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ENGINEERING PROPERTIES OF LIGHTWEIGHT FOAMED CONCRETE STRENGTHEN WITH FIBREGLASS NETTING

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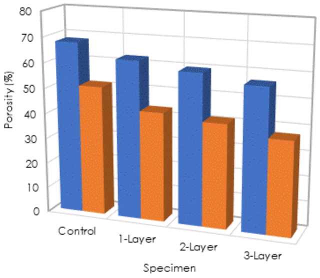
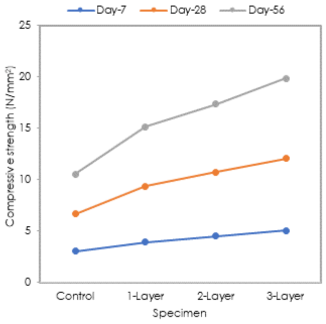
Graphical abstract





Abstract

Lightweight foamed concrete (LFC) is widely recognised as a low-density concrete with multiple applications. Yet, since its weight is approximately half that of conventional concrete, its strength should also be lower. Hence, synthetic and natural short fibres were utilised by previous researchers to enhance the performance of LFC. The use of textiles as reinforcing elements has attracted substantial attention in recent years. Consequently, the purpose of this study was to conduct an experimental investigation to determine the engineering properties of LFC reinforced with fibreglass mesh netting. In this study, LFC samples with densities of 550 kg/m^3 and 1150 kg/m^3 were formulated using a constant cement-to-sand ratio of 1:1.5, and a cement-to-water ratio of 0.45. The LFC specimens were jacketed with 1 layer, 2 layers and 3 layers fibreglass netting. The properties determined were compressive strength, flexural strength, split tensile strength, porosity, water absorption, UPV and drying shrinkage. Accordingly, the results showed that the incorporation of fibreglass netting in LFC helps reduce the absorption of water and the porosity of LFC for all densities. In addition to crack control, fibreglass netting also improves the drying shrinkage, flexural, compressive, tensile strengths and UPV. The optimal engineering properties were achieved with the addition of 3-layer fiberglass netting for 1150 kg/m^3 density LFC.

Keywords: Foamed concrete, compression, porosity, flexural strength, water absorption

Abstrak

Konkrit ringan berbusa (LFC) diiktiraf secara meluas sebagai konkrit berketumpatan rendah dengan pelbagai aplikasi. Namun, kerana beratnya lebih kurang separuh daripada konkrit konvensional, kekuatannya juga adalah lebih rendah. Oleh itu, gentian pendek sintetik dan semulajadi telah digunakan oleh penyelidik terdahulu untuk meningkatkan prestasi LFC. Penggunaan tekstil sebagai elemen pengukuhan telah menarik perhatian sejak beberapa tahun kebelakangan ini. Oleh itu, tujuan kajian ini adalah untuk menjalankan eksperimen untuk menentukan sifat kejuruteraan LFC yang diperkuat dengan jaringan gentian kaca. Dalam kajian ini, sampel LFC dengan ketumpatan 550 kg/m^3 dan 1150 kg/m^3 telah diformulasikan menggunakan nisbah simen-pasir 1:1.5, dan nisbah simen-air 0.45. Spesimen LFC telah dijaket dengan 1 lapisan, 2 lapisan dan 3 lapisan jaring gentian kaca. Sifat yang ditentukan ialah kekuatan mampatan, kekuatan lentur, kekuatan tegangan membelah, keliangan, penyerapan air, UPV dan pengecutan pengeringan. Sehubungan itu, keputusan menunjukkan bahawa penggabungan jaring gentian kaca dalam LFC membantu mengurangkan penyerapan air dan keliangan LFC untuk semua ketumpatan. Selain kawalan retak, jaring gentian kaca juga meningkatkan pengecutan pengeringan, kekuatan lentur, kekuatan mampatan, kekuatan belahan dan UPV LFC. Sifat kejuruteraan yang optimum dicapai dengan penambahan jaring gentian kaca 3 lapisan untuk LFC ketumpatan 1150 kg/m^3.

Kata kunci: Konkrit berbusa, mampatan, keliangan, kekuatan lenturan, penyerapan air

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1.0 INTRODUCTION

One of the key factors in a nation's development is the construction industry, which dates back many centuries. The Pyramid of Khufu in Giza, Egypt, is an illustration of a historic structure that has grown in popularity as a tourist destination and is still standing strong today. Because of the primitive technology available at the time and the 2,300,000 blocks that went into making the pyramid, it took 20 years to finish building using traditional methods [1].

Yet, due to the increased need for new housing projects, high-rise commercial buildings, and other infrastructural development, this country has begun to convert from conventional techniques of construction to the prefabricated approach to suit current needs [3]. Also, the global construction industry has identified the need for future building materials to be economical, easy to use, lightweight, and environmentally friendly. To meet all requests and needs in this regard, numerous aspects must be taken into account, including the scope (project requirements), time (project completion time), and money (costs). So, in addition to being crucial for ensuring that structures have a longer lifespan and safe occupation, the choice of building materials is one of the keys to making sure that these three project management restrictions can be met [4].

Given Malaysia's expansion and urbanisation, the construction industry is in high demand, resulting in the construction of numerous industrial and residential buildings. The construction industry is a global economic driver and one of Malaysia's most important industries. Malaysia's construction method is based on a set conventional method, sometimes referred to as the traditional construction method. Currently, there is an increasing need for concrete with distinctive properties. In addition to physical-mechanical qualities, aesthetic qualities are also required. In addition to the industry's considerable demand for load-bearing electricity, the emphasis is placed on low total costs that are affordable [5].

Many studies have been conducted to discover the optimal building material. With its lightness and adaptability, foamed concrete has garnered considerable interest in the construction sector. Yet, numerous construction businesses have utilised lightweight reinforced concrete as a building material for decades. Reinforced lightweight concrete is less expensive than conventional building materials, which reduces the cost of construction and improves its performance. In numerous applications, such as bridge decks in highway bridge systems, offshore and marine structures, pavement reconstruction and stabilisation of existing buildings, slabs and joints in high-rise buildings, and precast concrete, the advantages of using concrete with high loading at lower weights are prevalent [6].

Due to the construction industry's demand for lightweight, durable, simple-to-manufacture, and cost-effective construction materials, the use of lightweight concrete in buildings has increased in recent years, attracting many researchers interested in investigating this lightweight concrete. Lightweight concrete is defined as a type of concrete that contains an expanding agent, hence increasing the volume of the mixture while simultaneously providing extra properties, such as mailability and lower dead weight [7]. The future demand for construction materials that are lightweight, durable, user-friendly, inexpensive, and environmentally sustainable has been identified by worldwide foresight groups. One of the ideas has been the manufacturing, manufacturing, and usage of non-conventional building materials, with the potential use of LFC as a building material [8].

LFC, commonly referred to as aerated concrete, does not contain coarse aggregate and can be handled as aerated mortar [9]. Typically, LFC is manufactured by introducing air or other gases into cement slurry and fine sand. The distinction between LFC and regular concrete is that LFC does not use coarse aggregates; instead, homogenous cells formed by air in the form of small bubbles are used to replace traditional aggregates [10,11]. In industrial applications, pulverised fuel ash or other siliceous material replaces sand, and lime can be used for cement. There are numerous methods for preparing LFC. The first method involves injecting the gas into the mixture during its plastic state through a chemical reaction [12]. The second way for introducing air is by mixing in stable foam or whipping the air with an air-training agent. In precast concrete factories where precast units are subsequently autoclaved, the first process is typically used to produce concrete with moderately high compressive strength and low drying shrinkage. The second method is typically used for in-situ concrete, which is suitable for roof insulation and pipe lagging [13].

Before applying the foam, the mortar density typically ranges between 2100 kg/m^3 and 2300 kg/m^3. The LFC's density decreases to the optimal density limit after foam application. Synthetic and protein agents are the two types of foaming agents commonly utilised in LFC. The foam density ranges between 60 and 80 grams/litre [14]. Compared to synthetic-based surfactant, protein-based surfactant produces foam with considerably smaller bubbles and a bonding structure that is stronger and more stable. The generated bubbles can make mortar lighter than conventional concrete [15].

On the other hand, it is important to note that LFC has a low density, which makes it strong when subjected to compression but weak when subjected to tension. Because of this drawback, its application in building construction has been restricted, particularly for load-bearing and semi-structural components [16]. This is because the cement matrix contains a significant number of microcracks, which are caused by the high porosity of the cement [17]. These microcracks result in the material having very low tension and being very brittle when it is compressed [18]. Despite this, LFC is being utilised not only for the primary purpose of level correction in home development and as a fill-in material for load works, but it is also being utilised in construction as a semi-structural element [19]. Despite this, a significant amount of research has been done in an effort to enhance the performance of LFC due to the fact that it has the potential to be used as a structural building material [20,21]. Researchers are showing an increasing interest in LFC as a result of its qualities, which include its high thermal insulation and its acoustical shielding properties, particularly when low densities of the material are applied [22,23].

LFC offers a variety of benefits, such as increasing the dead weight of a structure, which reduces the need for supporting components like as base and lower story walls [24,25,26]. As a result of the absence of coarse aggregate and the effect of the ball bearing, LFC also has a greater consistency [27,28]. Hence, it does not need to be compacted and has an excellent load distribution [29,30]. Therefore, LFC can be moulded into the desired shapes and injected directly into the required location [31]. However, the principal issue with reinforced lightweight concrete construction is the rusting of reinforced steel, which greatly reduces the life and durability of concrete structures. As a substitute for welded wire mesh, fibre mesh can effectively aid in the elimination of corrosion because it is corrosion-resistant. Moreover, the use of fibreglass netting in LFC reduces crack width and increases the longevity of concrete. In addition, to crack management, fibreglass netting can improve the mechanical qualities of LFC, such as its resistance to cracking, impact, and dynamic load.

This project will evaluate the potential use of fibreglass netting to improve the engineering features of LFC. The base of fibreglass netting is a woven mesh that is coated with an alkali-resistant macromolecule latex. Its alkali-resistant mesh obtains good alkali tolerance, high strength, water resistance, durability, softness, and age resistance after receiving a surface coating. The product is widely used for wall reinforcement, outer wall insulation, and waterproof roofing in the construction industry and is regarded as appropriate for such applications. Alkali-resistant fibreglass netting is softer and merely disperses stress associated with deformation (stress associated with deformation beyond the temperature of deformation) but cannot share the tension of the adhesive layers.

2.0 METHODOLOGY

2.1 Materials

The primary materials used to produce slurry mortar include Ordinary Portland Cement (OPC), fine sand, and clean water. This type of cement is compatible with Type 1 Portland Cement as per the BS 12 standard. To produce a stable foam, a portable foaming device is used Noraite PA-1 is one of the protein agents used in foam production. Given its stability and smaller bubbles, it makes the bubbles induce a stronger bonding structure compared to synthetic-based surfactant; thus, it was chosen in this analysis. The weight of the foam used in this study varies in the 55-75 gram /litre range. The fine aggregate used was natural fine sand obtained from a local distributor in Malaysia. To identify the suitability of the sand to be used, according to the ASTM C33-03, a sieve analysis was conducted. Figure 1 shows the sand grading curve for the fine sand employed in this research.

Fibreglass netting was formulated to address and overcome problems of cracking at an early age. This alkali-resistant fibreglass netting helps prevent crack propagation in a plastic condition. The fibreglass netting creates a three-dimensional support network during the plastic settlement phase that resists the downward pull of gravity, thus keeping it aggregated in suspension and fostering uniform bleeding. A network of fibre mesh also increases the concrete's tensile strain ability during the plastic shrinkage process. For this study, three separate fibreglass nettings were used, namely 1 layer, 2 layers and 3 layers. Figure 2 illustrates the preparation of the samples in which the fibreglass netting was placed in steel moulds before infilling of LFC.

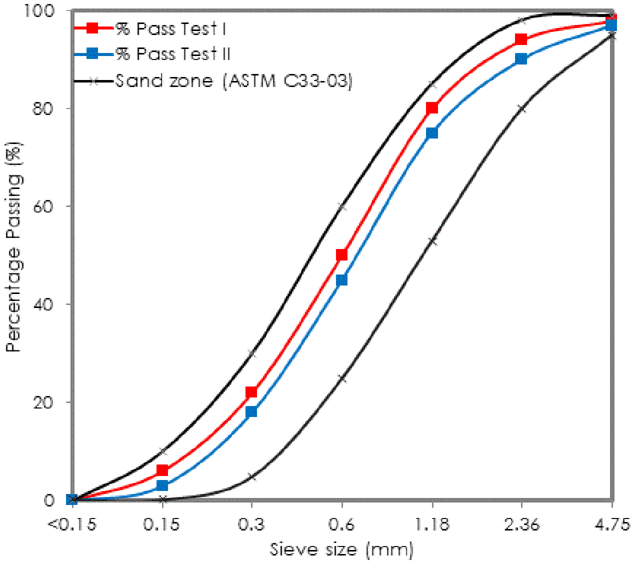

Figure 1 Sand grading curve for fine river sand in accordance with ASTM C33-03

Figure 2 Fibreglass netting was placed in the moulds

2.2 Mix Design

LFC densities of 550 kg/m³ and 1150 kg/m³ were prepared in this study. Table 1 displays the mix proportions for both densities fabricated and tested. The cement-to-sand ratio was maintained at the ratio of 1:1.5 while the water-cement ratio opted was 0.45 as it gave adequate workability.

Table 1 LFC mix proportions

LFC sample	Density (kg/m³)	Fibreglass netting	Cement (kg/m³)	Sand (kg)	Water (kg)
CTRL-550	550	-	212.2	318.3	95.5
1L-550	550	1 layer	212.2	318.3	95.5
2L-550	550	2 layers	212.2	318.3	95.5
3L-550	550	3 layers	212.2	318.3	95.5
CTRL-1150	1150	-	428.8	643.3	193.0
1L-1150	1150	1 layer	428.8	643.3	193.0
2L-1150	1150	2 layers	428.8	643.3	193.0
3L-1150	1150	3 layers	428.8	643.3	193.0

2.3 Testing Methods

The aim of this investigation was to establish the engineering properties of LFC strengthened with different layers of fibreglass netting. The properties evaluated were compressive strength, flexural strength split tensile strength, ultrasonic pulse velocity (UPV), drying shrinkage, water absorption and porosity. Table 2 summarizes the types of tests, specimen size and standard code of reference implemented.

Table 2 Types of tests, specimen size and standard reference for testing

Types of tests	Sample size	Standard
Compression	100 x 100 x 100 mm cube	BS12390-3
Flexural	100 x 100 x 500 mm prism	BS12390-5
Splitting Tensile	100 dia x 200 mm high cylinder	BS12390-6
UPV	100 x 100 x 500 mm prism	BS12504-4
Shrinkage	75 x 75 x 275 mm prism	BS6073-1
Water Absorption	75 dia x 100 mm high cylinder	BS1881-122
Porosity	50 dia x 100 mm high cylinder	BS993-1

3.0 RESULTS AND DISCUSSION

3.1 Axial Compressive Strength

The result of the compressive strength for LFC with the inclusion of fibreglass netting is shown in Figure 3 and Figure 4. There is a significant improvement in axial compressive strength beginning from day-7 to day-56. On day 7, the highest compressive strength was 5.03 N/mm², for the 3-layer fibreglass netting, while on day-56, the compressive strength was 7.82 N/mm². There was an increase of 55.5% in axial compressive strength. Control LFC specimen had lower compressive strength compared to the LFC with the inclusion of fibreglass netting. On day-56, for the control LFC specimen, the result was 3.89 N/mm², while the result of 1150 kg/m³ with 1-layer fibreglass netting was 5.81 N/mm², 6.64 N/mm² (2-layer) and 7.82 N/mm² (3-layer). There was a significant improvement in compressive strength with an increase in the number of layers of fibreglass netting for all densities. On day-56, there was a noticeable increase in compressive strength of 47%, 48% and 55% for 1-layer, 2-layer and 3-layer (1150 kg/m³ density), respectively, in comparison with the control specimen. When a load is applied, fibreglass netting prevents the propagation of cracks in the plastic condition of the cement matrix. This indicates that the addition of fibreglass netting will enhance the compressive strength proportionally.

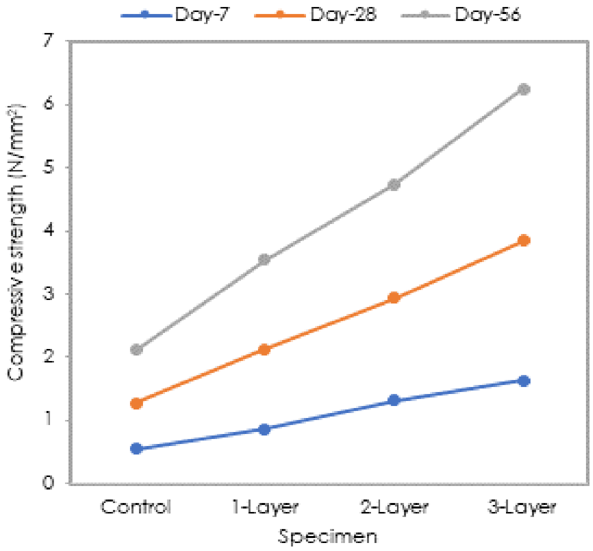

Figure 3 Compressive strength of 550 kg/m³ density LFC with different layers of fibreglass netting

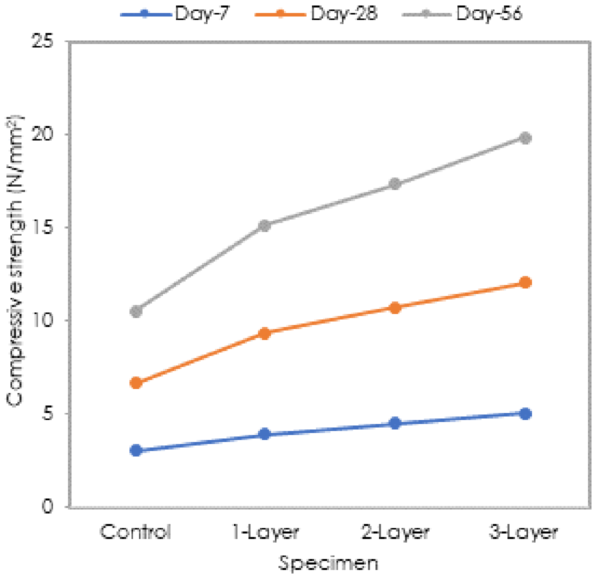

Figure 4 Compressive strength of 1150 kg/m³ density LFC with different layers of fibreglass netting

3.2 Flexural Strength

Figure 5 and Figure 6 show the influence of different layers of fibreglass netting on the flexural strength of 550 kg/m^3 and 1150 kg/m^3 density at different testing ages, respectively. The highest flexural strength is 1.80 N/mm^{2,} which is at 1150 kg/m^3 density and 3 layers of fibreglass netting on day-56. The higher density of LFC and the more layers of fibreglass netting resulted in a higher ultimate flexural load. Both densities considered in this research had a noticeable increase in flexural strength with increasing fibreglass netting layers. This is shown as the flexural strength of 3-layer fibreglass netting (1150 kg/m^3) on day-56 which was 1.80 N/mm^{2,} while the flexural strength of 1-layer fibreglass netting (1150 kg/m^3) was merely 1.34 N/mm^2 on day-56.

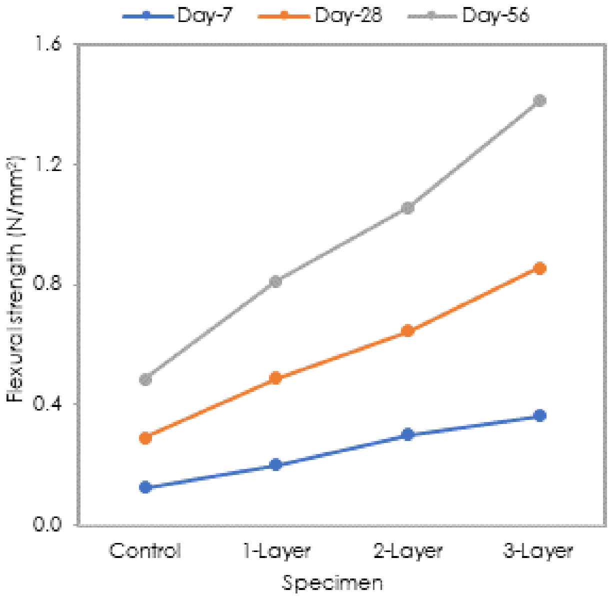

Figure 5 Flexural strength of 550 kg/m^3 density LFC with different layers of fibreglass netting

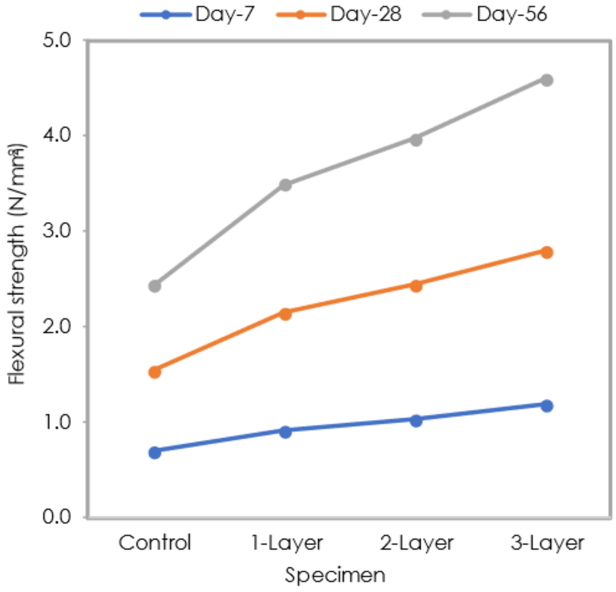

Figure 6 Flexural strength of 1150 kg/m^3 density LFC with different layers of fibreglass netting

There was a 34% increase in the utilisation of 1 layer of fibreglass netting over 3 layers of fibreglass netting. The flexural strength result of 3 layers of fibreglass netting was much higher than 1 layer of fibreglass netting given the fracture process of fibre-reinforced LFC consisting of progressive fibre debonding that slowed the spread of cracks [32]. However, Gokce *et al.* [33] stated that when LFC expands under a flexural load, it causes internally induced cracking. The crack has a limited distance over which it can spread before reaching the fibreglass netting, thus preventing the crack formation from growing.

3.3 Tensile Strength

Figure 7 and Figure 8 show the influence of different layers of fibreglass netting on the tensile strength of 550 kg/m^3 and 1150 kg/m^3 densities at different testing age, respectively. Based on these figures, LFC's tensile strength increased, given the number of layers of fibreglass netting increased. Moreover, it shows that the control samples of 550 kg/m^3 and 1150 kg/m^3 were the lowest. The lowest tensile strength recorded was 0.09 N/mm^2 which was the control LFC at day-7.

For 1150 kg/m^3, the highest tensile strength was 0.38 N/mm^{2,} which was at day-56 with the 3 layers of fibreglass netting. From the result, both densities of the control LFC had the lowest tensile strength compared to the LFC with the inclusion of fibreglass netting. With the increase in the age of curing, the highest tensile strength will be achieved. As such, according to the result, it can be concluded that the increase of the layers of fibreglass netting in the LFC resulted in greater adhesion on the cementitious material.

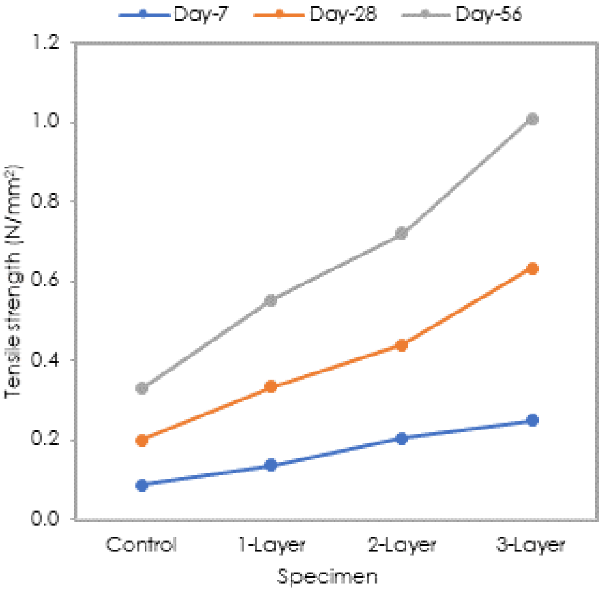

Figure 7 Split tensile strength of 550 kg/m^3 density LFC with different layers of fibreglass netting

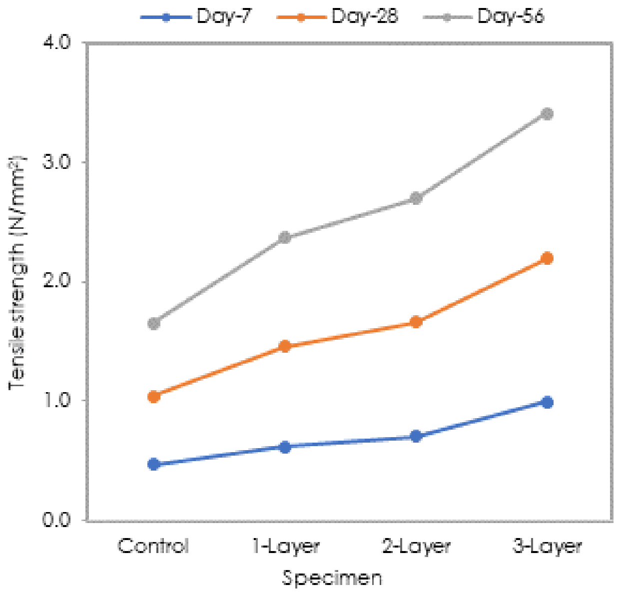

Figure 8 Split tensile strength of 1150 kg/m³ density LFC with different layers of fibreglass netting

3.4 Water Absorption

Figure 9 shows the effect of different layers of fibreglass netting on the water absorption capacity of 550 kg/m³ and 1150 kg/m³ densities of LFC. The graph's general pattern shows a gradual decrease in water absorption capacity from the control LFC to the LFC with 3 layers of fibreglass netting. Control LFC of 550 kg/m³ and 1150 kg/m³ had the highest water absorption capacity of 27.4% and 17.9% respectively. Next, the addition of 1 layer of fibreglass netting for 550 kg/m³ and 1150 kg/m³ reveals the second-highest water absorption capacity of 25.7% and 14.2% correspondingly.

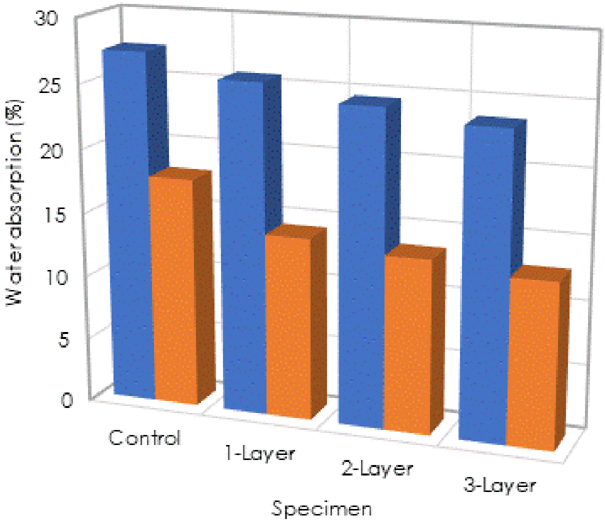

Figure 9 Water absorption of 550 and 1150 kg/m³ densities LFC with different layers of fibreglass netting

From the experimental results, the amount of water absorption may be decreased by up to 15% after the inclusion of the 3-layer fibreglass netting in the LFC. This is because the bonding between the fibreglass netting was firm, and the water could not readily be drained by the best bonding between the fibre and LFC [34].

3.5 Porosity

Figure 10 shows the influence of different layers of fibreglass netting on the porosity of 550 kg/m³ and 1150 kg/m³ densities LFC. From this result, it is evident that the inclusion of fibreglass netting plays an important role in reducing the porosity of LFC. The control LFC of 550 kg/m³ and 1150 kg/m³ shows the highest porosity percentage of 67.9% and 51.2%, Next, the addition of 1 layer of fibreglass netting at both 550 kg/m³ and 1150 kg/m³ show the second-highest porosity percentage of 62.5% and 43.2% correspondingly. The 2-layer of LFC jacketing for 550 kg/m³ and 1150 kg/m³ achieved the porosity percentage of 59.7% and 41.2%, respectively. Moreover, 3 layers of fibreglass netting enclosure of both 550 kg/m³ and 1150 kg/m³ densities show the lowest porosity of 56.5% and 37.3%, respectively.

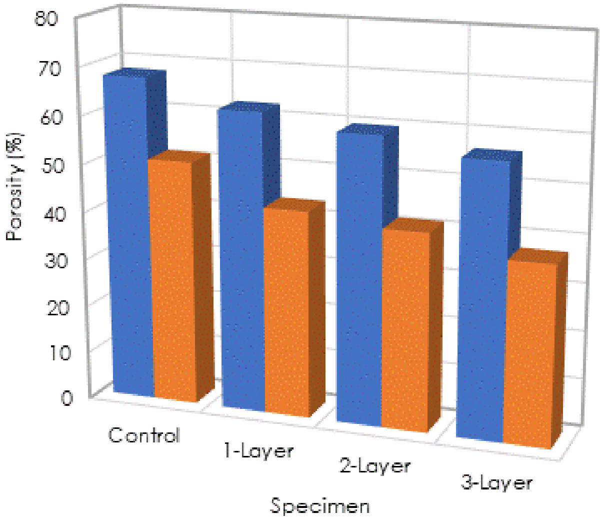

Figure 10 Porosity of 550 and 1150 kg/m³ densities LFC with different layers of fibreglass netting

Accordingly, this proves that the lowest micro-structural characteristics are affected using fibreglass netting. The proportion of greater voids also reduces, leading to a tighter range of air void capacity. In addition, for a given density, the addition of fibreglass netting contributed to an improvement in the number of voids by preventing them from combining and creating a wider range of void sizes relative to the equivalent standard mixture [35]. Higher fibreglass netting numbers had the lowest volume of air voids resulting in the lowest porosity.

3.6 Drying Shrinkage

Figure 11 and Figure 12 show the effect of different layers of fibreglass netting on the drying shrinkage of 550 kg/m^3 and 1150 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. At a density of 1150 kg/m^3 with 3 layers of fibreglass netting, the result obtained showed that the inclusion of 3-layer fibreglass netting 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 not good for LFC since it can cause the propagation of cracking in the future.

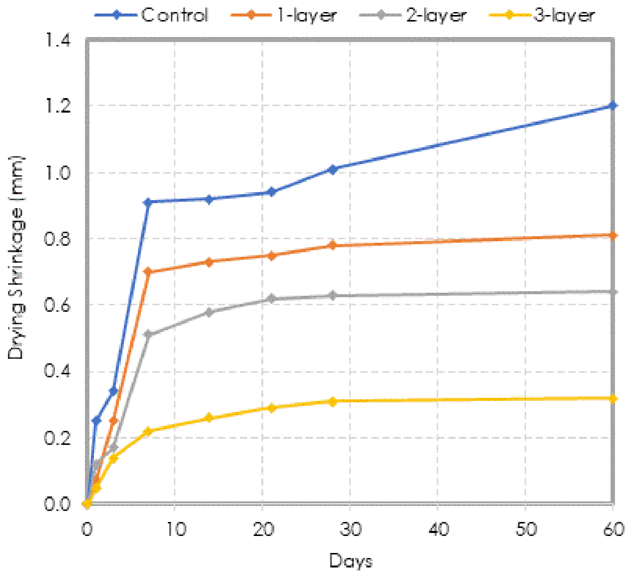

Figure 11 Drying shrinkage of 550 kg/m^3 density LFC with different layers of fibreglass netting

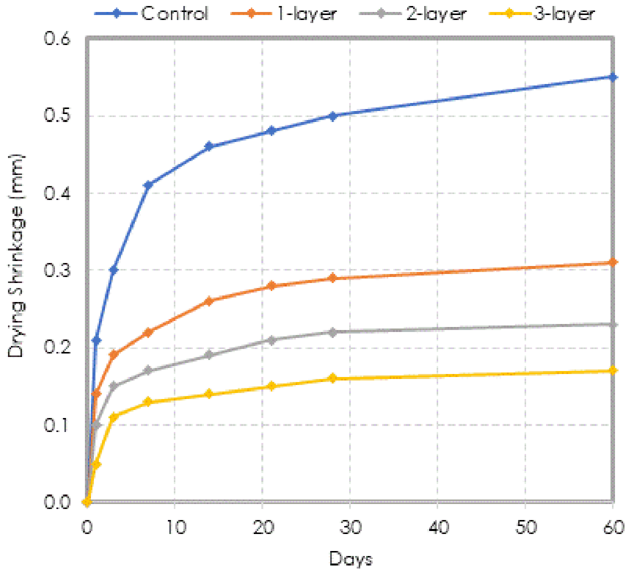

Figure 12 Drying shrinkage of 1150 kg/m^3 density LFC with different layers of fibreglass netting

According to this result, the inclusion of fibreglass netting in the LFC can reduce the drying shrinkage. From an overall view, the drying shrinkage for 1150 kg/m^3 was lower than 550 kg/m^3. This is because the foam volume is lower at 1150 kg/m^3 compared to 550 kg/m^3. It should also be pointed out that the increase in the foam volume will increase the shrinkage given the growth in the pore size [36,37]. This result can reduce nearly 85%-90% of the drying shrinkage of the control LFC by utilising a 3-layer of fibreglass netting.

3.7 Ultrasonic Pulse Velocity (UPV)

Figure 13 shows the influence of different layers of fibreglass netting on an ultrasonic pulse velocity (UPV) of 550 kg/m^3 and 1150 kg/m^3 densities LFC. The control LFC resulted in the lowest performance compared to the LFC with the inclusion of fibreglass netting. The graph's general trend shows a steady improvement in the UPV results from the control LFC when applying a 3-layer of fibreglass netting. For the 550 kg/m^3 and 1150 kg/m^3, the inclusion of 3 layers of fibreglass netting displays the highest UPV, which is 1612 m/s and 1998 m/s, respectively. The highest UPV shows the best quality of the LFC. Next, the addition of a 2-layer of fibreglass netting of both 550 kg/m^3 and 1150 kg/m^3 densities show the second-highest value of UPV, which was 1543 m/s and 1899 m/s correspondingly. The lowest UPV was the control LFC which was 1491 m/s for 550 kg/m^3 density and 1971 m/s for 1150 kg/m^3 density. The lowest UPV is the poorest quality of LFC.

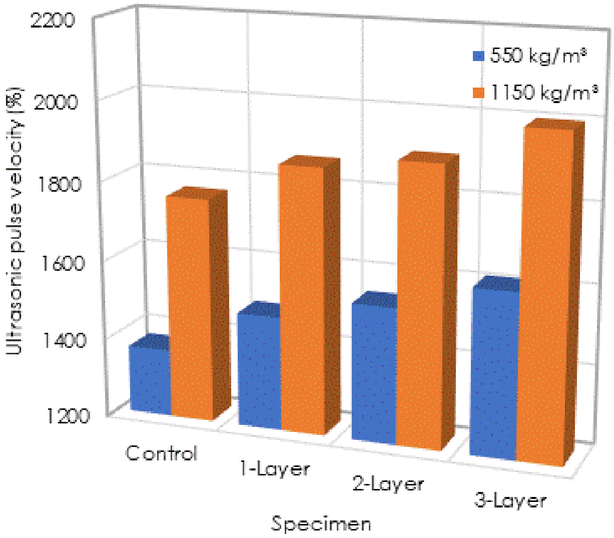

Figure 13 Influence of different layers of fibreglass netting on ultrasonic pulse velocity (UPV) of 550 kg/m^3 and 1150 kg/m^3 densities LFC

In conclusion, the value of the UPV depends on the quality of the LFC. The higher the velocity of the ultrasonic pulse, the greater the consistency of the LFC [38]. Particularly, with 3 layers of fibreglass netting, it achieved the highest velocity compared to the others. Therefore, it can be inferred that the fibreglass netting contributes to a rise in the pulse velocity of LFC.

Eventually, the influence of an increase in curing time and age on UPV will be observed as an improvement in UPV [39]. This can be explained by a decrease in empty spaces or an increase in the gel-space ratio with paste hydration [40].

4.0 CONCLUSION

The aim of this research was to assess the engineering properties of LFC reinforced with fibreglass mesh netting. LFC samples with densities of 550 kg/m3 and 1150 kg/m3 were made utilising a constant cement-to-sand ratio of 1:1.5, and a cement-to-water ratio of 0.45. The LFC specimens were jacketed with one, two, and three layers of fibreglass netting. The results reveal that the performance of unreinforced LFC was hindered by its high porosity, water absorption capacity, and drying shrinkage. When the foam volume increased, the LFC density decreased, but the values for the engineering properties tests at the specified curing age increased. The strength properties (compression, flexural and split tensile strengths) of LFC improved dramatically with the inclusion of fibreglass netting. As expected, the addition of 3-layer jacketing with fibreglass netting led to the highest strength values. Fiberglass netting limits the spread of cracks in the cement matrix's plastic state when a load is applied. Besides, the porosity, water absorption and drying shrinkage improved significantly once layers of fibreglass netting were increased. The 3-layer fibreglass netting gave the optimal results for shrinkage, water absorption and porosity. This is because of the solid bond between the fibreglass netting and the inability of the water to easily drain from the best bond between the fibre and LFC.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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