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Application of Alkali-Resistant Woven Fibre Mesh Confinement to Strengthen Lightweight Foamed Concrete

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ABSTRACT

Lightweight foamed concrete (LFC) is a low-density concrete with numerous applications. However, because its weight is nearly half that of traditional concrete, its strength can also be expected to be reduced. This research investigates the possibility of using LFC reinforced with alkali-resistant woven fibre mesh to improve its mechanical properties. One of the key issues of reinforced lightweight concrete construction is the deterioration of reinforced steel, which has a considerable impact on the reliability of concrete structures. Because it is corrosion resistant, fibreglass netting can effectively solve the corrosion problem as an alternative to welded wire mesh. In this investigation, two densities of LFC (700 kg/m3 and 1400 kg/m3) were cast and tested with three different layers of fibreglass netting, one layer, two layers, and three layers. Compressive strength, flexural strength, and splitting tensile strength were determined. According to the findings, including woven fibre mesh in LFC improves flexural strength, compressive strength, and splitting strength. The addition of three layers of woven fibre mesh resulted in the best mechanical performance for all mechanical qualities studied in this study.

1. Introduction

Due to Malaysia's rapid economic development and urbanisation, the construction industry is still in great demand, which has led to the construction of numerous commercial and residential structures. One of the largest economic drivers in the world and in Malaysia is the construction industry. Malaysia uses a set conventional approach, commonly referred to as the traditional building method, as its foundation for construction [1]. The need for concrete with distinctive properties is currently increasing. Not only physical-mechanical properties but also aesthetic attributes are required. The emphasis is on low total costs that are manageable given the need in the sector, in

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addition to the high demand for load-bearing power [2]. Additionally, the demand for sustainable development in the building and construction sector is rising today. Numerous studies have been done to meet this need. Researchers are becoming more interested in the possible applications of lightweight foamed concrete (LFC) in the building sector. LFC, however, is a brittle material that requires reinforcement to boost its strength, ductility, and toughness to delay structural failure. Corrosion issues brought on by using steel reinforcement in LFC will reduce its long-term endurance and necessitate expensive maintenance. The weight of the building also increases the need for steel reinforcement.

To discover the best construction material, numerous investigations have been conducted. LFC has garnered a lot of interest in the construction sector due to its lightweight and adaptability [3]. But for many years, reinforced lightweight concrete has been a popular building material among construction firms. Reinforced lightweight concrete can be used since it is less expensive than conventional building materials and performs better [4]. 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, frequently benefit from using concrete with high loading and smaller weights [5].

Given the demand in the construction industry for lightweight, durable, simple-to-manufacture, and affordable construction materials, the usage of lightweight concrete in buildings has increased lately, drawing many scholars interested in studying this LFC. A type of concrete known as lightweight concrete is one that uses an expanding agent to increase the volume of the mixture while also enhancing other properties, such as mailability and reducing dead weight [6]. The future need for building materials that are lightweight, strong, simple to use, affordable, and more ecologically friendly has been recognised by foresight organisations around the world. One of the ideas has been the development, production, and use of an alternative remedy, non-conventional building materials, with the potential use of LFC as a building material.

LFC, commonly referred to as aerated concrete, can be used as an aerated mortar because it doesn't contain coarse aggregate. LFC is typically created by adding air or other gases to fine sand and cement slurry. Pulverized fuel ash or another siliceous material can be used in place of sand in industrial applications, where cement can be substituted with lime [7]. There are various methods for preparing LFC. The first method involves adding the gas to the mixture through a chemical reaction while it is still in a plastic state. The second method, which whips air in using an air-training agent or mixes stable foam, is utilised to introduce air. The first approach is typically used in precast concrete factories to create concrete with suitable high strength and low drying shrinkage before precast units are autoclaved. The second technique is typically used for in-situ concrete and is appropriate for pipe lagging or roofing insulation.

Prior to adding the foam, the mortar density used in LFC typically ranges between 2000 kg/m^3 and 2200 kg/m^3. The LFC's density falls to the ideal density limit after the foam application [8]. Synthetic and protein agents are the two main kinds of foaming agents utilised in LFC. The foam used has a density of 55 to 75 grams/litre. In comparison to synthetic-based surfactant-based foam, the protein-based foam has substantially smaller bubbles and a stronger, more stable bonding structure [9]. By creating air bubbles, mortar can become lighter than conventional concrete [10].

LFC also offers a number of benefits, including increasing a building's dead weight, which reduces the need for supporting elements like base and lower-level walls. Given the absence of coarse material and the impact of the ball bearing, LFC also has a higher consistency. As a result, it has an excellent load spread and does not require compaction. LFC may therefore be piped directly to the location where it is needed and utilised to cast into the necessary shapes [11]. The rusting of reinforced steel, which adversely affects the life and durability of concrete structures, is the fundamental issue that reinforced lightweight concrete construction must deal with. Since fibre mesh is corrosion-resistant, it can successfully help to solve the corrosion problem as a replacement for welded wire mesh [12].

Woven fibre mesh is also used in LFC to reduce fracture width and increase concrete's durability. Woven fibre mesh can improve LFC's mechanical qualities, such as cracking resistance, impact resistance, and dynamic load resistance, in addition, to crack management. In order to enhance LFC's engineering qualities, this study will look into the potential application of woven fibre mesh in LFC [13]. A woven mesh called woven fibre mesh serves as the foundation for a layer of alkali-resistant macromolecule latex. This alkali-resistant mesh gains the qualities of having good alkaline tolerance, high strength, water resistance, durability, softness, and resistance to ageing after receiving a surface coating. The product is frequently used in the construction industry for waterproof roofing, wall reinforcement, and outer wall insulation [14]. Alkali-resistant woven fibre mesh has a softer texture and is unable to distribute the tension of the adhesive layers; it can only distribute the stress related to deformation [15].

2. Experimental Program

2.1 Materials and mix design

Ordinary Portland Cement (OPC), fine sand, and clean water are the key ingredients required to make slurry mortar. According to the BS 12 standard, this cement is compatible with Type 1 Portland Cement. A portable foaming apparatus is used to create a stable foam. One of the protein agents utilised in foam generation is Noraite PA-1. Because of its stability and smaller bubbles, it induces a stronger bonding structure in the bubbles when compared to synthetic-based surfactants; consequently, it was chosen for this investigation. The weight of the foam utilised in this investigation ranges between 50 and 65 grammes per litre. The fine aggregate utilised was natural fine sand acquired from a Malaysian wholesaler. A sieve analysis was performed in accordance with British Standard BS822:1992 to determine the appropriateness of the sand to be utilised. Furthermore, the water used to mix the components was pure and free of dirt and other organic contaminants. This study used a water-cement ratio of 0.45, which was also used in prior studies to ensure fair LFC workability. The woven fibre mesh was designed to address and overcome cracking issues at an early stage. This alkali-resistant woven fibre mesh aids in the prevention of fracture propagation in a plastic state. During the plastic settling phase, the fibreglass netting forms a three-dimensional support network that resists gravity's downward pull, keeping the aggregate suspended and promoting uniform bleeding. A network of woven fibre mesh also improves the tensile strain ability of concrete during the plastic shrinkage process. Three different layers of woven fibre mesh were employed in this study: one layer, two layers, and three layers.

Fig. 1. Alkali-resistant woven fibre meshes were positioned in the steel mould

Figure 1 depicts the sample preparation, in which the woven fibre mesh was inserted in steel moulds prior to the infilling of LFC. Table 1 shows the mix proportions for both densities evaluated in this study. Two densities of 700 kg/m^3 and 1400 kg/m^3 we cast and tested.

Table 1
Mix proportions

Specimen Reference	Density (kg/m^3)	Layer (nos)	Cement (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)
Control-700	700	-	266	400	120
WFM1-700	700	1 layer	266	400	120
WFM2-700	700	2 layers	266	400	120
WFM3-700	700	3 layers	266	400	120
Control-1400	1400	-	519	779	234
WFM1-1400	1400	1 layer	519	779	234
WFM2-1400	1400	2 layers	519	779	234
WFM3-1400	1400	3 layers	519	779	234

2.2 Experimental Program

Flexural, compression, and splitting tensile strength tests were used to study the mechanical properties of foamed concrete strengthened with alkali-resistant woven fibre mesh. The compression test was carried out on a cube of 100mm x 100mm x 100mm in line with the BS EN 12390-3 [16] standard. As the final result, the average compressive test result from three specimens was chosen. The flexural test was then performed using a prism measuring 100mm x 100mm x 500mm in line with BS EN 12390-5 [17]. A three-point flexural test was utilised to measure the flexural strength of foamed concrete. The average flexural test result from three specimens was chosen as the final result. A BS EN 12390-6 [18] cylinder of 100mm diameter x 200mm height was also tested for splitting tensile strength. Three specimens were created and evaluated, with the final result being the average of the three flexural test findings.

3. Results and Discussion

3.1 Axial compressive strength

Figures 2 and 3 depict the outcome of the compressive strength for LFC with the addition of different numbers of layers of woven fibre mesh. From day 7 to day 56, the axial compressive strength significantly increases for both densities considered in this study. For 1400 kg/m^3 density, the 3L-WFM had the highest compressive strength on day 7, which was 6.93 N/mm^2, whereas, on day 60, it was 10.42 N/mm^2. The axial compressive strength increased by 50.4% from day 7 to day 60. Compared to the LFC with woven fibre mesh, the control LFC (without it) exhibited a lower compressive strength. Day-60 results for the control LFC specimen were 5.51 N/mm^2 for 1400 kg/m^3 density. For both densities, the compressive strength significantly increased as the number of layers of woven fibre mesh increased. In comparison to the control specimen, the compressive strength of the 1L-FM, 2L-FM, and 3L-FM (1400 kg/m^3 density) specimens increased noticeably on day-60 by 46.1%, 61.3%, and 89.1%, respectively. Woven fibre mesh aids in preventing the propagation of cracks in the cement matrix's plastic state after the load was applied. This implies that adding woven fibre mesh will increase the compressive strength in line with this. Besides, the suppression with woven fibre mesh in the shape of a jacket and the increase in the initial elastic stiffness of LFC were responsible for all the improvements. When the applied load caused lateral deformation, the tension in the jacket (woven fibre mesh confinement) was activated due to the lateral expansion of the LFC [19]. Furthermore, when exposed to a higher applied load, the woven fibre mesh prevented microcracks and slowed crack spreading [20].

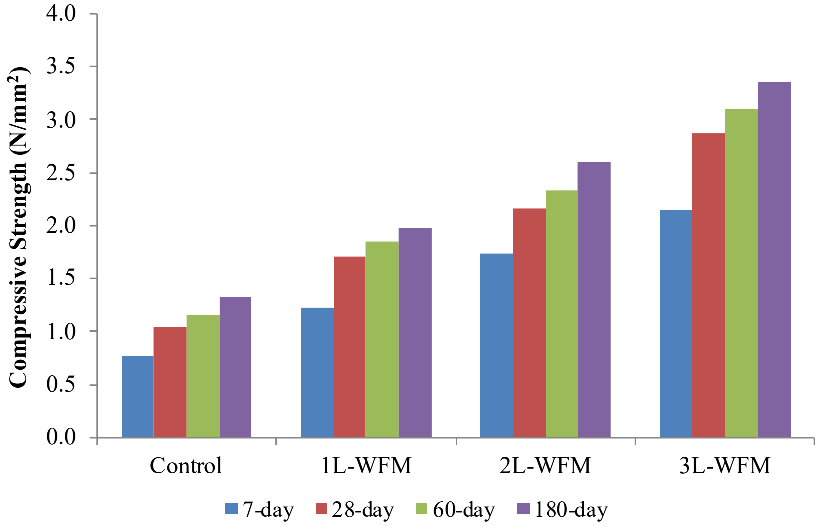

Fig. 2. Compressive strength of 700 kg/m^3 density confined with different numbers of layers of woven fibre mesh

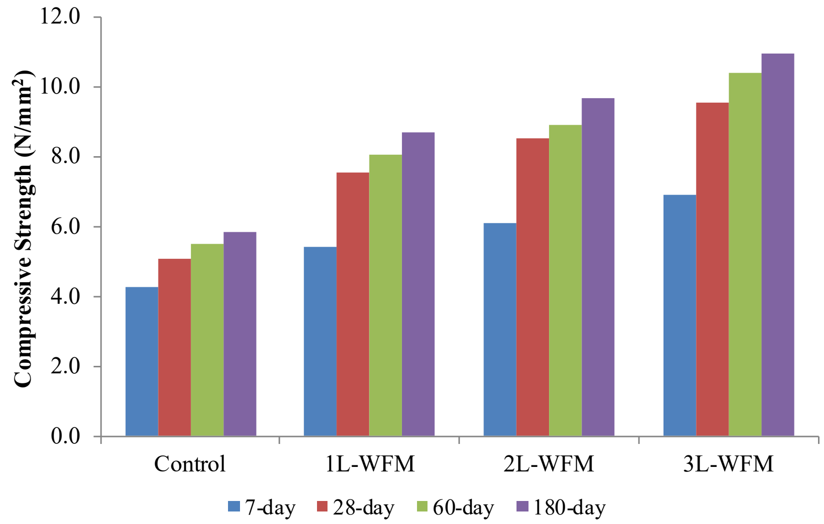

Fig. 3. Compressive strength of 1400 kg/m^3 density confined with different numbers of layers of woven fibre mesh

3.2 Flexural strength

Figures 4 and 5 illustrate the effect of varying numbers of layers of woven fibre mesh on the flexural strength of composites with densities of 700 kg/m^3 and 1400 kg/m^3, respectively, when tested at a range of ages. When there are three layers of woven fibre mesh and a density of 1400 kg/m3, the flexural strength is 4.40 N/mm^2, which is the greatest possible value. The larger ultimate flexural stress was the direct result of the higher density of LFC as well as the increased number of layers of woven fibre mesh. Both densities that were taken into consideration for this investigation showed a discernible increase in flexural strength with increasing the number of layers of woven fibre mesh. This is demonstrated by the fact that the flexural strength of 1L-FM (1400 kg/m^3) was only 2.56 N/mm2, whereas the flexural strength of 3L-FM (1400 kg/m^3) was 4.13 N/mm^2 on day 60. When compared to the utilisation of three layers of woven fibre mesh, the application of one layer of woven fibre mesh saw a 61.3% increase. Given that the fracture process of fibre-reinforced LFC consisted of progressive fibre debonding that slowed the spread of cracks, the flexural strength result of 3 layers of woven fibre mesh was significantly greater than the flexural strength result of 1 layer of woven fibre mesh. On the other hand, internally induced cracking occurs in LFC when it expands under a flexural load because of stress [21]. The fracture can only extend for a certain distance before it reaches the woven fibre mesh, which prevents the crack creation from spreading further along its path [22].

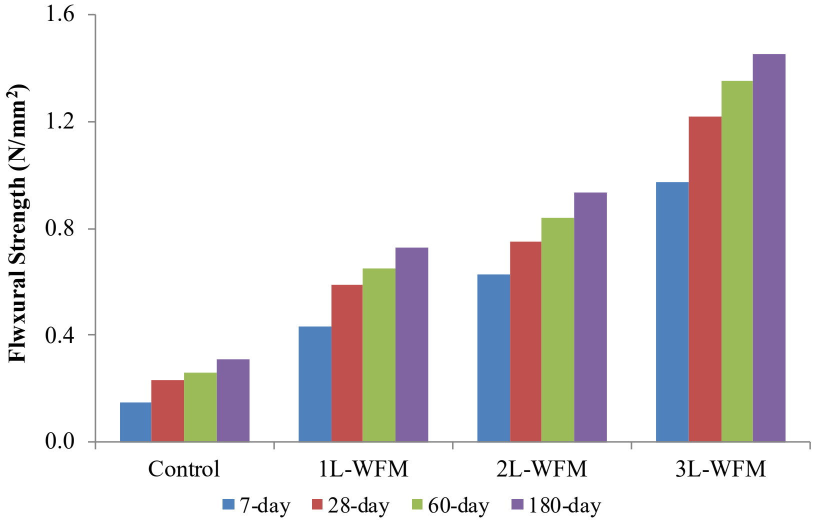

Fig. 4. Flexural strength of 700 kg/m^3 density confined with different numbers of layers of woven fibre mesh

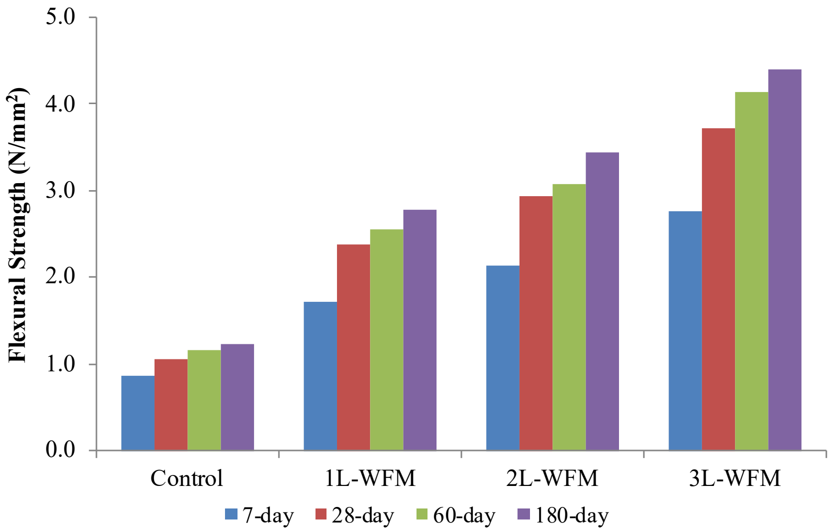

Fig. 5. Flexural strength of 1400 kg/m^3 density confined with different numbers of layers of woven fibre mesh

3.3 Tensile strength

Figures 6 and 7 illustrate the effect that the number of layers of alkali-resistant woven fibre mesh has on the tensile strength of samples with densities of 700 kg/m^3 and 1400 kg/m^3 after being subjected to a variety of testing ages, respectively. According to these numbers, the tensile strength of LFC rose, which makes sense considering the rise in the number of layers of alkali-resistant woven fibre mesh. In addition, it was discovered that the control samples with densities of 700 kg/m^3 and 1400 kg/m^3 had the lowest strengths.

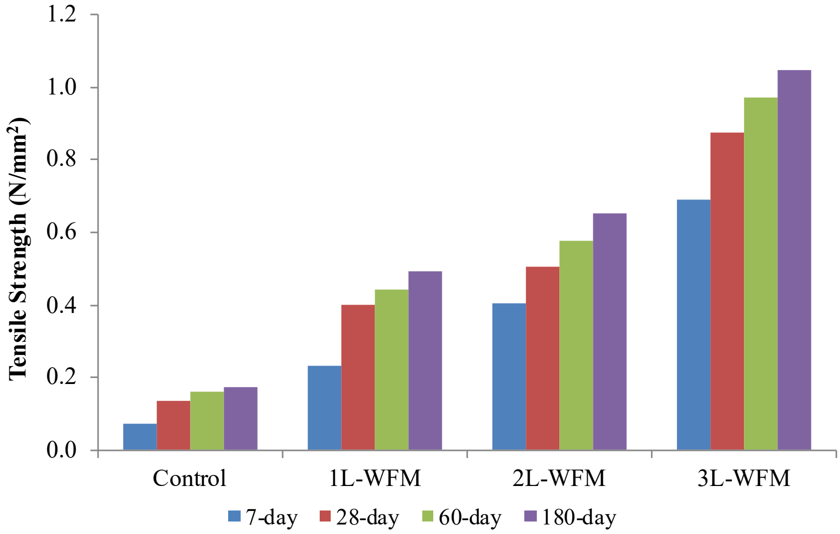

Fig. 6. Tensile strength of 700 kg/m^3 density confined with different numbers of layers of woven fibre mesh

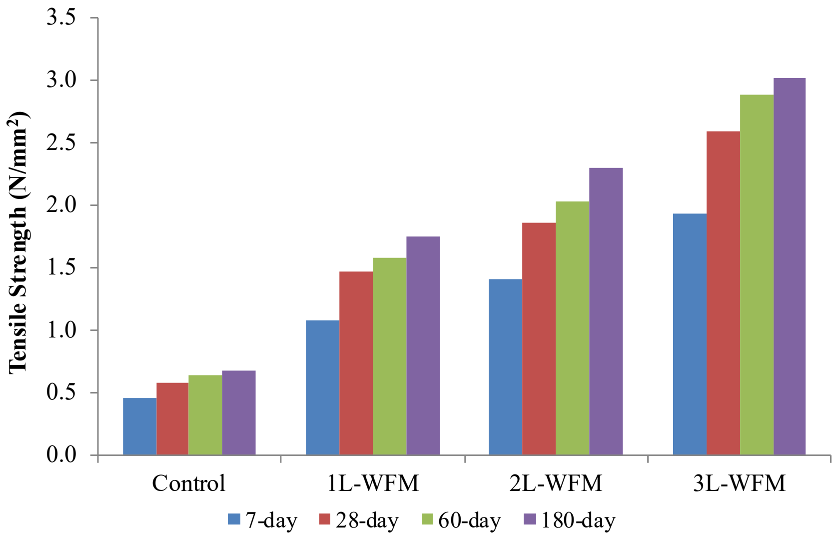

Fig. 7. Tensile strength of 1400 kg/m^3 density confined with different numbers of layers of woven fibre mesh

On day-56, the control LFC (700 kg/m^3 density) had a tensile strength of 0.16 N/mm^2, which was the lowest value ever recorded. At day 56, when there were three layers of woven fibre mesh, the material had a tensile strength of 0.97 N/mm^2. According to the findings, the tensile strength of both densities of the control LFC was much lower than that of the LFC that had woven fibre mesh incorporated into its composition. When the age of curing is increased, the tensile strength of the material will increase to its maximum potential. According to the findings, one can therefore draw the conclusion that an increase in the number of layers of woven fibre mesh in the LFC led to a better adhesion to the cementitious material [23,24]. The significant increase in the tensile strength of LFC was due to the higher flexibility of the woven fibre mesh, which caused a higher strain on the cement matrix [25,26].

4. Conclusion

The purpose of the study was to investigate the mechanical properties of LFC that have been strengthened with woven fibre mesh. In order to accomplish this goal, three tests were conducted namely, a compression test, a flexural test and a splitting tensile test. The results revealed that the presence of 3 layers of woven fibre mesh led to the optimal compressive, flexural and tensile strength of LFC. This indicated that the confinement with woven fibre mesh can prolong the life span of LFC compared to other fibres, where there will be a reduction in strength in the long-term performance due to the deterioration of the natural fibres and the corrosion of steel fibres. This is because the natural fibres and the steel fibres both corrode over time. Even while the application of textile fabrics in the construction sector, such as woven fibre mesh, is not a novel concept, the design requirements for this application have not yet been specified, particularly for LFC. This is notably the case with woven fibre mesh. The purpose of these findings from the preliminary inquiry is to demonstrate its possible application as a reinforcing component in building work.

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