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Efficacy of Foamed Concrete Jacketing using Innovative Fibreglass Fabric for Durability Properties Improvement

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ABSTRACT

This study intended to observe the effectiveness of foamed concrete jacketing using fibreglass fabric with the goal to enhance its durability properties. LFC of two densities of 500 kg/m^3 and 1000 kg/m^3 were cast and tested. The LFC specimens were wrapped with 1 layer, 2 layers and 3 layers of fibreglass fabric. The parameters evaluated were porosity, water absorption, drying shrinkage and ultrasonic pulse velocity. The results revealed that adding fibreglass fabric to LFC decreased its porosity and water absorption for both densities. Fibreglass fabric did more than only prevent cracks; it also reduced the drying shrinkage and increased the ultrasonic pulse velocity of LFC. Three layers of fibreglass fabric offered optimal results for all properties studied. As a result of the fibreglass fabric's ability to prevent moisture evaporation and consequent dimension changes in the confined LFC, drying shrinkage strain was kept least. The use of fibreglass fabric not only prevented water from escaping but also stopped it from probing the cement matrix. This preliminary study shows a huge potential to use fibreglass fabric as a strengthening medium to improve the properties of LFC.

1. Introduction

One of the most important sectors that contribute significantly to the growth of a nation is the construction industry, which has been around for many decades. An example of an ancient structure that is still standing to this day is the Pyramid of Khufu, which can be seen in Giza, Egypt. The Pyramid of Khufu is a historical structure that has evolved into a tourist destination due to its significance in the past. Due to the lack of advanced technology available during that era, the construction of the pyramid, which consisted of 2,300,000 individual blocks, required a period of twenty years to be finished using methods that were considered standard at the time. In emerging countries like Malaysia, the construction industry is one of the primary catalysts for achieving quick advancement and an increase in overall economic activity. In general, the building practices that are put into

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practice in Malaysia can be categorised as conventional or traditional building practices [1]. The completion of structures using these methods takes significantly more time compared to the completion of structures using non-conventional methods. In addition, these methods are not environmentally friendly because they typically employ timber as the raw material; however, timber can only be used two to three times for the formwork and involves intensively huge transportation activities. Non-conventional methods also allow structures to be completed in a shorter amount of time [2]. In a global context, prefabricated construction approaches are not considered to be novel; however, their use in the construction industry of Malaysia is still relatively uncommon for a variety of reasons. These reasons include high overall costs, a lack of expertise and familiarity among workers, a lack of environmental awareness, and a lack of scientific information when compared to conventional construction methods.

Despite this, over the course of the last few decades, this nation has begun to shift away from traditional methods of construction and toward the prefabricated approach in order to meet the needs of the current market. This is due to the high demand for new housing developments, high-rise commercial buildings, and other types of infrastructure development [3]. In addition, the global construction industry has come to the consensus that the materials used in future building projects will need to be more ecologically friendly, lightweight, long-lasting, user-friendly, and cost-effective. In this regard, there are a lot of aspects that need to be addressed to satisfy all of the demands and wants, and these factors include the scope (which refers to the requirements of the project), the time (which refers to the length for finishing the project), and the money (costs). Consequently, the selection of building materials is one of the keys to ensuring that these three constraints of project management can be followed. In addition to its significance in ensuring that buildings have a longer lifespan and are safe to occupy, this significance stems from the fact that the selection of building materials is one of the keys to ensuring that these three constraints can be followed. Concrete is a type of building material that is used extensively in the construction business. In comparison to wood, concrete is more resistant to deterioration, and it can also be constructed into a variety of different forms with less effort [4]. Through a process known as hydration, it is created by combining cement with water and coarse aggregates or sand. This results in the formation of a solid matrix. The range for its density is between 2240 and 2400 kilogrammes per cubic metre, and the range for its compressive strength is between 20 and 40 newtons per square millimetre [4]. Despite this, using regular concrete as a building material comes with a few limitations that should be considered [5]. The heavyweight of normal concrete is inconvenient because it requires a bigger amount of concrete to be cast across a structure that has a longer span. This makes the use of normal concrete more expensive [6]. They also mentioned that the transportation of a precast reinforced concrete plant is expensive because of the high density of the material, which ranges from 2400 kg/m3 to 2800 kg/m^3, and the need for large machinery to handle it [7].

In addition, the development of precast concrete systems and components, also known as an industrialised building system (IBS), has caught the interest of the construction industry in Malaysia [8]. This system is known as IBS. One of the many construction components, which was used for a residential development project in Putrajaya, was lightweight foamed concrete for non-load-bearing wall systems [9]. There are many different construction components. Jalal et al. assert that the Pantheon, which was constructed by the Romans in the year 126, was the first known structure to make use of lightweight concrete. Therefore, the application of LFC in the building industry will not only provide a more advanced and lighter concrete-based material, but it will also, at the same time, accelerate the construction process and increase the production rate of buildings as well as the overall development of infrastructure [10]. On the other hand, it should be brought to your attention that LFC has a low density (between 500 kg/m^3), which makes it strong when subjected to compression but weak when subjected to tension [11]. Because of this drawback, its application in building construction has been restricted, particularly for load-bearing and semi-structural components. This is because the cement matrix contains a significant number of microcracks, which are caused by the high porosity of the cement. These microcracks result in the material having very low tension and being very brittle when it is compressed. Despite this, LFC is being used not only as a fill-in material for load works and principally for level correction in house development, but it is also being employed as a semi-structural element in construction [12]. Despite this, a significant amount of research has been done to enhance the performance of LFC due to the fact that it has the potential to be used as a structural building material. Researchers are becoming increasingly interested in LFC because of its qualities, which include its superior thermal insulation [13] and acoustical shielding properties [14], particularly when low concentrations of the material are applied.

Despite this, LFC has an excellent compressive strength but a low-tension strength because of the creation of numerous microcracks brought about by the combination of soft and brittle components in the matrix. The application of a load will cause the matrix to begin to fail because of the microcracks spreading throughout the structure. Because there is no applied force in the tensile zone, LFC is unable to support the continued increase of tensile stress. Additionally, LFC has a larger shrinkage, which is approximately two to three times greater than that of regular concrete [15]. As a result of this, there will be changes to the size of the structural components as well as the induction of cracking [16]. LFC has a high porosity because of the presence of air spaces that are trapped inside the matrix [17].

The development of textile fabric reinforcements is therefore anticipated to address all the drawbacks that have been highlighted due to the concerns that have been mentioned previously [18]. One example of this kind of textile fabric material is fibreglass fabric. This textile fabric, which possesses continuous multi-filaments and a weft knitting weave, could be a suitable alternative for use as a reinforcing element in LFC because it is anticipated to increase the toughness and tensile properties of the basic matrix [19]. This possibility arises because it could be used to increase the tensile properties of the basic matrix [20]. In addition to this, it can keep the substantial drying shrinkage that occurs in low-density LFC under control. Hence this research was conducted to investigate the durability properties of LFC with the inclusion of using fibreglass fabric.

2.Experimental Program

2.1 Materials and Mix Design

The main components needed to manufacture slurry mortar are clean water, fine sand, and ordinary Portland cement. This cement is compatible with Type 1 Portland Cement, as per the BS 12 standard. To produce a stable foam, a portable foaming device is employed. Noraite PA-1 is one of the protein agents used in foam production. It was chosen for this experiment because, compared to synthetic-based surfactants, it promotes stronger bonding structures in the bubbles due to its stability and smaller bubble size. Between 50 and 65 grammes per litre are the weight ranges of the foam used in this experiment. The natural fine sand used in the fine aggregate was purchased from a wholesaler in Malaysia. In addition, the water used to combine the ingredients was clean and devoid of any organic impurities. For fair LFC workability, a water-cement ratio of 0.45 was chosen in this investigation, as it had been in earlier ones. The fibreglass fabric was created to solve and eliminate early cracking problems. This woven fibre mesh with alkali resistance helps to stop fracture propagation while the material is still pliable. Fibreglass fabric creates a three-dimensional support network during the plastic settling phase that counteracts gravity's downward force, keeping the aggregate suspended and encouraging uniform bleeding. The tensile strain capacity of concrete is also enhanced by a network of fibreglass fabric during the plastic shrinkage process. In this investigation, fibreglass fabric in three different layer configurations; one layer, two layers, and three layers was used. Figure 1 shows how the sample was made, with the fibreglass fabric being placed in steel moulds before the LFC was added. The mix proportions for the two densities considered in this investigation are shown in Table 1.

Fig. 1. Fibreglass fabrics were placed accordingly in the steel moulds

Table 1
LFC mix design for 500 kg/m^3 and 1000 kg/m^3 densities

Sample Code	Density (kg/m^3)	FGF Layer (nos)	Cement (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)
Control-500	500	-	194	291	87
FGF1-500	500	1 layer	194	291	87
FGF 2-500	500	2 layers	194	291	87
FGF 3-500	500	3 layers	194	291	87
Control-1000	1000	-	378	562	169
FGF 1-1000	1000	1 layer	378	562	169
FGF 2-1000	1000	2 layers	378	562	169
FGF 3-1000	1000	3 layers	378	562	169

2.2 Experimental Program

The testing included flexural, compression, and splitting tensile tests to investigate the mechanical properties with the use of various types of additives.

2.2.1 Ultrasonic pulse velocity test

By measuring the propagation speed of a transmitted longitudinal ultrasonic pulse in the cross-sectional area, the ultrasonic pulse velocity test was evaluated. The LFC prisms' dimensions were measured to be 100 mm x 100 mm x 500 mm. An electro-acoustical transducer was employed as illustrated in order to assess the transmission of the ultrasonic pulse. With the aid of an electrical signal sent by a second transducer post and moving along a pulse's known path length within the specimen, it is kept in contact. The magnetic transducer displayed the transmitted time and velocity. Based on the standards outlined in BS EN 12504-4 [21], the standard processes were carried out. For all mixed designs, a mortar prism with the size 100 mm x 100 mm x 500 mm was prepared and evaluated on day 28.

2.2.2 Porosity test

The porosity test was conducted using the vacuum saturation method. On day 28, the LFC specimens were subjected to this test by being placed in a vacuum desiccator. With reference to the LFC specimens, this test tries to quantify the percentage of air voids because it has a direct bearing on the durability results. Three LFC specimens with dimensions of 50 mm in height and 45 mm in diameter were chosen from each batch and dried in an oven for 72 hours, or until the weight did not change. Each specimen was then cooled, and the weight of each was noted as W_{dry}. The specimens were kept completely submerged in a vacuum chamber until the 72nd hour or until no bubbles were visible. Both the weights of the specimens in the water ($W_{s,a}$) and the air ($W_{s,w}$) were recorded.

$$\text{Total porosity, }(\%) = \left(\frac{W_{s,a} - W_{dry}}{W_{s,a} - W_{s,w}}\right) \times 100\% \qquad (1)$$

where,

$W_{s,a}$ = weight of saturated sample in air
W_{dry} = weight of oven-dried sample
$W_{s,w}$ = weight of saturated sample in water.

2.2.3 Water absorption test

A water absorption test is thought to be crucial for determining the proportion of water absorbed by the LFC specimens at a particular period. Additionally, the porosity and density of LFC could be affected by a larger water percentage absorption. The water absorption test was conducted, as instructed in BS 1881-122 [22]. Samples in the form of cylinders measuring 75 mm in diameter and 100 mm in height were created. Three samples from each batch were removed from their packaging on the day of the test's age and put in the oven to dry for 72 hours. The next phase involved recording the weight (W_d) of each cooled, oven-dried specimen before submerging them entirely in a water tank for close to 30 minutes. The test specimen's weight was then recorded as W_s in a saturated condition after any extra water was afterwards wiped off with a dry cloth. The water absorption has been signified as a percentage of W_a, which was calculated by employing Equation (2). In the end, the average water absorption for these three samples was considered.

$$Water\ absorption, (\%) = \left(\frac{W_s - W_d}{W_d}\right) \times 100\% \qquad (2)$$

where,

W_s = Saturated surface dry weight
W_d = Oven-dried weight.

2.2.4 Drying shrinkage test

In accordance with ASTM C878 [23] requirements, the shrinkage test was initiated. The prism that was employed had a width of 75 mm and a length of 250 mm, and its overall length, which included the rod and the cap nuts and was depicted in Figure 4, was estimated to be 290 mm. In order to achieve an average result for each test, a minimum of three specimens were required to be taken. The initial length measurement was obtained using a length comparator that was furnished with a 250m invar bar and had the capacity to modify the value by a maximum of 0.001mm.

Adjustments were made to the length of the comparator based on each specimen's respective reference invar.

3. Results and Discussion

3.1 Ultrasonic pulse velocity

The influence of different layers of fibreglass fabric on ultrasonic pulse velocity (UPV) of 500 kg/m^3 and 1000 kg/m^3 densities LFC is shown in Figure 2. The performance of the control LFC was lower than that of the LFC with fibreglass fabric. The overall trend of the graph demonstrates a steady improvement in the UPV results from the control LFC when 3 layers of fibreglass fabric are used. The use of three layers of fibreglass fabric results in the maximum UPV at 500 kg/m^3 and 1000 kg/m^3, which are 1722 m/s and 2476 m/s, respectively. The highest UPV indicates the best LFC quality. The addition of two layers of fibreglass fabric with densities of 500 kg/m^3 and 1000 kg/m^3 results in the second-highest UPV value, 1693 m/s and 2470 m/s, respectively. The control LFC had the lowest UPV, 1640 m/s for 500 kg/m^3 density and 2341 m/s for 1000 kg/m^3 density. The LFC with the lowest UPV has the poorest quality. Finally, the UPV's value is determined by the quality of the LFC. The greater the velocity of the ultrasonic pulse, the more consistent the LFC. When compared to the others, it achieved the highest velocity with three layers of fibreglass fabric. As a result, it can be concluded that fibreglass fabric contributes to an increase in LFC pulse velocity. The effect of increasing cure time and age on UPV will eventually be seen as an improvement in UPV [24]. With paste hydration, this can be explained by a decrease in empty spaces or an increase in the gel-space ratio [25].

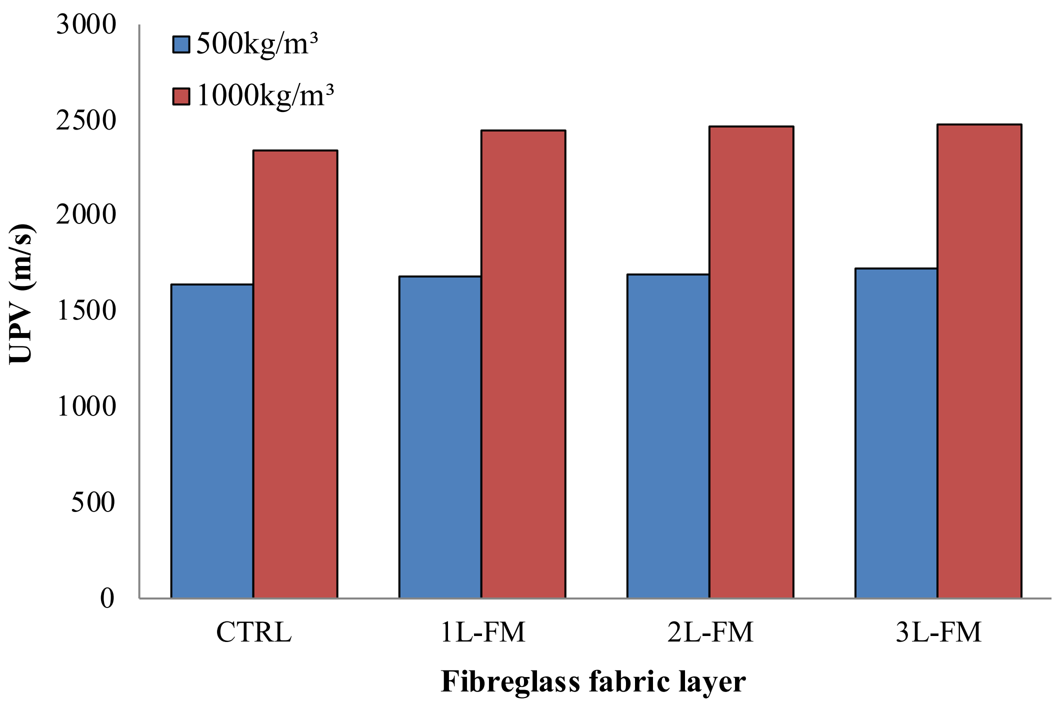

Fig. 2. Ultrasonic pulse velocity of LFC confined with varying layers of fibreglass fabric

3.2 Porosity

The impact of various fibreglass fabric layers on the porosity of LFC at 500 kg/m^3 and 1000 kg/m^3 densities is depicted in Figure 3. This finding makes it clear that fibreglass fabric is a significant factor in lowering the porosity of LFC. The addition of 1 layer of fibreglass fabric at both 500 kg/m^3 and 1000 kg/m^3 results in the second-highest porosity percentage, with respective values of 56.2% and 35.3%, trailing only the control LFC, which has the greatest porosity percentage of 61.1% and 41.7%. For 500 kg/m^3 and 1000 kg/m^3, two layers of LFC jacketing with fibreglass fabric resulted in porosity percentages of 53.6% and 34.5%, respectively. The lowest porosity is found in 3 layers of fibreglass fabric enclosures with densities of 500 kg/m^3 and 1000 kg/m^3, respectively, with values of 51.2% and 29.8%. This demonstrates that the usage of fibreglass fabric has an impact on the lowest micro-structural properties. A smaller range of air void capacity results from a decrease in the fraction of larger voids. Fibreglass fabric also helped increase the number of voids for a given density by preventing them from mixing and producing a wider range of void sizes than the equivalent conventional mixture [26]. The lowest porosity was found in the higher fibreglass fabric numbers, which also had the lowest air void volume.

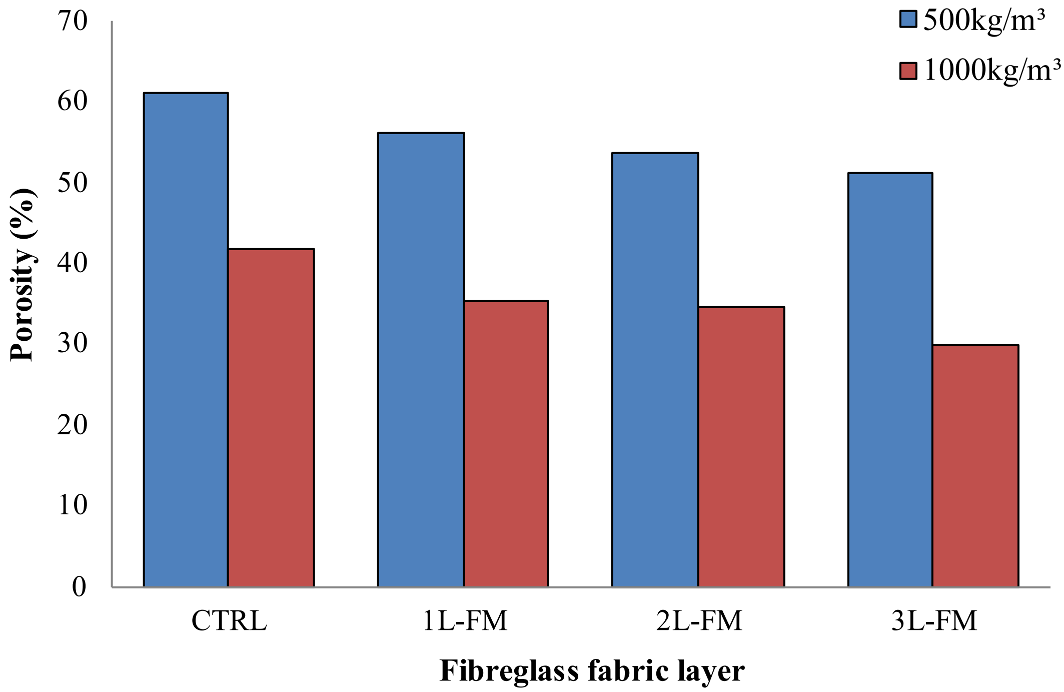

Fig. 3. Porosity of LFC confined with varying layers of fibreglass fabric

3.3 Water Absorption

The impact of various layers of fibreglass fabric on the LFC's capacity to absorb water at densities of 500 kg/m^3 and 1000 kg/m^3 is depicted in Figure 4. The overall trend of the graph reveals a steady reduction in the capacity to absorb water from the control LFC to the LFC with three layers of fibreglass fabric. The maximum water absorption capacity was demonstrated by control LFC at 500 kg/m3 and 1000 kg/m3, with respective values of 24.1% and 13.8%. The second-highest water absorption capacity is revealed by adding 1 layer of fibreglass fabric for 500 kg/m^3 and 1000 kg/m^3, respectively, yielding values of 22.4% and 10.7%. According to the testing findings, adding fibreglass fabric to the LFC may provide approximately 20% reduction in the amount of water absorption. This is due to the solid bond between the fibreglass fabric and the inability of the water to easily drain from the finest bond between the fibre and LFC. Due to its hydrophobic nature, the inclusion of a fibreglass fabric within the cement matrix was successful in preventing water from penetrating the LFC. Hydrophobic materials offer an alternative approach to the problem of preventing the diffusion of water molecules into LFC. In this scenario, increased water absorption would cause swelling of the LFC, which will in turn lead to a reduction in the material's mechanical performance [27]. On the other hand, hydrophilic fibres have the propensity to attract water molecules, which leads to higher penetration of water not only into the cement matrix but also into the fibres themselves, which causes a debonding of the fibres and the matrix because of the expansion of the swollen fibres [28]. This can be avoided by selecting hydrophobic fibres [29].

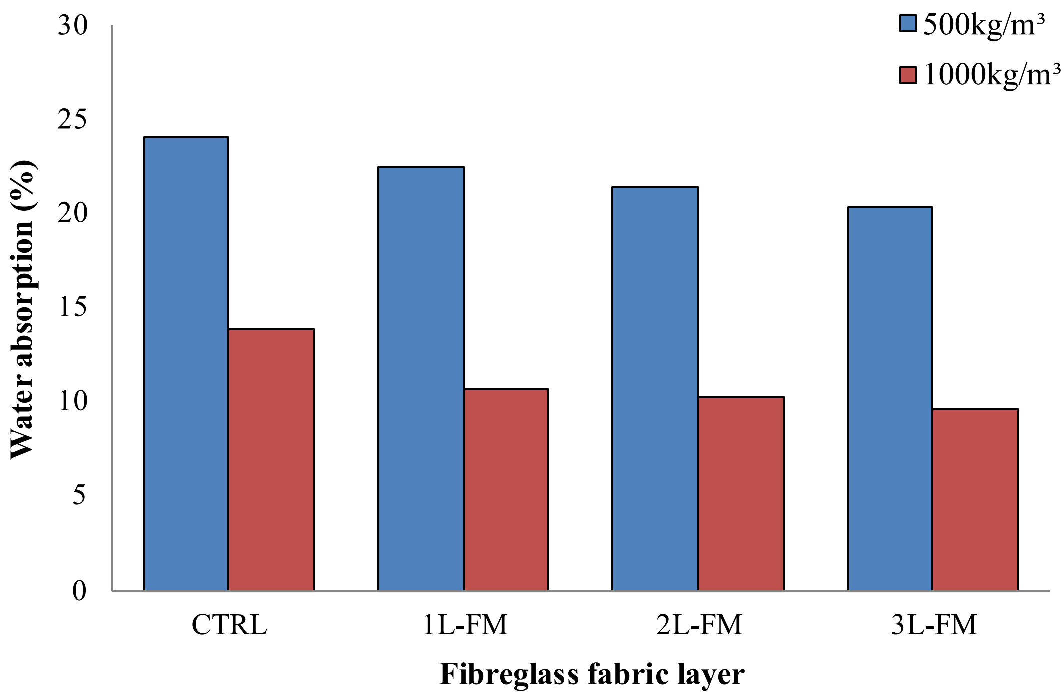

Fig. 4. Water absorption of LFC confined with varying layers of fibreglass fabric

3.4 Drying Shrinkage

Figures 5 and 6 show the effect of different layers of fibreglass fabric on the drying shrinkage of 500 kg/m^3 and 1000 kg/m^3 density LFC, respectively. From the overall observation, on day-3, the drying shrinkage of LFC significantly increased, but following day-7, the shrinkage of LFC slightly increases until reaching day-56. This is because, during the first 3 days, the LFC specimen was not fully hardened. The rapid increase in drying shrinkage at the early stage is due to the rapid loss of moisture from the surface of the specimen, while for the later stages, the rate of increase in the drying shrinkage is reduced with time depending on the removal of moisture from the concrete. At a density of 1000 kg/m^3 with 3 layers of fibreglass fabric, the result obtained showed that the LFC had the lowest value of drying shrinkage percentage while the control sample has the highest value of drying shrinkage. The highest value of drying shrinkage is considered not good for LFC since it can cause the propagation of cracking in the future. According to this result, the inclusion of fibreglass fabric in the LFC can reduce the drying shrinkage. From an overall view, the drying shrinkage for 1000 kg/m^3 was lower than 500 kg/m^3. This is because the foam volume is lower at 1000 kg/m^3 compared to 500 kg/m^3 density. It should also be pointed out that the increase in the foam volume will increase the shrinkage given the growth in the pore size [30]. Due to the fibreglass fabric's ability to prevent moisture from the cement paste from evaporating and modifying the LFC's dimensions, the drying shrinkage strain of the contained LFC was reduced [31]. The fibreglass fabric not only stopped water from leaking out of the LFC, but it also stopped it from diffusing into the cement matrix. This result can reduce nearly 75%-85% of the drying shrinkage of the control LFC by utilising 3-layers of fibreglass fabric.

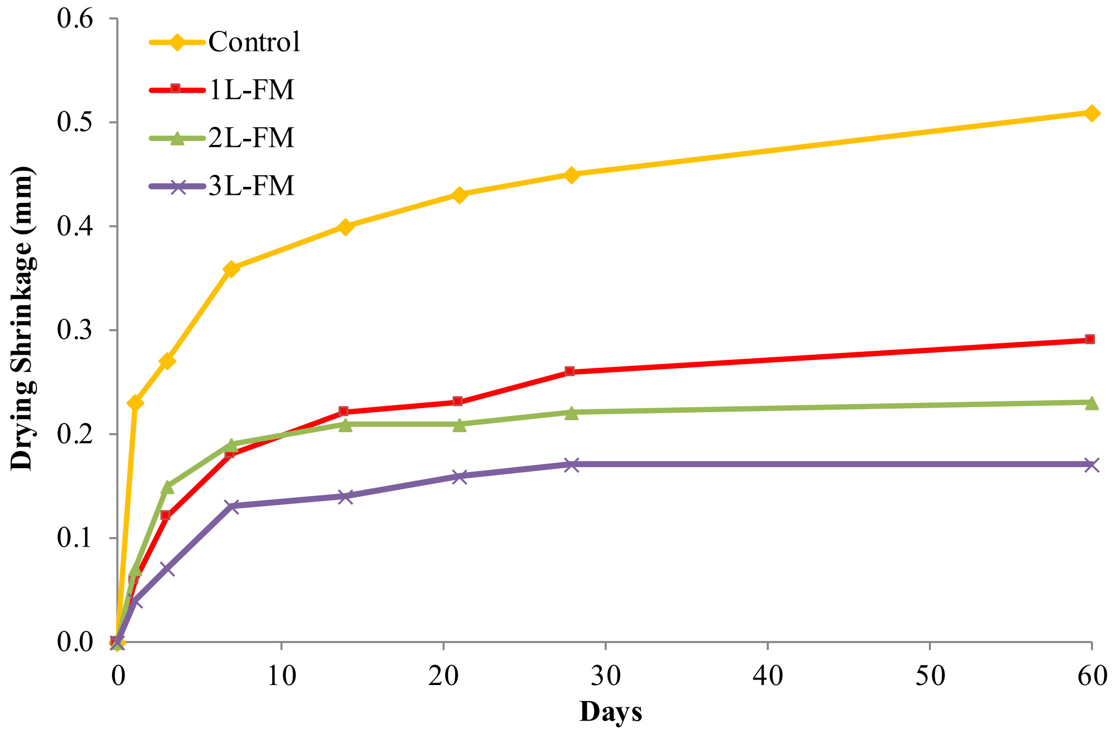

Fig. 5. Drying shrinkage of 500 kg/m^3 density LFC confined with varying layers of fibreglass fabric

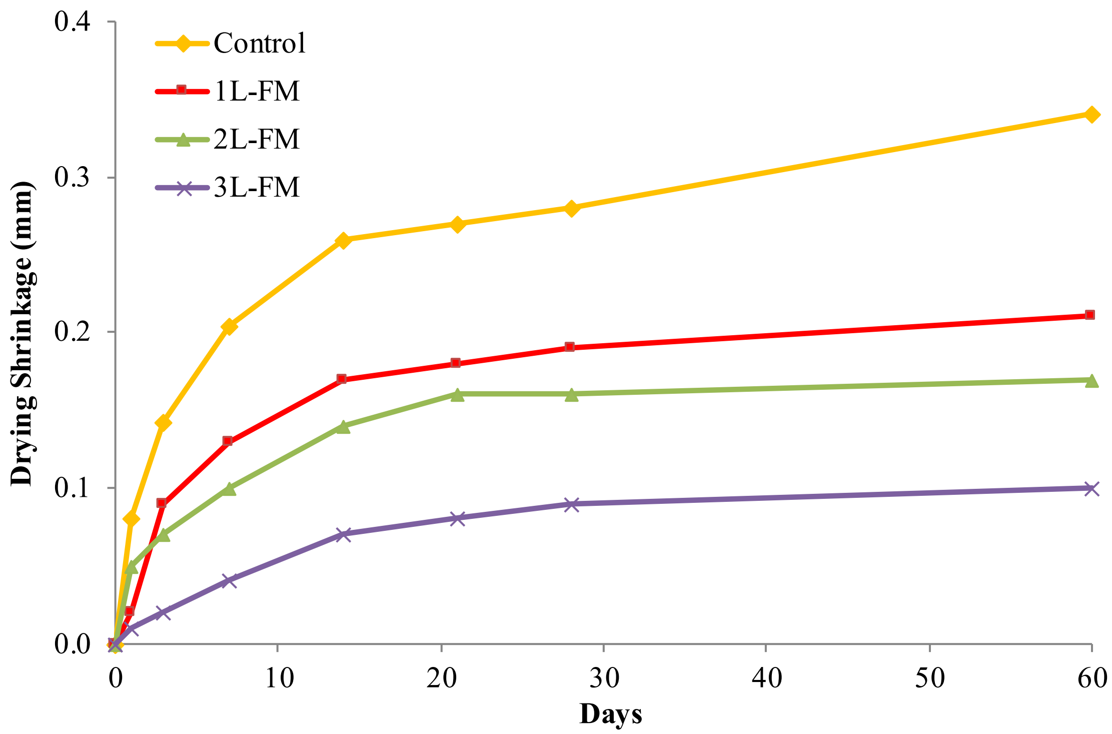

Fig. 6. Drying shrinkage of 1000 kg/m^3 density LFC confined with varying layers of fibreglass fabric

4. Conclusion

In conclusion, the experimental findings of this study demonstrated that the addition of fibreglass fabric to LFC reduced both the porosity and water absorption of LFC for both densities considered in this investigation (500 and 1000 kg/m^3). Fibreglass fabric improved LFC's drying shrinkage and UPV in addition to controlling cracks. As a result, the three layers of fibreglass fabric used provided the optimum technical qualities for all properties considered in this investigation. The drying shrinkage strain of the confined LFC was minimised because of the fibreglass fabric's capacity to prevent moisture from the cement paste from evaporating and changing the LFC's dimensions. Fibreglass fabric not only prevented water from leaking out of the LFC but also prevented the water from diffusing into the cement matrix. This was accomplished by preventing the water from diffusing. The results from this study showed that confinement with fibreglass fabric might extend the lifetime of LFC-based structure compared to other types of fibres, which would result in a loss of strength in the long-term performance due to the deterioration of fibres and the corrosion of steel fibres. This is due to the fact that both natural and steel fibres degrade with time. Although the idea of using fibreglass fabric in the building industry is not new, the design specifications for this application, particularly for LFC, have not yet been determined and recognized. These preliminary investigation results serve to illustrate how it might be used as a reinforcing element in construction projects.

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