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Innovative Application of Interwoven Fiberglass Mesh to Strengthen Lightweight Foamed Concrete

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ABSTRACT

This paper discusses the innovative application of interwoven fiberglass mesh (FM) to strengthen lightweight foamed concrete (LFC). Two samples having 600kg/m^3 and 1200kg/m^3 densities were prepared and evaluated. The study evaluated tensile, compressive, and flexural strength. Synthetic textile fabric-based FM possessing alkali resistance was employed. The samples were wrapped with 1 to 3-layer(s) of FM. To obtain equivalent results, the water-to-cement ratio was fixed at 0.45 whereas the cement-sand proportion was constant at 1:1.5. The experimental outcomes implied that confinement with 3-layers of FM gave the greatest results for all strength properties studied in this research. The improvement in strength properties of LFC was achievable because FM confinement caused the LFC to have higher starting elastic stiffness. Confining FM within LFC offers noteworthy enhancements in deformability and strength. These enhancements grow as the count of confined layers is increased. Moreover, mortar tensile strength affects confinement failure occurring due to FM cracking.

1. Introduction

In the construction sector, lightweight foamed concrete (LFC) use has increased extensively, causing increased production levels and application areas. LFC provides a cost-effective substitute for lightweight construction at scale [1]. It is used for structural elements, separators, and filling road embankments and grades. It has a straightforward production process, covering initial manufacturing to the final application [2]. For the past 30 years, LFC has predominantly been applied for pipeline infill, backfill of retaining panels, insulation to foundations, trench restoration and sandwich filling for prefab components [3,4]. Though, there has been increasing attention to using LFC as a lightweight semi-structural component in building construction to take benefit from its excellent insulation performance [5,6].

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However, LFC is acknowledged to be relatively fragile in nature under flexural and compression stresses, where its flexural strength is barely around one-tenth of LFC's under compression [7,8,9]. Consequently, LFC bending elements could not sustain such loads that characteristically emerge for the duration of their service life. Most LFC experiments employed continuous reinforcing beams to enhance tensile and bending stress-bearing capacity and compensate for inadequate ductility [10,11]. Moreover, steel-based strengthening addressed tensile and shear stress concerns about critical points on LFC parts [12,13]. Steel offers better LFC strength; however, the micro-crack formation must be addressed to manufacture LFC having desirable tensile characteristics [14,15].

The need to upgrade existing structures has increased notably during the past two decades. Attention is required for seismically active and inactive areas because of upgraded design requirements and structural weakening in seismically inactive areas [16,17]. However, areas with seismic activity have older constructions adhering to outdated requirements, requiring upgrades to ensure their performance meets present recommendations [18-20]. Reinforced concrete constructions are extensively upgraded using confinement techniques [21,22]. These techniques attempt to increase confinement for the entire structure or the likely plastic hinge areas [23,24]. Concrete confinement is one of the most recurrently used techniques to strengthen LFC and enhance ductility. This technique enhances LFC stiffness and axial and bending strength [25,26]. It is common knowledge that composite element monolithic characteristics determine process success [27]. Therefore, this research focuses on laboratory appraisal of the engineering properties of alkali-resistant FM-confined LFC.

2. Materials and Mix Design

2.1 Cement

The cement utilized for this research was procured from YTL Sdn. Bhd. The samples adhere to Type I Portland Cement requirements defined by BS 12. Cement preparation was performed, and the sample was protected using plastic to prevent hydration until it was mixed. Table 1 indicates the chemical composition of this cement.

Table 1
Portland cement chemical composition

Chemical compound	Portland cement
Aluminium Oxide	3.60
Silicone Dioxide	16.00
Sulphur trioxide	3.10
Potassium oxide	0.34
Calcium oxide	72.00
Ferric Oxide	2.90
Magnesium Oxide	1.50
Sodium oxide	n/d

2.2 Sand

River sand with fine particles was dried and processed using a 2.36 mm sieve. BS 882 recommended practices were followed to enhance the flow characteristics and consistency as per BS12620.

2.3 Water

Potable tap water was employed in this experiment. It was ensured that the water was free from ions or dispersed elements that could hamper hydration and other processes concerning cellular mortar mixtures. The portable water was also utilized to prepare the foaming material for aeration.

2.4 Surfactants

Protein-based surfactant was employed in this study to create foam; it has higher stability than other commercially available products. Researchers assert that protein-based substances have relatively low bubble size, higher stability, and closely packed bubble distribution. A foam marker was used along with an air compressor to create bubbles using a water to surfactant ratio of 33:1. The density of foam varied between 55 to 65 kg/m^3 to produce cellular mortar. This protein-based foam was utilized to mix with the fresh cement hence the bulk density can be monitored via the amount of air bubbles created in the mortar mix.

2.5 Interlaced Fiberglass Mesh (FM)

This study used 160 gsm FM (also called textile fabric) for confinement to enhance LFC mechanical characteristics. This textile comprises synthetic fibers with higher LFC durability due to enhanced protection against alkali material. The substance is versatile, eco-friendly, and lightweight. FM employed in this research is displayed in Figure 1.

Fig. 1. Interlaced fiberglass mech of 160gsm

2.6 LFC Mix Design

For this research, there were 2 mixes were prepared. The density chosen was 600 kg/m^3 and 1200 kg/m^3. The LFC samples were jacketed with 1 layer to 3 layers of FM. The sand-to-cement proportion was fixed at 1:1.5, while the water-to-cement proportion was 0.45. Table 2 reveals the mix design prepared.

Table 2
Mix proportions

Target Density (kg/m^3)	Mix Proportion (s:c:w)	OPC (kg)	Fine sand (kg)	Water (kg)
600	1:1.5:0.45	23.03	34.54	10.36
1200	1:1.5:0.45	44.69	67.04	20.11

3. Experimental Setup

Samples aged 28 days were subjected to axial compression strength analysis. 100 x 100 x 100 mm cubes were employed to assess the compressive strength based on the BS12390, as depicted in Figure 2. The flexural assessment also comprised 28-day-old samples. Prismatic samples with 100mm x 100mm x 500mm dimensions were tested per the BS ISO 1920-8:2009 standard. Figure 3 demonstrates the setup for the flexural test. Moreover, the tensile breaking test was performed based on ASTM C496 recommendations. A cylindrical sample with 200mm in height and 100mm in diameter was used for this test (see Figure 4).

Fig. 2. Compression test setup in accordance with BS12390

Fig. 3. Bending test setup corresponding to BS1521

Fig. 4. Splitting tensile strength test setup measurement based on ASTM C496

4. Results and Discussion

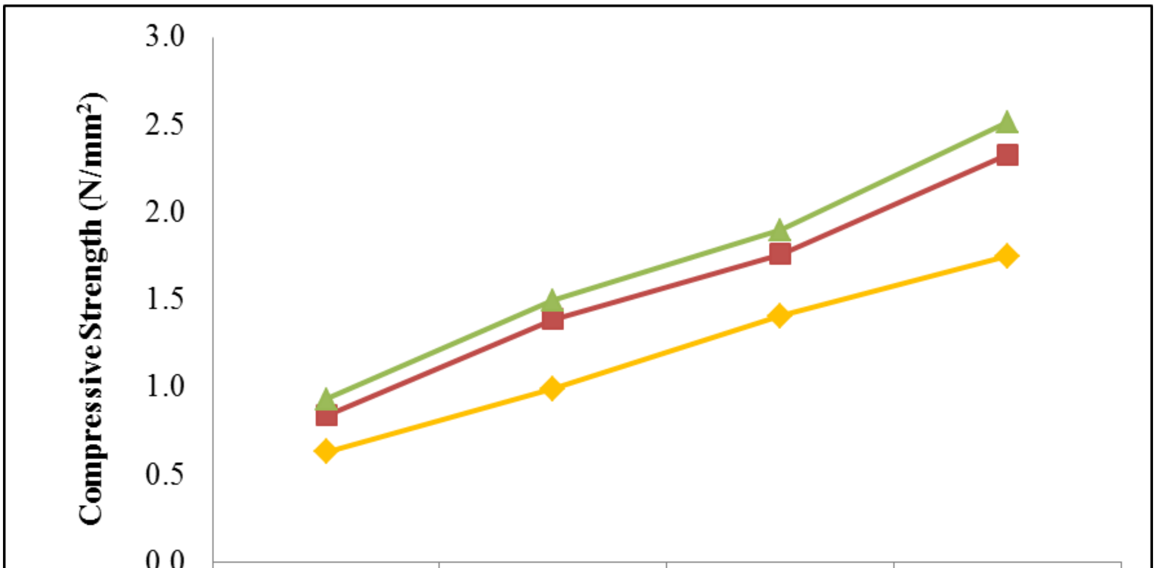
4.1 Compressive Strength

Figures 5 and 6 depict axial compression test outcomes for 600 and 1200 kg/m^3 densities. These two diagrams suggest that FM confinement with three layers provided the maximum compressive strength. It might be said that confining mortar with textile covering significantly enhances compressive strength and deformability characteristics. Strength is a function of mortar tensile strength and increases as the confining layer count rises. Confining LFC using FM offers a notable increase in deformability and strength characteristics [28]. More layers increase mortar strength, affecting failure characteristics concerning debonding or fiber fracture.

According to Raj *et al*., [29], the foam volume itself regulates the strength under compression for LFC of lower density rather than the physical properties of LFC. Thus, the compressive strength of LFC is principally a function of its bulk density. In addition, Dalal *et al*., [30] emphasized that at higher densities, the compressive strength is not influenced by the distribution of air voids, but rather by the more uniform distribution of voids. Huang *et al*., [31] also discovered that the production of LFC with finer sand results in a more even spreading of air voids compared to coarse sand. Due to the LFC's brittle nature, a strengthening component is required to increase its strength. Chi *et al*., [32] found that the inclusion of carbon textiles improves the compressive strength of LFC by stopping the microcracks. Hence, the jacketing of LFC with 3-layer of fiberglass meshes enhanced the compressive strength of LFC, as shown in Figure 5 and Figure 6.

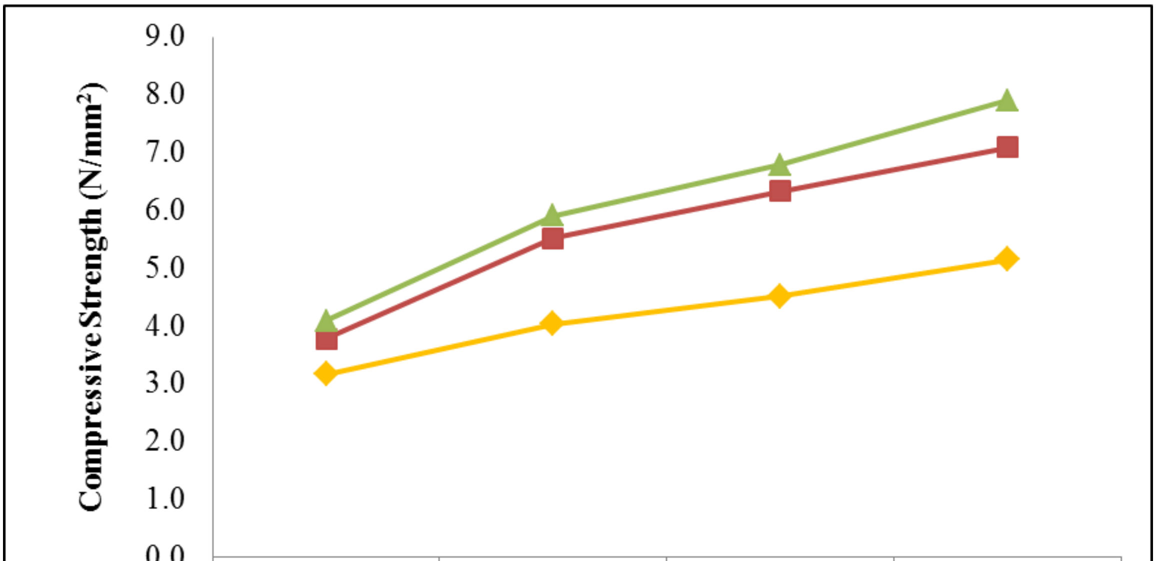
As can be seen from Figures 5 and 6, the LFC sample covered with a single 28-day-cured FM layer provided 65% higher compressive strength than the control sample; there was a 46% rise in strength for 1200 kg/m^3 LFC. Using two FM layers at 28 days increased LFC sample strengths by 110% and 68% for 600 and 1200 kg/m^3 samples. Moreover, the experiment indicated that three FM layers provided the most strength. Measurements on day 28 indicated 177% and 88% enhancement in compressive strength than the control sample for 600 kg/m^3 and 1200 kg/m^3 samples, demonstrating that FM is suitable for LFC strengthening. The presence of FM reduced microcrack formation and crack propagation when subjected to higher loads. Dalal *et al*., [30] indicated that ductility and resistance were primarily determined by fiber properties that delayed crack formation.

Naaman [33] also highlighted in their study that the different number of jacketing also contribute to the enhancement in strength. A 54% improvement was accomplished with the introduction of 1 to 2 layers of FM. Huang *et al*., [31] revealed that using FM jackets enhances the compressive characteristics of ordinary concrete. More FM layers are expected to provide adequate confinement by enhancing deformation-bearing capacity. Furthermore, an enhancement in the concrete load-carrying capacity leads to greater crack stress. Therefore, the highest compressive strength obtained from this study was for 1200 kg/m^3 density LFC that was confined with 3 layers of FM for 180 days.



	Control	1L-FM	2L-FM	3L-FM
7-day	0.63	0.99	1.41	1.75
28-day	0.84	1.39	1.76	2.33
56-day	0.93	1.50	1.90	2.52

Fig. 5. LFC compressive strength of 600kg/m^3 density with a different stratum of confinement



	Control	1L-FM	2L-FM	3L-FM
7-day	3.17	4.04	4.52	5.15
28-day	3.78	5.52	6.34	7.10
56-day	4.09	5.91	6.79	7.91

Fig. 6. LFC compressive strength of 1200kg/m^3 density with a different stratum of confinement

4.2 Flexural Strength

Flexural strength outcomes for 600 kg/m^3 and 1200 kg/m^3 samples are depicted in Figures 7 and 8. Axial compressive strength outcomes were similar. The two figures indicate that three FM layers provided maximum strength. Prudently produced textiles using inorganic binding substances offer good flexural load-bearing ability because these binders appropriately strengthen reinforced concrete. It is evident that every LFC sample had better flexural strength as curing time was increased. Mydin *et al.*, [34] indicated that 56-day test should be utilized for the characteristic strength of LFC instead of 28-day test due to the strength growth in the cementitious matrix. Though, the LFC specimens confined with interlaced fiberglass mesh showed a substantial improvement in flexural strength. The increase in the LFC flexural strength was due to the existence of the interlaced fiberglass mesh which reacted as a fortifying segment to keep and constrain the LFC composite strongly to elude unexpected failure and to improve the LFC ductility as well [35].

The existence of FM enhances the flexural strength of LFC by discontinuing the formation of additional cracks under flexural load. The confinement of LFC with a 3-layer of FM gave the best results of flexural strength of LFC, as shown in Figure 7 and Figure 8. Confinement of 600 kg/m^3 LFC with 1 layer of FM at 28 days amplified the flexural strength by 153% in comparison to the control LFC specimen and boosted the flexural strength of 1200 kg/m^3 density LFC by 127%. Notable improvements of 221% and 179% were also achieved for the LFC specimens with densities of 600 and 1200 kg/m^3, correspondingly confined with 2 layers of FM at 28 days.

Additionally, the greatest flexural strength of LFC that was attained in this investigation was with 3 layers of confinement of FM. An outstanding improvement of 421% and 254% in the flexural strength in comparison with the control at the corresponding densities on day-28 revealed that the FM has the potential to be used as a reinforcing component in LFC. These improvements that were accomplished were due to the upsurge in the initial elastic toughness of LFC. Besides, the FM is also represented to prevent the formation of microcracks and stop the dispersal of cracks on exposure to an advanced flexural load.

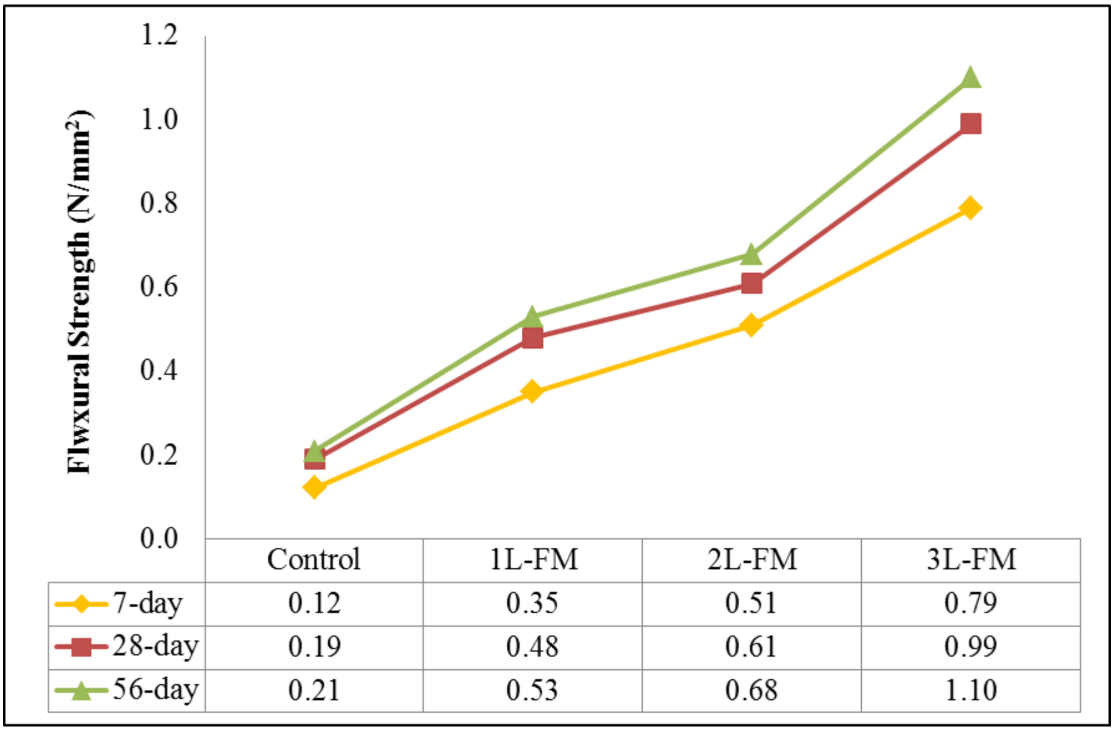


Fig. 7. LFC flexural strength of 600kg/m^3 with a different stratum of confinement

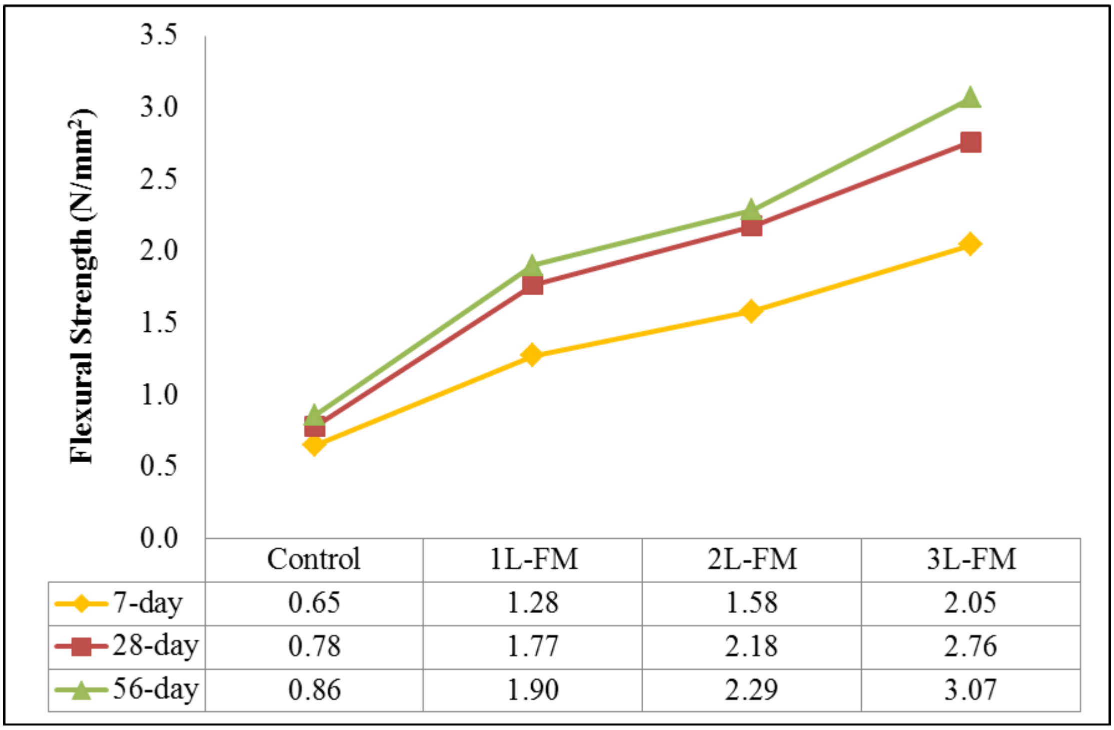


Fig. 8. LFC flexural strength of 1200kg/m^3 with a different stratum of confinement

4.3 Splitting Tensile Strength

Splitting tensile strength outcomes for 600 and 1200 kg/m^3 samples are depicted in Figures 9 and 10. These plots indicate that using three FM layers maximized splitting tensile strength. When subjected to tensile loading, vertical cracking was observed under LFC confinement; cracking increased slowly but continuously. Wider cracks form when the stress peak is achieved, leading to failure [16]. When the LFC was covered with 1 layer, the tensile strength improved by 186%, 200%, and 153% for the LFC samples with densities of 600 kg/m^3 and 1200 kg/m^3 correspondingly, compared to the unconfined specimens at 28 days. For 2 layers of confinement, increases in the tensile strength of 273% and 223% were attained for the respective densities. Superior augmentations of tensile strength of 545% and 349% were achieved when the LFC specimens were confined with 3 layers of FM for 600 and 1200 kg/m^3 densities, correspondingly.

The remarkable improvement demonstrates that FM has the capacity to be employed as LFC strengthening component. The strength property was also enhanced as the amount of FM layers for the LFC jacketing was raised. This study employed FM samples with superior fiber-to-matrix and fiber-to-fiber bonding, facilitating stretchability and preventing LFC collapse [36]. As highlighted by Othuman Mydin et al. [37], the augmentation of tensile strength is owing to the holding capacity of the fiberglass that aids the splitting strength capacity of LFC.

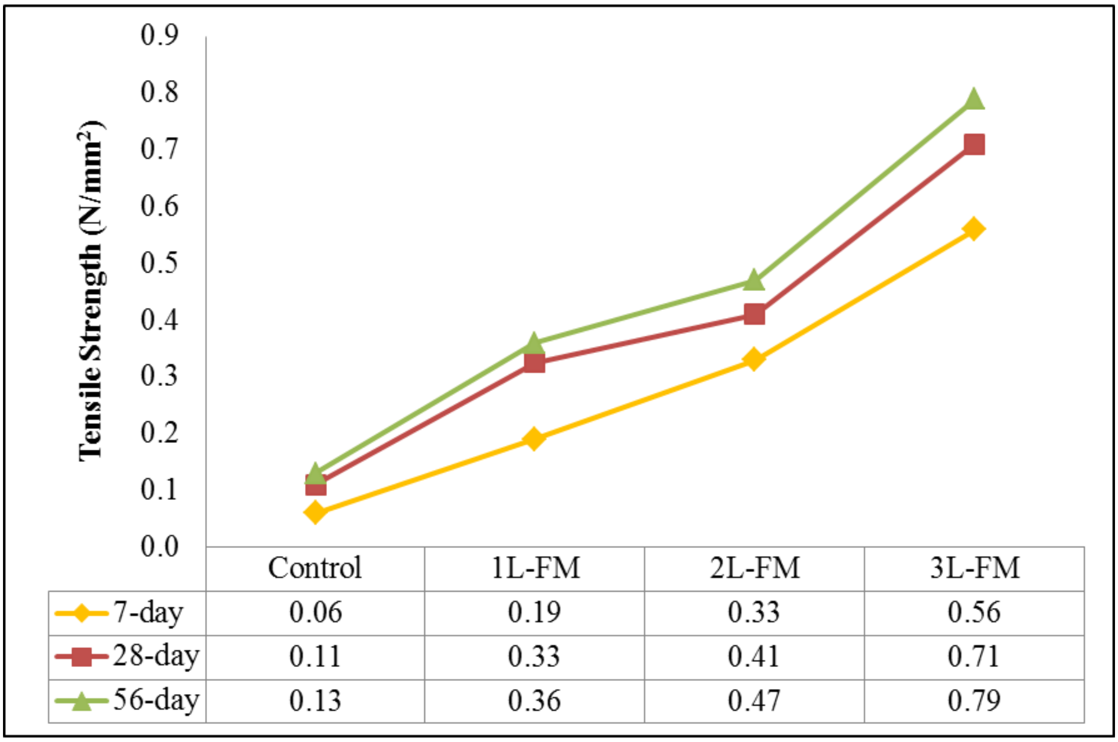


Fig. 9. Splitting tensile strength of LFC of 600kg/m^3 with a different stratum of confinement

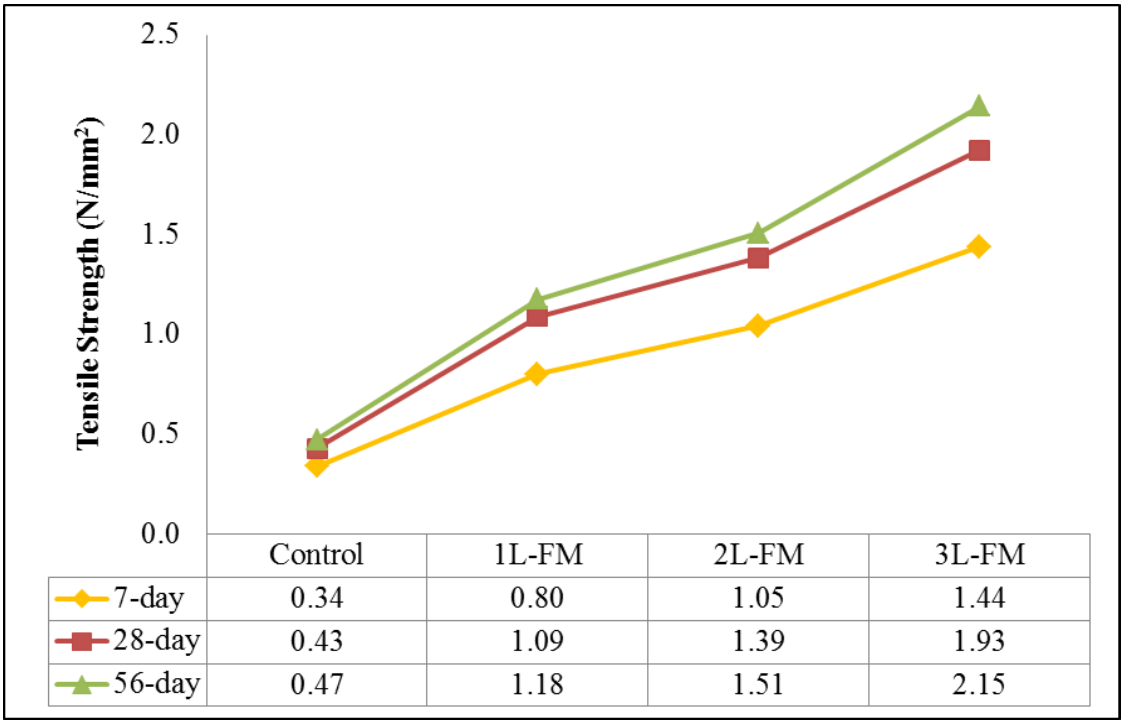


Fig. 10. Tensile strength of LFC of 1200kg/m^3 with a different stratum of confinement

5. Conclusion

This study concludes that FM confinement offers noteworthy increases in tensile, flexural, and compressive strength while enhancing deformability characteristics. Moreover, confined samples had relatively low effectiveness compared to fiber-reinforced plastic confinement. Effectiveness changes are minor concerning strength; however, the differences in peak strain are more prominent.

Deformability and strength characteristics of LFC are more desirable when FM confinement is used. Such gains are directly proportional to confining layer count. Mortar tensile strength also affects the confinement failure mechanism, i.e., debonding or fiber cracking.

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