ranging between 60-70 g/liter for the production of LFC depends on the use of the concrete.

3. Experimental study

There are three tests conducted in this research. These tests are compressive and flexural strength as well as drying shrinkage. The reading taken for each sample is the average of three readings. A total of 3 mixes including the control mix are listed in Table 2.The compressive strength tests were conducted according to BS1881: Part 116: 1983 using Unit Test DHR 200 machine at 7 days, 14 days and 28 days. Compressive strength is tested using the standard of the sizes of the normal brick that use in the construction (230mm×110mm×76mm). The flexural strength also conducted up to the same age of 7, 14 and 28 days. The flexural strength is done using the same size of the rectangular brick that use in the compression test. The drying shrinkage test was done for prism specimens with by referring to the standard test of BS ISO 1920-8:2009 with the specimen dimension of (40×40×160mm). The results taken for drying shrinkage were at the age of 1, 3, 5, 7, 14, and 28 days.

Table 2. Mix design for the research

Mix	Mix Density (kg/m^3)	Mix Ratio	Cement (kg)	Fine Aggregates (kg)	Water (kg)
Mix 1	600	1:1:0.45	14.03	14.03	6.31
Mix 2	800	1:1:0.45	18.24	18.24	8.21
Mix 3	1000	1:1:0.45	22.45	22.45	10.10

4. Results and discussion

There are three tests conducted in this research. These tests are compressive and flexural strength as well as drying shrinkage

4.1. Compressive Strength Test

These specimens are tested by compression testing machine after 7, 14, and 28 days curing accordance with BS EN 12390-3 (2009) [5]. Load should be applied gradually at the rate of 3kN/sec till the specimens fails. The maximum load that achieved is then divided with the total area the specimen gives the compressive strength of concrete in N/mm^2.

From Figure 3, the data obtained from these experiment show that the compressive strength for each density shows an increasing progressive from the earlier stage until to the end of the stages. The LFC with $800kg/m^3$ show the highest percentage of the increasing in the compressive strength about 42% from the first day of testing until the last day of the test. The lowest density keeps the minimum percentage of the increment of the strength about 15%. The concrete with $1000kg/m^3$ have a high strength compressive due to the less volume of the foam concrete in the concrete, compared to the $600kg/m^3$ that have a lowest strength of compressive. This is because; the higher of volume of foam in the concrete will increase the void throughout the sample. The number of volume of the foaming agent in the concrete is the factor that affects the compressive strength. It shows that, the lowest densities have a huge of number void within the sample that make the sample is lightest and at the same time the void also make the wall around the void become thin and weaken the structure within the sample.

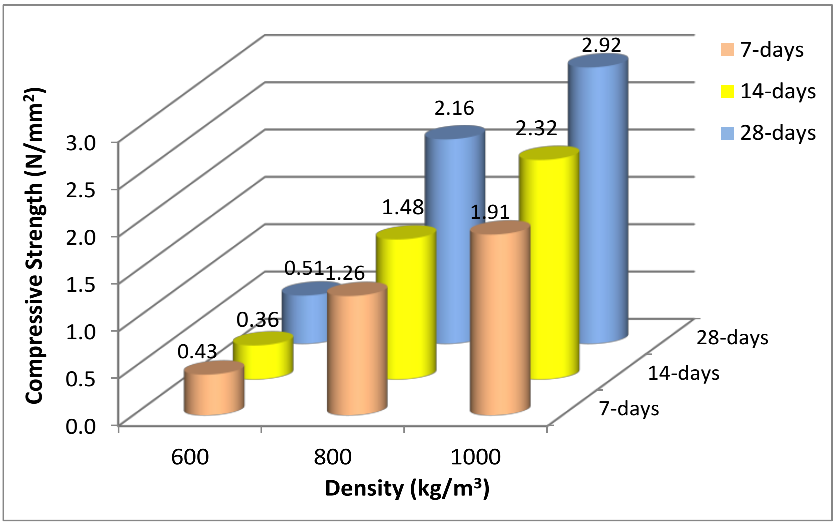

Figure 3. Compressive strength of LFC with different densities

It should be noted that the compressive strength of the LFC will be increase drastically until the LFC achieved the maximum strength at the 90 days and the strength will be constant afterwards, at the day 7, in general, the concrete only achieved it strength accommodate about 70% from its total strength. The compressive strength and other functional properties of lightweight foamed concrete are greatly influenced by the amount of air content introduced by foaming agents [6].

4.2 Flexural Strength Test

Flexure tests are generally used to determine the flexural modulus or flexural strength of a material. The material is laid horizontally over two points of contact (lower support span) and then a force is applied to the top of the material through one points of contact (upper loading span) until the sample fails. The splitting tensile strength was carried out on the foamed concrete in accordance with the provision for lightweight concrete, BS EN 12390-6 [7].As can be seen from Figure 4, flexural Strength of Concrete is about 10-20% of compressive strength depending on the type, size and the mix proportion of the material that used. However, the best correlation for specific materials is obtained by laboratory tests for given materials and mix design. The test determined by third-point loading is lower than the centre-point loading, sometimes by as much as 15%. Based on the chart, all the mix design achieved the 10-20% of the tensile strength based on their compressive strength. The strength of the flexural strength shows an improvement of the strength by the enhancement of the test day. The percentage of the improvement of the $600kg/m^3$ indicate the lowest of improvement of the strength from ($0.154N/mm^2$) to ($0.250N/mm^2$), compared to $1000kg/m^3$ that drastically rise from the day 7 ($0.715N/mm^2$) to the day 28 ($1.157N/mm^2$).

The data obtained from the chart shows that the strength of the flexural strength is parallel with the compressive strength of the specimen. It should be pointed out tthat the foamed that produced the void within the concrete is the factors of the tensile strength become more weaken. It is because the number of bubble of the foamed in the concrete described the thickness of the wall void in the main structure of the LFC. The lowest density of LFC has a huge amount of the foamed agent that weaken the structure of the void that makes the structure is more porous compared to the solid to gain the strength. The number of the void also is the main critical point of the flexural failure because the void in the concrete is the trigger for the crack that leads to the failure.

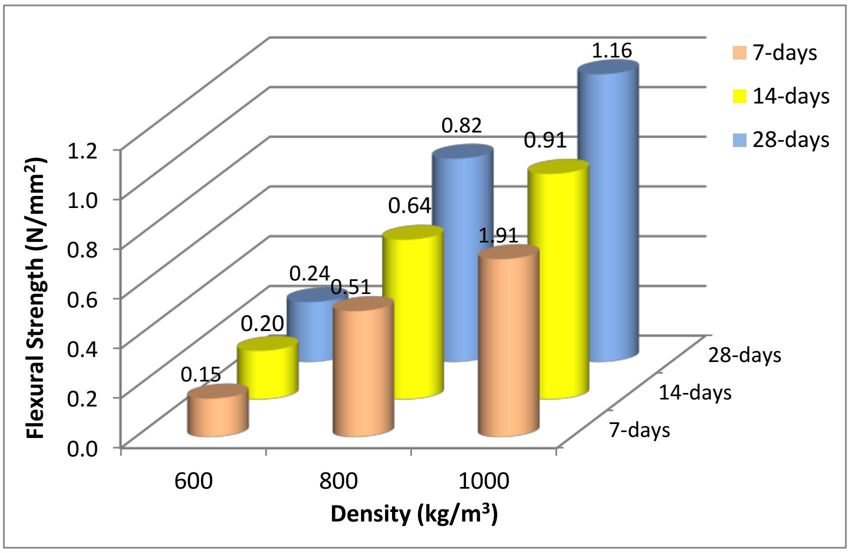

Figure 4. Flexural strength of LFC with different densities

4.3 Drying Shrinkage Test

In order to study the effect of dry density on LFC brick with respectively of 600, 800, and 1000 kg/m^3 are prepared. See Table 2 for the mix proportion design. The shrinkage process is happen when the hydration of the binding material that increases, the solid volumes and the particles contact closely that lead the framework of the strength LFC increase. The results of drying shrinkage for all specimens in this research are revealed in Figure 5. From the results, the 600kg/m^3 LFC density is show the highest drying shrinkage compared to the highest density of LFC that had low drying shrinkage.

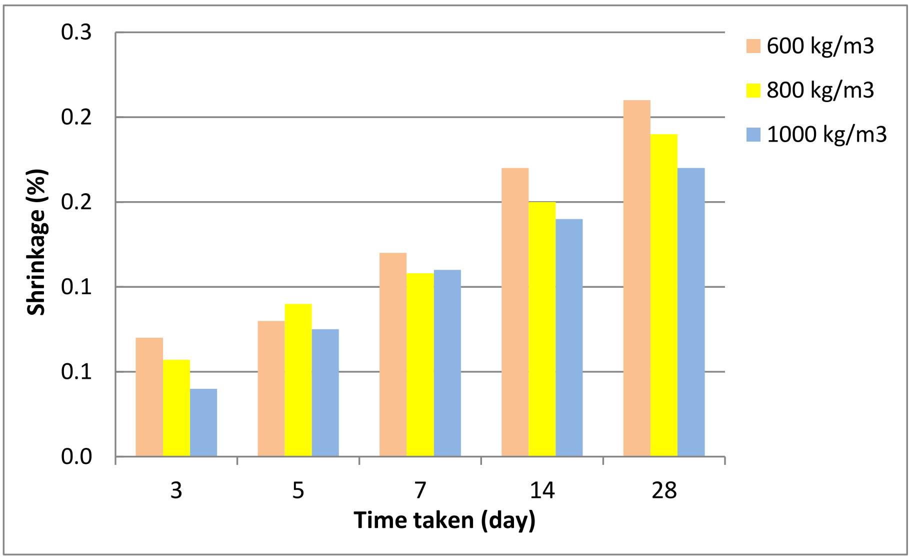

Figure 5. The percentage of shrinkage of different LFC densities

The results show that the lowest (600kg/m^3) density of the LFC had a highest percentage of the shrinkage at earlier of the stages and keep still high at the end of the stages of the study. The greater of the density show the deflection of the percentage that has the lowest percentage of shrinkage. It shows that the dry densities LFC show a linear relationship with the shrinkage percentage because the loss of volume with the decrease of the water content due to the hydration of binding material. [8] At the ages of 3, the entire specimen with respectively 600, 800, and 1000 kg/m^3 record the high enhancement of the percentage from the day the specimen is demould and the original length is measured. All the specimen shows an increasing of the drying shrinkage with the lowest density keep as the higher shrinkage compared to the high density of LFC [9, 10].

The higher amount of water in the fresh concrete, the greater the drying shrinkage affects [11, 12, 13]. Increase of the water content by 1% will approximately increase the drying shrinkage by 3%. [14, 15]. The shrinkage potential of a particular concrete is influenced by the amount of mixing [16, 17]. The relationship between the amount of water content of fresh concrete and the drying shrinkage is linear.

Conclusion

There are 3 conclusions can be withdrawn from this study:

- Rising of the number foaming agent in the LFC does not enhance the compressive strength. It shows that the strength of LFC in the compressive is depend the solidity of the concrete since the 600 kg/m3 is contain the high number of foaming agent; that increase the number of void in the concrete that weaken the structure of the concrete and the most lowest of the compressive strength among the others.
- The enhancement of the foaming agent in the concrete due to make the LFC lighter must be followed by decrease the mix ratio for the LFC due to the cement content that exceed the minimum cement content in the LFC design that leads to the high percentage of the shrinkage for the 600 kg/m3. The 1000 kg/m3 shows the minimum content of the cement ration that suitable for the density (1:1) and have the lowest percentage of shrinkage and the increasing of percentage by the test also was low.
- Too much foaming agent in the concrete is make the concrete is more porosity and weaken the structure of the concrete from the inside. Concrete usually have a tensile strength in ranging about 10-20% from the compressive strength. The void in the concrete will be the trigger for the crack occurred when the load in applied on the sample. LFC that have a huge amount of the void will be a path for the crack travel from the weakest point of the LFC.

Acknowledgments-The author would like to thank Ministry of Higher Education Malaysia for their funding of this research under Fundamental Research Grant Scheme (Grant No. 203/PPBGN/6711514) with research title: Fundamental Study to Establish Thermal Insulation, Mechanical Properties and Fire Retardant Mechanism of Coir Fibre Reinforced Lightweight Foamcrete.

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(2018) ; http://www.jmaterenvironsci.com