

Effect of lightweight foamed concrete confinement with woven fiberglass mesh on its drying shrinkage

Efecto del confinamiento del hormigón ligero espumado con malla de fibra de vidrio tejida sobre su contracción de secado

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Abstract

Drying shrinkage is the major drawback of lightweight foamed concrete (LFC) as reported by many researchers. It is happened due to the loss of water in the capillary of concrete mixture. This problem caused the changes of dimension or volume of the concrete structure which lead to the cracking and failure thus shorten the life performance of the material. Once the water evaporated from the cement paste, it is impossible to replace it back. Thus, this paper studies the drying shrinkage behaviour of LFC with the confinement of woven fiberglass mesh at three different densities were 600kg/m³, 1100kg/m³, and 1600kg/m³. The woven fiberglass mesh implemented in this research is a synthetic textile fabric with an alkali resistance characteristic. The LFC specimens were wrapped 1-layer to 3-layer(s) of woven fiberglass mesh to enhance the drying shrinkage performance. The drying shrinkage test was measured accordance with the ASTM C157 specification and cured under air storage condition. Protein-based foaming agent (NORAITE PA-1) was used to produce the desirable density of LFC. The result shows that confinement of 160g of woven fiberglass mesh significantly improves the drying shrinkage of LFC compared to control and the enhancement also increase as the layer(s) of textile fabric is added from 1-layer to 3-layer(s). Besides, the densities of LFC also play an important role to control its drying shrinkage behaviour. As proven at higher density of LFC the reduction of drying shrinkage value can be obtained.

Keywords: Foamed concrete, drying shrinkage; durability, lightweight material, strain; textile fabric, confinement

Resumen

Según han informado muchos investigadores, la contracción por secado es el principal inconveniente del hormigón ligero espumado (LFC). Se produce debido a la pérdida de agua en el capilar de la mezcla de hormigón. Este problema provoca cambios en las dimensiones o el volumen de la estructura de hormigón, lo que conduce a la aparición de grietas y fallos, acortando así la vida útil del material. Una vez que el agua se evapora de la pasta de cemento, es imposible reponerla. Por lo tanto, este trabajo estudia el comportamiento de la contracción por secado del LFC con el confinamiento de la malla de fibra de vidrio tejida a tres densidades diferentes: 600kg/m³, 1100kg/m³ y 1600kg/m³. La malla fibra de vidrio tejida implementada en esta investigación es una tela textil sintética con una característica de resistencia al álcali. Las muestras de LFC se envolvieron con una o tres capas de malla de fibra de vidrio tejida para mejorar el rendimiento de la contracción por secado. La prueba de contracción por secado se midió de acuerdo con la especificación ASTM C157 y se curó en condiciones de almacenamiento al aire. Se utilizó un agente espumante a base de proteínas (NORAITE PA-1) para producir la densidad deseada del LFC. El resultado muestra que el confinamiento de 160g de malla de fibra de vidrio tejida mejora significativamente la contracción por secado del LFC en comparación con el control, y la mejora aumenta también a medida que se añaden la(s) capa(s) de tejido textil de 1 a 3 capas. Además, las densidades de LFC también juegan un papel importante para controlar su comportamiento de contracción por secado. Como se ha demostrado, a mayor densidad de LFC se puede obtener una reducción del valor de la contracción de secado.

Palabras clave: Hormigón espumado, contracción por secado, durabilidad, material ligero, tensión, tejido textil, confinamiento

1. Introduction

Drying shrinkage is one of the drawbacks faced in LFC. This problem causes the LFC structure shrink and reduced in volume then leads to the decreasing of LFC strength. Since the drying shrinkage of LFC is higher compared to normal strength concrete, then by confinement of woven fiberglass mesh in LFC, it can decrease the drying shrinkage percentage of LFC. Thus, the percentage changes were recorded in this test and the result will be compared to LFC without any confinement as reference.

(Kearsley, 1999) stated that the LFC is noticed to be weak and non-durable due to its characteristic which is high shrinkage value where it can lead to changes in dimensions and cracks in the matrix. Besides, the average percentage of drying shrinkage in LFC is about two to three times greater than conventional concrete (Kearsley, 1999). (Roslan et al., 2013) revealed that the typical range of drying shrinkage value in LFC is in between 0.1% to 0.35% of the total volume of the hardened concrete matrix. This shrinkage occurs because of water exits from the micro-pores. According to (Al-Haidary, 2010), the micro-pores are distributed among the main paste (matrix) of LFC due to the removal of extra water out of it during the setting time. As reported by (Fedorov and Mestnikov, 2018), the highest values of shrinkage deformations lead to low strength characteristic in LFC. This has been explained by (Rai and Kumar, 2017), in which LFC possesses high drying shrinkage due to the absence of aggregates where the result is up to 10 times greater than has been observed in the normal weight concrete.

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Besides, based on the investigation of the shrinkage behaviour of LFC related to the drying shrinkage, moisture content, and composition as the basic factors which has been conducted by (Nambiar and Ramamurthy, 2009), they found that the drying shrinkage is minimized due to the increased foam content. Also, the lesser drying shrinkage at higher volume of foam was due to the poor content of paste in the mix, hence causing the minimum content of pores to significantly affect the shrinkage. (Amran et al., 2015) stated that drying shrinkage in LFC also controlled by the type of material use in matrix design, higher cement and water contents, and mineral admixture in LFC. (Namsone et al., 2017) also justified that the possible shrinkage problem in LFC is caused by carbonation which increases the risk of cracking and loss of its durability. They also added that the high volume of open pores is the main reason for increased drying shrinkage value in LFC.

As reported by (Zamzani, 2019), the drying shrinkage of LFC is dramatically high in early age until 30 days and then continues to increase slowly. This is because at the early aged of the test, the specimens were not fully hardened, and the lowest percentage of drying shrinkage value was achieved at the higher density of LFC.

2. Materials and design

There are four common material utilized in the production of LFC which were cement, fine aggregate (sand), water, and foam. Besides, 160 grams per square meter (GSM) of woven fiberglass mesh also employed in this research to investigate its functionality in order to improve the drying shrinkage behavior of LFC. In this research, Ordinary Portland Cement (OPC) commercially known as 'Castle' brand cement produced by the Cement Industry of Malaysia was used which is in accordance with the specifications of Type 1 Portland Cement in (ASTM C150-04, 2009). (Table 1) shows the chemical compound of OPC used (provided by supplier) and the Portland cement (Type 1) as stated in the ASTM standard.

Table 1. Chemical compound of OPC and the Type 1 Portland Cement as stated in ASTM standard

Chemical compound (%)	Ordinary Portland Cement (OPC)	Specification limit (ASTM)
SiO ₂	16.00	20.00 min
Al ₂ O ₃	3.90	6.0 max
Fe ₂ O ₃	2.90	6.0 max
MgO	1.50	6.0 max
SO ₃	3.10	3.0 max

The fine aggregate (sand) size utilized in this research is less than 1.18mm diameter with the specific gravity 2.74 and fineness modulus 1.35. The grading limits are according to (ASTM C778-06, 2006) (Figure 1) depicts the grading curve of fine aggregate used in this study. Fine aggregate is suitable for producing the LFC since the coarse aggregate caused bigger pores existence and create an inconsistent mix which affects the LFC properties.



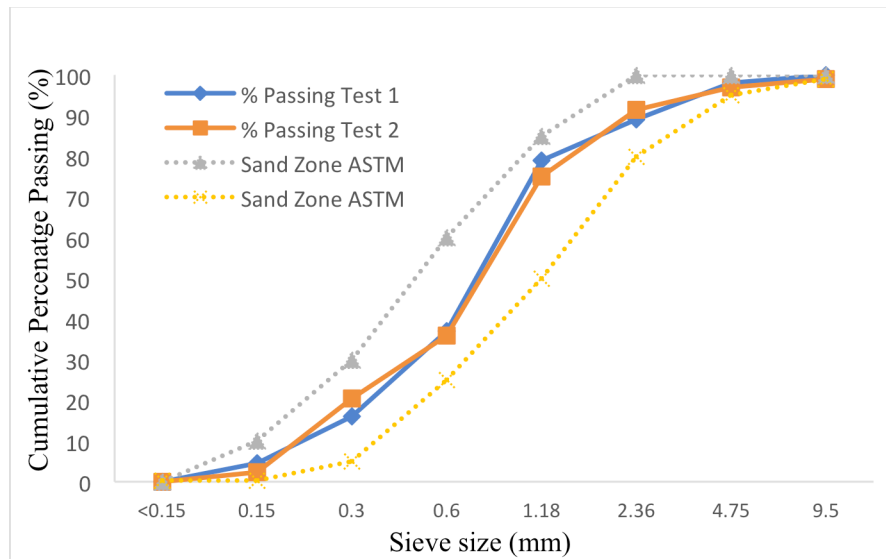


Figure 1. Grading curve of the fine aggregate used

The presence of water is necessary to mix the cement and fine aggregate to form the cement slurry through chemical reaction which will lead to the hardened mortar paste. The clean water (free from any harmful substance) was used which is compliant with (ASTM C1602-C05, 2006), the specification for mixing water used in producing cement concrete. Protein-based foaming agent (NORAITE PA-1) used in this research to produce the foam that will be added into the cement slurry to get the desirable density. 2.9% of foaming agent was diluted into 30L of water before supplied it to the foam generator refer to (Figure 2).



Figure 2. Foam generator

Furthermore, 160 GSM woven fiberglass mesh refer to (Figure 3) also known as textile fabric was used as confinement in this study to enhance the drying shrinkage of LFC. This textile fabric categorized as synthetic fiber that comprising an alkali resistance which can prolong the durability performance of LFC. It is also eco-friendly,



lightweight, and flexible (can be form to any form). (Table 2) shows the physical properties of 160 GSM woven fiberglass meshes provided by TKS Bio Sdn. Bhd. While (Table 3) displays its composition.

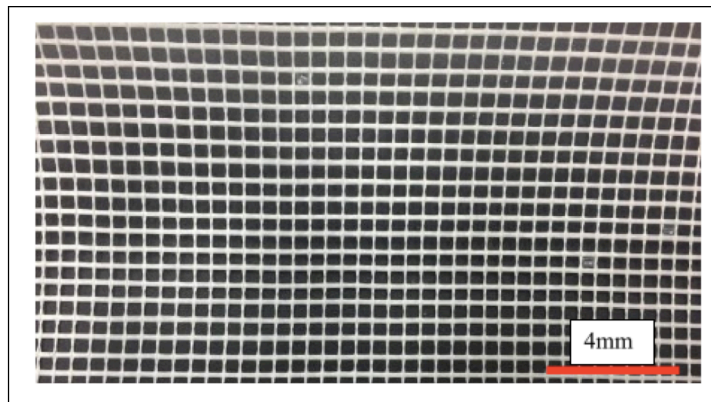


Figure 3. 160GSM woven fiberglass mesh

Table 2. Physical properties of woven fiberglass mesh

Properties	160 GSM woven fiberglass mesh
Mesh size	4.0mm x 5.0mm
Coating type	Alkali resistance
Mass (g/m ²)	160±5
Igmiton point	759.2°F (404°C)
Melt point	320.0°F (160°C)
Tensile strength (MPa)	1407
Elongation at break (%)	3.07%
Compliance	ASTM C1116-02
Quality assured facility	ISO 9001:2008

Table 3. Composition of woven fiberglass mesh

Oxide components (AR-glass)	Percentage by weight (%)
SiO ₂	65.4
ZrO ₂	17.3
TiO ₂	1.2
Al ₂ O ₃	1.6
Fe ₂ O ₃	1.7
CaO	7.2
MgO	0.7
Na ₂ O	0.6
K ₂ O	0.4
B ₂ O ₃	2.2
Li ₂ O	0.3
F ₂	0.5
Others	0.9



The mix design of the LFC mixes as shown in (Table 4) were prepared using three different densities with confinement of 1-layer to 3-layers of woven fiberglass mesh and the control (unconfined) sample as references. 1L-FM indicates the LFC specimen confined with 1-layer of woven fiberglass mesh, 2L-FM for 2-layer and 3-layers is 3L-FM. To get the comparable results, the water to cement ratio was fixed to 0.45 as practice by (Talaei et al., 2014) while the cement to sand ratio constant at 1:1.5. Three different densities were chosen based on the application categorized of the LFC which were 600kg/m³ for non-structural building material, 1100kg/m³ for semi-structural while 1600kg/m³ for structural building material in real practice.

Figure 3. View of beams on profile (Abdallah et al., 2019) (a) Traditional design beam (b); Optimized beam

Sample	Mix density (kg/m ³)	Mix ratio		Mix proportions, kg/m ³		
		Cement/sand	Water/cement	Cement	Sand	Water
Control	600	1:1.5	0.45	230.24	345.36	103.61
	1100	1:1.5	0.45	410.79	616.18	184.86
	1600	1:1.5	0.45	591.34	887.01	266.10
1L-FM	600	1:1.5	0.45	230.24	345.36	103.61
	1100	1:1.5	0.45	410.79	616.18	184.86
	1600	1:1.5	0.45	591.34	887.01	266.10
2L-FM	600	1:1.5	0.45	230.24	345.36	103.61
	1100	1:1.5	0.45	410.79	616.18	184.86
	1600	1:1.5	0.45	591.34	887.01	266.10
3L-FM	600	1:1.5	0.45	230.24	345.36	103.61
	1100	1:1.5	0.45	410.79	616.18	184.86
	1600	1:1.5	0.45	591.34	887.01	266.10

This test was conducted by using Mitutoyo brand digital indicator (accuracy up to 0±0.001 mm) with 298 mm of reference bar. Drying shrinkage test was performed according to (ASTM C157/C157M, 2005) where three specimens of the prism (75 x 75 x 285mm) were installed with a pair of steel screw and cap nut. After demoulding, LFC specimens were placed in the length comparator as setup in (Figure 4) and rotated anti-clockwise to get the data. The readings were taken and recorded as L_i. Then, the steps were repeated for the next aged of testing, which is at day 1, 3, 7, 14, 21, 28, and 56. These reading were recorded as L_x where x represents the subsequent of testing aged.



Figure 4. Instrument for drying shrinkage test



As previously mentioned, higher drying shrinkage is one of the major drawbacks of LFC. The disadvantages surely affect LFC strength. This is because drying shrinkage caused the changes of dimension in LFC where the evaporation of moisture content in the cement matrix leads it to shrink. However, confinement of woven fiberglass mesh in LFC undoubtedly can enhance the drying shrinkage behavior. (Figure 5), (Figure 6), and (Figure 7) depicted the development of drying shrinkage result for LFC confined with 160g woven fiberglass mesh.

The test results showed that the control specimen has the uppermost drying shrinkage strain when compared to the confined LFC for the three respective densities and the value is reduced as the increase of LFC density. The confinement of 160g woven fiberglass mesh significantly improved the drying shrinkage of LFC. At density 600kg/m³, confinement of 1-layer woven fiberglass mesh in LFC improved 48%, while 1100kg/m³ enhanced the drying shrinkage value 57% and 43% for the 1600kg/m³ LFC compared to the unconfined specimen at 56 days. When the number of layer(s) for the woven fiberglass mesh is increased, 2-layers and 3-layers, the drying shrinkage behavior also decreases 52 to 77% than the control.

At the early stage of the test, all the specimens show inconsistent drying shrinkage measurement as the specimens are not fully hardened yet. However, at the day-30 and above the graph shows only slightly increment in drying shrinkage for the confined LFC while the control specimen shows the noticeable increases. Besides, (Karim et al., 2015) also clarified that the rapid increases of drying shrinkage at the early ages is due to the rapid loss of moisture from surface of the specimen while for the later ages, the rate of increase of drying shrinkage is reduced with time depending on the moisture movement of concrete.

Aforementioned, the reduction of drying shrinkage strain for the confined LFC is due to the role of the woven fiberglass mesh that impedes the evaporation of moisture contains in the cement paste that leads to the altering of the LFC dimension. The woven fiberglass mesh not only prevents the water from diffused to the cement matrix, but it also avoids the loss of existing water in LFC. This also has been proved by (Falliano et al., 2019) that the unreinforced specimens exhibit a shrinkage that decreases with increasing dry density. (Namsone et al., 2017) also stated that the addition of fiber can reduce the risk of shrinkage and stabilize the fresh mix.

Even though many factors can influence the drying shrinkage behavior in LFC as reported in the previous investigation, however, based on the interpretation from these three figures, it can be concluded that the major influences to the drying shrinkage behavior in this study are (1) the density of LFC; and (2) the number of layer(s) for the woven fiberglass mesh confinement. Thus, at density 1600kg/m³ LFC confined with 3-layers woven fiberglass mesh conquer the good performance of drying shrinkage while the poor behavior shown by the unconfined LFC at density 600kg/m³.

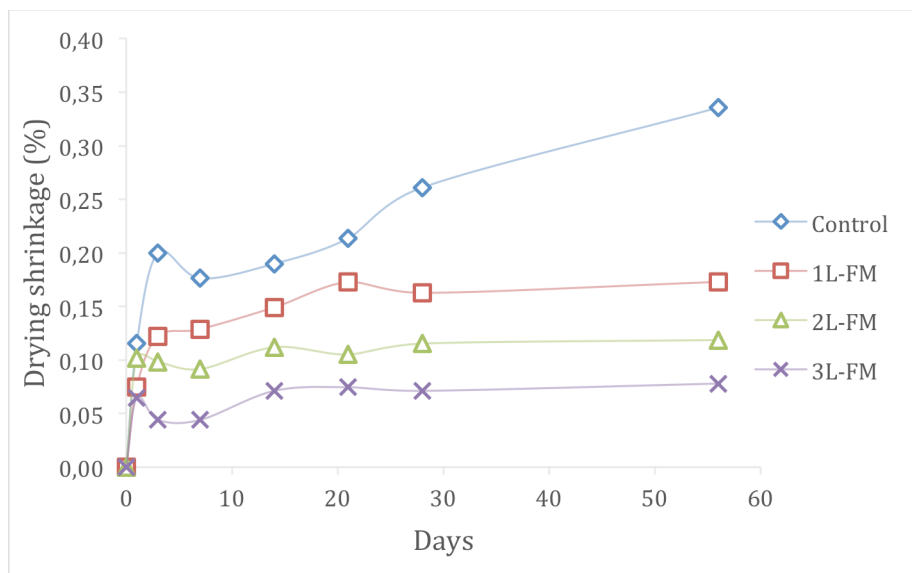


Figure 5. Drying shrinkage results of 600kg/m³ density LFC confined with different number of layer(s) of 160g woven fiberglass mesh.



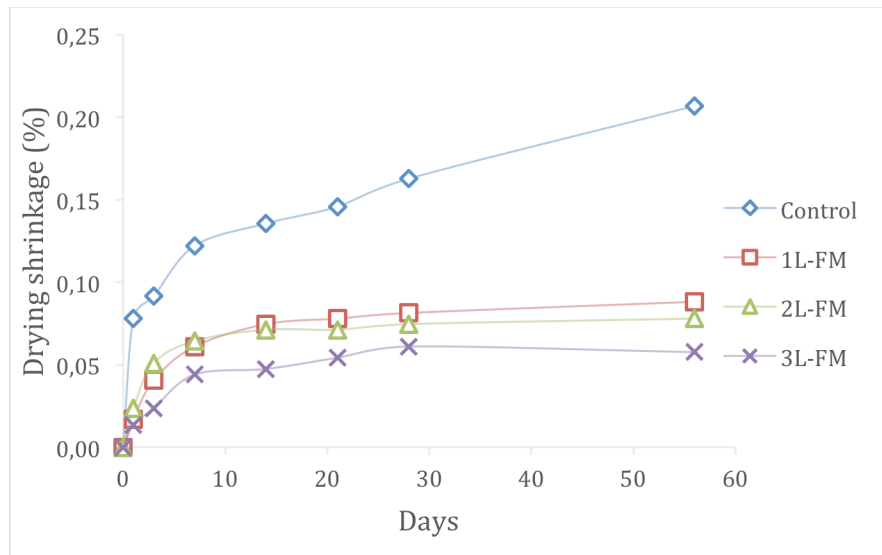


Figure 6. Drying shrinkage results of 1100kg/m³ density LFC confined with different number of layer(s) of 160g woven fiberglass mesh.

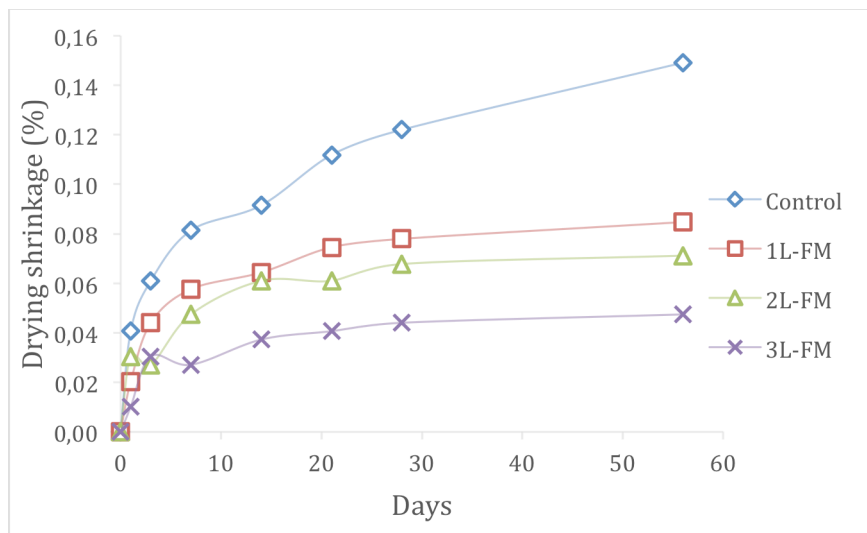


Figure 7. Drying shrinkage results of 1600kg/m³ density LFC confined with different number of layer(s) of 160g woven fiberglass mesh

4. Conclusions

This paper describes the drying shrinkage behavior of LFC confined with different number of layer(s) of woven fiberglass mesh at three different densities. Thus, based on the interpretation of the data obtained, few conclusions are observed as follows:

1. The higher drying shrinkage obtained at the low density of LFC and vice versa which is correlated to the volume of foam added.



2. The utilization of woven fiberglass mesh significantly improves the drying shrinkage issue in LFC where at density 600 kg/m^3 , percentage of drying shrinkage was decreased by 48%, while 57% and 43% for 1100 kg/m^3 and 1600 kg/m^3 , respectively, compared to the unconfined specimen at 56 days.
3. Besides, the addition number of layer(s) employed also influenced the drying shrinkage behavior of LFC, where confinement of 2-layers and 3-layers of woven fiberglass mesh decreased the percentage of drying shrinkage from 52 to 77% than the control.
4. *The reduction of percentage of drying shrinkage of LFC was due to the role of woven fiberglass mesh, which impeded the evaporation of moisture from the paste, thereby altering the dimensions of the LFC. Besides, the present of woven fiberglass mesh in LFC also can hold the cementitious matrix strongly so that restrict the volume changes in LFC compared to unconfined specimen that do not have any additive to offer this support.*

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