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Investigating The Load Carrying Capacities of Lightweight Foamed Concrete Strengthen with Fiber Mesh

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Abstract: Lightweight foamed concrete (LFC) is well known as a low-density concrete with a wide range of applications. However, since its weight is almost half that of conventional concrete, its strength can also be expected to be lower than that of normal concrete. Thus, short fibres (synthetic and natural fibres) were used by previous researchers to improve the performance of LFC. Even though there were improvements in its mechanical properties, yet these had a negative impact on its durability in the long term due to the deterioration of the fibres. Recently, the use of fiber mesh as a reinforcing element has gained considerable attention. Thus, the aim of this research was to perform an experimental investigation to establish the load carrying capacities of fiber mesh reinforced LFC. In this research, LFC specimens were designed with densities of 650 kg/m^3, 1150 kg/m^3 and 1650 kg/m^3 with a constant cement-to-sand ratio of 1:1.5, and cement-to-water ratio of 0.45. The fiber mesh selected for this research has a weight per area of 145 g/m^2. The number of layer(s) for the observed confinement was detailed down to its effect on the performance of the LFC. The load carrying capacities of the LFC were examined under compression, bending and tension. Overall, the reinforcement with fiber mesh improved the load carrying capacities of the LFC. A confinement with 3 layers of fiber mesh showed significant results, where enhancements of 153% (650 kg/m^3), 97% (1150kg/m^3), and 102% (1650 kg/m^3) were obtained for the load carrying capacity in compression; 372% (650 kg/m^3), 258% (1150 kg/m^3), and 332% (1650 kg/m^3) for the load carrying capacity in bending; and 507% (650 kg/m^3), 343% (1150 kg/m^3), and 332% (1650 kg/m^3) for the load carrying capacity in tension, respectively, compared to the control LFC.

Keywords: Foamed concrete, load carrying capacity, compression, bending, mechanical properties, fiber mesh

1. Introduction

Concrete is a building material that is being widely used in the construction industry due to its resistance to deterioration compared to wood, and it is also easier to build in several forms. It is produced by combining cement with water and coarse aggregates or sand to form a solid matrix through the hydration process [1], [2]. Its density ranges between 2240 kg/m^3 to 2400 kg/m^3, and its compressive strength ranges between 20 N/mm^2 to 40 N/mm^2 [3]. Despite that, there are some drawbacks to using normal concrete as a construction material. Raupit et al. [4] reported that the heavy weight of normal concrete is inconvenient since it requires a larger volume of concrete to be cast over a structure with a long span. They also added that the transportation of a precast reinforced concrete plant is extremely expensive since heavy machinery is required to handle it due to its high density, which is in the range of 2300 kg/m^3 to 2700 kg/m^3.

Comprehensive research into concrete has been conducted over many years, and there is a growing interest among researchers to carry out investigations to improve the quality of concrete for use in the construction industry. Lightweight foamed concrete (LFC) is one of the innovative products that has been developed for lighter and more

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sustainable constructions [5], [6]. Ramamurthy et al. [7] defined LFC as a lightweight material that consists of cement paste with air voids entrapped in the mortar following the introduction of a suitable foaming agent into the cement slurry. According to research conducted by Zaidi & Li [8], the difference between LFC and normal concrete is that no coarse aggregates are used in LFC, but instead, homogeneous cells produced by air in the form of small bubbles are added to replace the traditional aggregates. Fig. 1 demonstrates the scanning electron microscope (SEM) images for concrete mixed with foam and without foam. The addition of a foaming agent in the manufacture of concrete produces LFC with a range of densities.

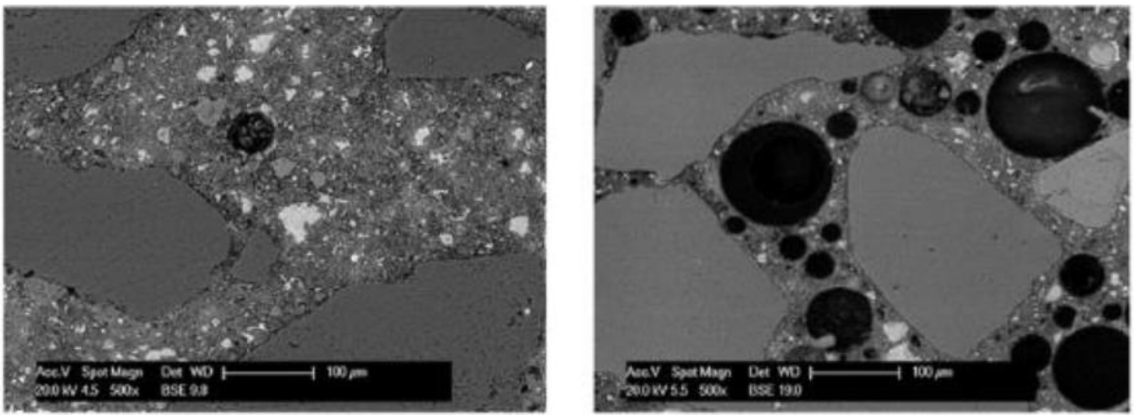


Fig. 1 - SEM images of concrete: mix without foam (left) and mix with foam (right)

Jalal et al. [9] stated that LFC is only comprised of fine sand mixed with cement, water, and foam, and it is regarded as a homogenous material unlike normal concrete as it does not contain any coarse aggregates. In addition, Alwi [10] reported that reducing the density of concrete will reduce the load that is applied to a building structure, and directly to the foundation of the building [11], and hence, this will enable smaller-sized foundations to be designed [12]. Besides, the growing development of precast concrete systems and components, referred to as an Industrialized Building System (IBS), has attracted the attention of the construction industry in Malaysia [13]. As mentioned by Shah [14] in his study, which highlighted the use of lightweight foamed concrete for non-load bearing wall systems, there are many construction components, one of which was used for a residential development project in Putrajaya. Apart from that, The Pantheon, which was built by the Romans in the year 126, is the first recorded structure that used lightweight concrete, as claimed by Mydin [15].

Thus, the implementation of LFC in the construction industry will not only offer an improved and lighter concrete-based material but, at the same time, will also accelerate the construction process and increase the production rate of buildings and the development of infrastructure holistically. However, LFC has a low density (between 500 kg/m^3), which is good for compression but weak when it comes to tension. This disadvantage has limited its use in building construction, particularly for semi-structural and load-bearing components. This is due to the presence of numerous microcracks in the cement matrix (due to high porosity), which cause the material to have very poor tension and to be very brittle under compression.

Despite that, LFC is not only being applied primarily for level correction in housing development and as fill-in material for load works but is also being used as a semi-structural element in construction. Nevertheless, many research has been conducted to improve the performance of LFC due to its potential use as a structural building material. There is a growing interest in LFC among researchers because of its characteristics such as its good thermal insulation and acoustics shielding properties [16], especially when low densities of the material are applied. Hence, this research project was performed to explore the potential use of fiber mesh reinforced LFC as a construction material. fiber mesh is a textile fabric that is widely used in normal concrete, also known as textile-reinforced concrete (TRC). It is an alkali-resistant material that can be used to replace the reinforcing steel in LFC.

2. Materials, Mix Design and Experimental Setup

2.1 Materials

Ordinary Portland cement (OPC) was used throughout this study. This OPC, which was Type 1 Portland cement, was applied according to ASTM C150-04 (2004). The cement, produced by the Cement Industry of Malaysia under the label, ‘Castle’. Fine sand was used as a filler to produce LFC. The sand utilized in this research was sieved manually using a no. 16 sieve (1.18 mm), in compliance with ASTM C778-06 [17], where 50 to 85% of the graded sand must be able to pass through the sieve. Fig. 2 shows the grading curve of fine sand used in this investigation. The specific gravity of this sand was 2.74, while its modulus was 1.35. Before casting the LFC specimens, a sieve analysis test was performed to ensure that the sand used in this research followed the standard. The sand was dried for 24 hours before being sieved to remove the moisture content in the sand.

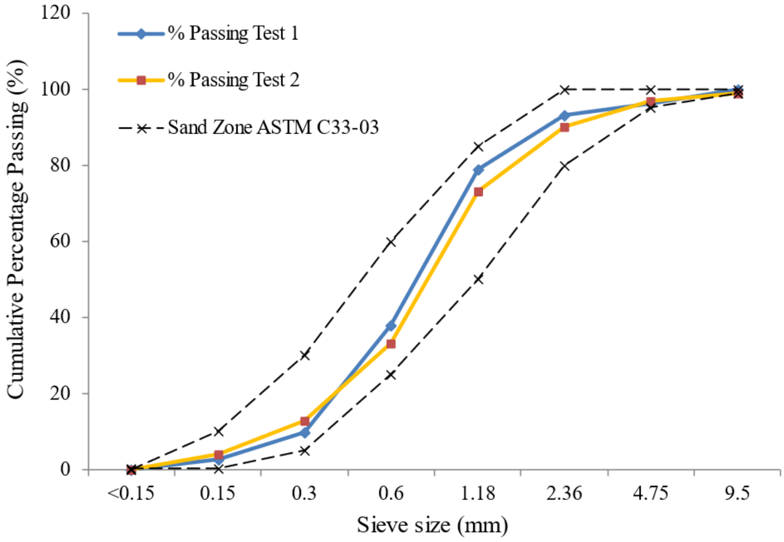


Fig. 2 - Grading curve of fine sand used

As stated in the literature, potable or non-potable water can be used to mix concrete. For this study, clean water (tap water) was used in the production of LFC. Water is an important agent that will bind the cement and filler through the process of hydration, thereby causing the hardening of the mortar paste. Based on a previous study, the water-to-cement ratio for LFC ranges between 0.4 and 1.25. Thus, in this experiment, the water-to-cement ratio was fixed at 0.45 to produce LFC with reasonable workability.

The outstanding characteristic of LFC is that the addition of foam in the mortar slurry will reduce its weight density. Foam is added to control and obtain a desirable density for the LFC. Thus, for this study, a protein-based foaming agent, namely, NORAITE PA-1, was used to produce a stable foam. This type of protein-based agent was selected as its bubbles are more stable and have a smaller-sized diameter. The foam, produced by mixing the protein-based agent with water, was then generated using a foam generator, where 30 liters of water were needed to dissolve 1 kg of foaming agent. The density of the foam applied in this study ranged between 65-75 g/L.

The fiber mesh used in this research was provided by TKS Bio Sdn. Bhd. Table 1 visualizes the fiber mesh physical properties. This fiber mesh known as a textile fabric, is categorized as a synthetic fiber (man-made fiber) and was chosen for its advantages as it is alkali-resistant, eco-friendly, has high strength, and requires no treatment unlike carbon and basalt textiles, which need a coating regimen to improve their bonding with the cementitious matrix. The same can be said of natural fibers (coconut fibers, banana trunks, etc.), which need to be treated, for example, with sodium hydroxide (NaOH) solution to prolong their durability in LFC. As shown in Fig. 3, the fiber mesh was cut and laid according to the dimensions of the moulds. The LFC specimen was confined with this fiber mesh and placed in the matrix based on the specified test, as shown in Table 2. Nevertheless, the specimen for the flexural test was not jacketed with this fiber mesh but was laid in a longitudinal direction to the LFC specimen. The chemical composition of fiber mesh is shown in Table 3.

Fig. 3 - The fiber mesh was cut and laid according to the dimensions of the moulds

Table 1 - Physical properties of fiber mesh

Mesh Size	4.0 mm x 5.0 mm
Colour	white
Coating Type	alkali resistant
Mass (g/m^2)	145±5
Ignition point	784.4ºF (398ºC)
Melting point	316.4ÂºF (158ÂºC)
Tensile strength (MPa)	1325
Elongation at break (%)	3.41%
Compliance	ASTM C1116-02
Quality assured facility	ISO 9001:2008

Table 2 - Position of fiber mesh confining LFC

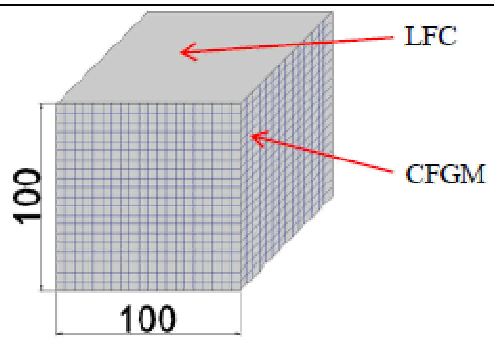
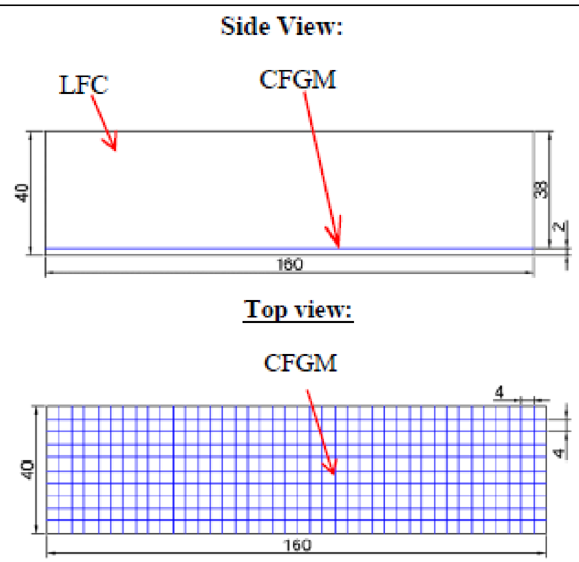
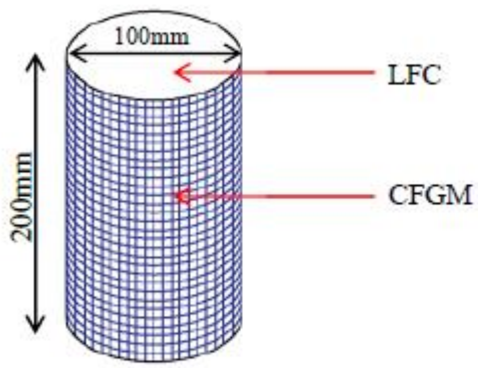
Axial compressive strength test	
Three-point bending strength test	
Tensile test	

Table 3 - Chemical composition of alkali-resistant fiber mesh

Oxide components (AR-glass)	Percentage by weight (%)
SiO_2	65.4
ZrO_2	17.3
TiO_2	1.2
Al_2O_3	1.6
Fe_2O_3	1.7
CaO	7.2
MgO	0.7
Na_2O	0.6
K_2O	0.4
B_2O_3	2.2
Li_2O	0.3
F_2	0.5
Others	0.9

Table 4 shows the mix proportions for LFC with densities of 650 kg/m^3, 1150 kg/m^3, and 1650 kg/m^3. The mix ratios for all the mixes were fixed, where the cement-to-sand ratio was 1:1.5, while the water-to-cement ratio was constant at 0.45. This was to ensure that comparable results were obtained for the confinement with fiber mesh as the main parameter to be investigated in this research. As referred to in Table 4, the control sample represents the LFC specimen without any confinement with fiber mesh, 1L-LFC stands for the 1-layer fiber mesh, 2L-LFC stands for the 2-layer fiber mesh, and 3L-LFC indicates the 3-layer fiber mesh. A slump test was performed until reading in the range of 21 to 26 cm was achieved (Fig. 4).

Table 4 - LFC mix proportions

Sample	Fiber mesh (layer)	Density (kg/m^3)	Mix ratio		Mix proportion (kg/m^3)		
			Cement to sand	Water to cement	Cement	Sand	Water
Control	-	650	1:1.5	0.45	230.24	345.36	103.61
	-	1150	1:1.5	0.45	410.79	616.18	184.86
	-	1650	1:1.5	0.45	591.34	887.01	266.10
1L-LFC	1	650	1:1.5	0.45	230.24	345.36	103.61
	2	1150	1:1.5	0.45	410.79	616.18	184.86
	3	1650	1:1.5	0.45	591.34	887.01	266.10
2L-LFC	1	650	1:1.5	0.45	230.24	345.36	103.61
	2	1150	1:1.5	0.45	410.79	616.18	184.86
	3	1650	1:1.5	0.45	591.34	887.01	266.10
3L-LFC	1	650	1:1.5	0.45	230.24	345.36	103.61
	2	1150	1:1.5	0.45	410.79	616.18	184.86
	3	1650	1:1.5	0.45	591.34	887.01	266.10

Fig. 4 - Slump test of LFC mix

2.3 Curing Method

The specimens were cured until the specified testing day to ensure that the LFC had hardened. Curing was very important in this study because it is the period required for the concrete to gain its strength by preventing the loss of moisture, which will lead to cracking [18]. All the specimens were cured by moisture curing, except for the specimens for the drying shrinkage test, which were cured under air-storage conditions, as described in ASTM C157/C157M (2005). Moisture curing was selected because it gives better results for the LFC tests [19]. The specimens were wrapped in plastic wrap, as shown in Fig. 5.

Fig. 5 - Moisture curing

2.3 Experimental Setup

The tests were performed to determine the LFC mechanical properties with the fiber mesh jacketing. Load carrying capacity tests in compression, bending and tension loads were performed to establish the mechanical properties. Table 5 shows the details of the specimens and standard codes referred to in these tests. Fig. 6, Fig. 7 and Fig. 8 show the setup for the compression test, bending test and tensile test to determine the load-carrying capacity correspondingly.

Table 5 - Mechanical properties tests

Type of Test	Specimen	Code
Load-carrying capacity in compression	Cube of 100mm x 100mm x 100mm	BS EN 12390-3: 2001
Load-carrying capacity in bending	Prism of 100mm x 100mm x 500mm	ASTM C 348
Load-carrying capacity in tension	Cylinder of 100mm diameter x 200mm height	ASTM C496/C 496M

Fig. 6 - Test for load-carrying capacity in compression

Fig. 7 – Test for load-carrying capacity in bending.

Fig. 8 - Test load-carrying capacity in tension

3. Results and Discussion

This section will present the experimental results of the load-carrying capacity in compression, bending and tension of the LFC specimens strengthened with fiber mesh. Additionally, the relationship between the load-carrying capacity in compression - in bending and bending-tensile strengths of LFC will be presented as well.

3.1 Load Carrying Capacity in Compression

Fig. 9, Fig. 10, and Fig. 11 present the load-carrying capacity results under compressive load for LFC with densities of 650 kg/m^3, 1150 kg/m^3, and 1650 kg/m^3 confined with a different number of layers of fiber mesh. The three figures show the same pattern of strength development, where all the LFC mixes were enhanced with increasing curing time. As the density of the LFC increased, its load-carrying capacity also increased significantly. For instance, for the control, LFC at day-180 and with a density of 650 kg/m^3, the load-carrying capacity achieved was 1.08 N/mm^2, while for the LFC with a density of 1150 kg/m^3, the load-carrying capacity obtained was 3.76 N/mm^2, which was 248% higher than that of the LFC with a density of 650 kg/m^3, and an increase of 157% (9.66 N/mm^2) was obtained for the LFC with a density of 1650 kg/m^3 compared to a density of 1150 kg/m^3.

According to Ramamurthy [7], at the lower density of LFC, the volume of foam controls the strength rather than the material properties. Thus, the load-carrying capacity in compression is primarily a function of the density. Besides, Shawnim & Mohammad [20] highlighted that at the higher densities, the compressive strength is not influenced by the distribution of air voids, but rather by the more uniform distribution of voids. Lim et al. [21] also mentioned that the production of LFC with finer sand results in a more uniform distribution of air voids compared to coarse sand. Due to the brittleness of LFC, a reinforcing element is needed to boost its compressive strength.

As proven by Raj et al. [22], the addition of fibers improves the load-carrying capacity of LFC by preventing microcracks. Therefore, the confinement of LFC with 160 g/m^2 of fiber mesh enhanced the load-carrying capacity of LFC, as shown in Table 6. As can be observed, the confinement of LFC with a density of 650 kg/m^3 with 1 layer of fiber mesh increased the load-carrying capacity by 48% compared to the control LFC with the same density and increased the load-carrying capacity of LFC with a density of 1150 kg/m^3 by 56%, while an increase of 61% was achieved for the load-carrying capacity of LFC with a density of 1650 kg/m^3. Notable improvements of 95%, 74%, and

78% were also obtained for the LFC specimens with densities of 650 kg/m^3, 1150 kg/m^3, and 1650 kg/m^3, respectively confined with 2 layers of fiber mesh.

Furthermore, the highest increase in load-carrying capacity that was found in this investigation was for the confinement of LFC with 3 layers of fiber mesh. The remarkable enhancements of 153%, 97%, and 102% in the load-carrying capacity compared to the control at the respective densities proved that the fiber mesh has the potential to be utilized as a reinforcing element in LFC. All the enhancements that were achieved were due to the confinement with fiber mesh in the form of a jacket, and the increase in the initial elastic stiffness of LFC. When the lateral deformation was developed because of the applied load, the tension in the jacket (fiber mesh confinement) was activated due to the lateral expansion of the LFC.

In addition, the fiber mesh also acted to prevent microcracks and retard the widening of cracks on exposure to a higher applied load. As reported by Dalal et al. [23], improved resistance and ductility are governed mainly by the fibers, which delay cracks in the matrix. The good bonding between the fiber mesh and cement matrix is one of the reasons for the improvement in the load-carrying capacity of LFC. Besides, Noor & Hazren [24] also highlighted in their study that the number of layers of confinement in concrete also contributes to the load-carrying capacity enhancement, where an augmentation of 54% was achieved by the application of between 1 to 2 layers of fiber mesh. Huang et al. [25] also justified that the use of fiber mesh jackets improves the load-carrying capacity of plain concrete, and an increase in the number of fiber mesh layers will lead to effective confinement due to the increase in the deformation capacity. Moreover, an improvement in the load-bearing capacity of concrete leads to higher ultimate crack stress [26]. Therefore, the highest load-carrying capacity obtained from this study was for LFC with a density of 1600 kg/m^3 that was confined with 3 layers of fiber mesh for 180 days.

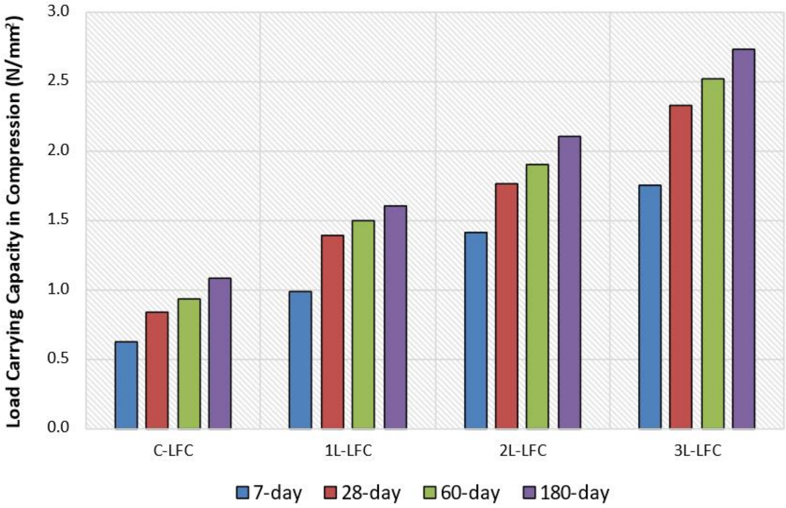


Fig. 9 – Load-carrying capacity in compression of LFC with a density of 650 kg/m^3 strengthened with a different number of layers of fiber mesh

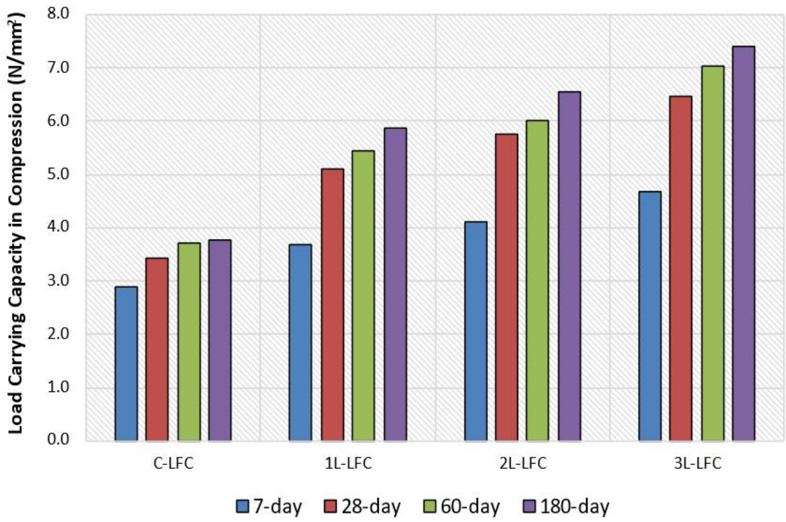


Fig. 10 – Load-carrying capacity in compression of LFC with a density of 1150 kg/m^3 strengthened with a different number of layers of fiber mesh

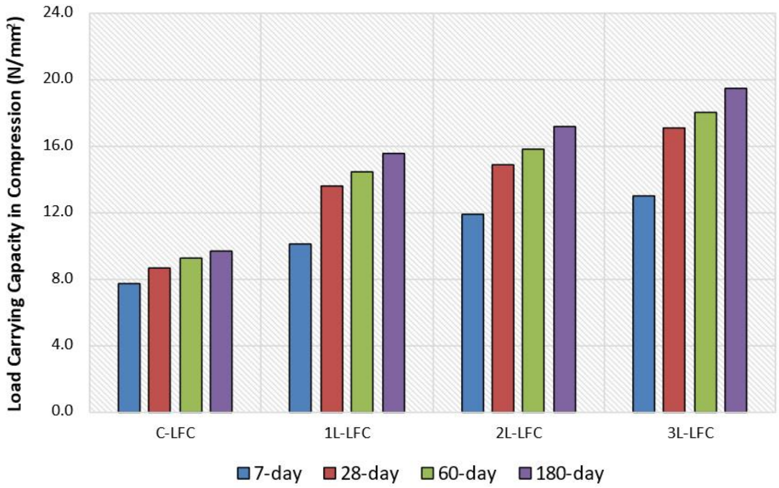


Fig. 11 - Load-carrying capacity in compression of LFC with a density of 1650 kg/m^3 strengthened with a different number of layers of fiber mesh

Table 6 - Percentage increase in load-carrying capacity in compression

Sample	650 kg/m^3	1150 kg/m^3	1650 kg/m^3
1 Layer – LFC	48%	56%	61%
2 Layer – LFC	95%	74%	78%
3 Layer – LFC	153%	97%	102%

3.2 Load-Carrying Capacity in Bending

Fig. 12, Fig. 13, and Fig. 14 show the results of the load-carrying capacity in bending strength for LFC with densities of 650 kg/m^3, 1150 kg/m^3, and 1650 kg/m^3. The confined LFC was embedded with 1 layer, 2 layers, and 3 layers of fiber mesh placed 2 mm from the bottom layer, while the unconfined (control) specimens did not have any reinforcement in the tensile zone. Based on observations from these three figures, all the specimens gained load-carrying capacity in bending with increasing curing time. The strength development increased steadily for 180 days. Besides, it could be seen that the load-carrying capacity in bending decreased with decreasing density. According to Lian et al. [27], the strength of concrete is affected by the volume of voids, which is related to the porosity. An increase in porosity reduces the strength of concrete, but the magnitude of this effect depends significantly on the size, shape, and distribution of the pores [28]. There was a noticeable increase in the load-carrying capacity in bending of the LFC from a density of 650 kg/m^3 to 1650 kg/m^3.

As described by Falliano et al. [29], this occurred because of the very low strength values corresponding to the lower densities of LFC. Moreover, it was noticed that the control specimens for the three respective densities displayed very poor bending behavior. The reason for this was that the control specimens had zero reinforcement in the tensile zone, where the sudden failure occurred as soon as a load was applied. A reinforcement strategy is needed to ensure that LFC with lower densities can be utilized as semi-structural or even more advanced structural elements in construction work. Thus, this study investigated the confinement of LFC with a reinforcing element that was subjected to a bending load. In Fig. 12, 1 layer of fiber mesh laid 2mm from the bottom layer increased the load-carrying capacity in bending of LFC by 136%, but when the number of layers was doubled (2 layers), the load-carrying capacity in bending was boosted by up to 204%, and it was effectively increased by 372% when 3 layers of fiber mesh were added compared to the unreinforced specimens. This trend of increase was also almost the same for the LFC specimens with densities of 1100 kg/m^3 and 1650 kg/m^3 (refer to Table 7). However, as shown in Fig. 13, at day-180, the same load-carrying capacity in bending result for the LFC confined with 1 layer of fiber mesh could also be obtained at an early age of curing for the specimen confined with 3 layers of fiber mesh, and it gained an increase of 258% compared to the control specimen when it reached 180 days.

As expected in Fig. 14, the highest load-carrying capacity in bending among all the specimens was achieved within 180 days by the LFC specimen with a density of 1650 kg/m^3 and embedded with 3 layers of fiber mesh in the tensile zone of the cement matrix. The significant increase in the load-carrying capacity in bending of LFC was due to the higher flexibility of the fiber mesh, which caused a higher strain in the cement matrix. Naaman [30] explained that when the cementitious composites crack under bending tension, the reinforcement in the cracked zone will contribute to both stiffness and strength, while the matrix will be cracked. The higher stiffness behavior of the fiber mesh will lead to the debonding of the fibers in the matrix due to the limited release of energy by the fiber mesh. Gencoglu & Mobasher

[31] clarified that AR-glass reinforcement provides suitable resistance in impact loading as it absorbs less energy (20-40% of potential energy).

Vogel et al. [32] also verified in their study that the specimen that had been reinforced with a fiber mesh was able to transfer more energy to its supports than the unreinforced specimen without the creation of large cracks. This was because the unreinforced specimen absorbed almost double the amount of impact energy (64.03%) compared to the reinforced specimen, which only absorbed 38.87% of the impact energy, with the rest of the energy being transferred to the supports. The structure of the fiber mesh itself was also the reason for the increase in the bending strength of the LFC. Basically, a fiber mesh is produced by combining several fibers to form a continuous fibre (known as a fiber mesh) with a warp and weft structure, either in a coil or a layered fashion. The fabric has a crimped geometrical structure, which provides enhanced bonding by mechanical effects.

Batur & Mindess [33] also explained that the additional enhancement of the bonding of the fabric is due to another mechanical anchoring provided by the fill yarns in the weft direction when the fabric is embedded in the cement matrix. Besides, the space between the fiber roving enables some sort of mechanical interlocking to occur between the fabric and the matrix, which induces the strength of LFC. This fiber mesh is not only able to resist fractures because of sudden loading but is also capable of withstanding high fracture toughness with high impact strength. Reddy et al. [34] also claimed that the good bonding of glass fabric produces higher impact strength. Moreover, Wong et al. [35] also mentioned that glass fiber is better in terms of both tensile strength and interfacial strength, resulting in the best impact strength compared to natural fibers (such as coir and palm fibers). They also highlighted that increasing the number of layers improves the impact strength. This is because the total surface area of the fiber mesh will be increased so that the additional impact energy is dissipated between the fiber layers through extensive delamination.

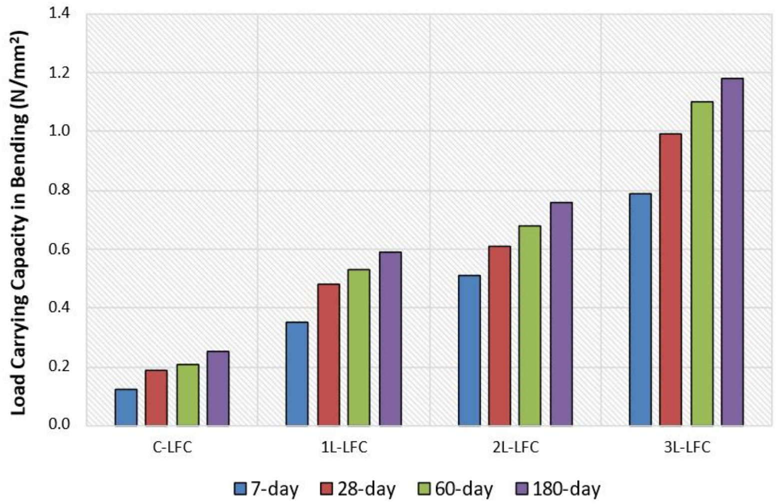


Fig. 12 - Load-carrying capacity in bending of LFC with a density of 650 kg/m^3 strengthened with a different number of layers of fiber mesh

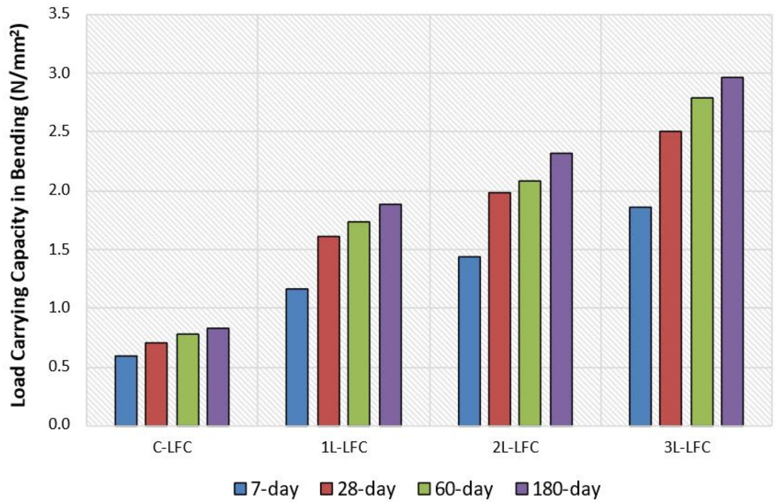


Fig. 13 - Load-carrying capacity in bending of LFC with a density of 1150 kg/m^3 strengthened with a different number of layers of fiber mesh

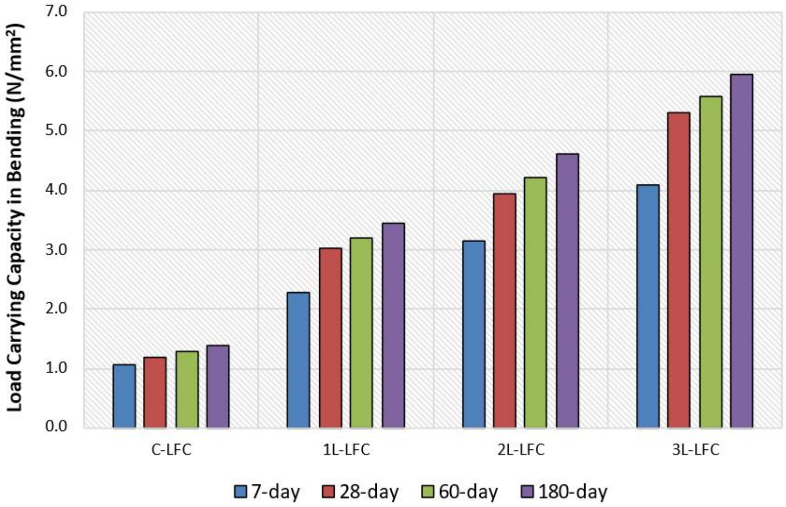


Fig. 14 - Load-carrying capacity in bending of LFC with a density of 1650 kg/m^3 strengthened with a different number of layers of fiber mesh

Table 7 - Percentage increase in Load carrying capacity in bending.

Sample	650 kg/m^3	1150 kg/m^3	1650 kg/m^3
1 Layer – LFC	136%	127%	149%
2 Layer – LFC	204%	180%	234%
3 Layer – LFC	372%	258%	332%

3.3 Load-Carrying Capacity in Tension

As reported by Amran et al. [36], the factors that influence load-carrying capacity in compression equally affect the load-carrying capacity in tension for LFC. Thus, unconfined LFC, which is brittle, possesses a lower load-carrying capacity in tension. This was proven by the results of the load-carrying capacity obtained in this study, which showed a similar trend as that of the load-carrying capacity in compression, as shown in Fig. 15, Fig. 16, and Fig. 17. These three figures demonstrated that the load-carrying capacity in the tension of the unconfined and confined LFC grew increasingly as the curing age progressed. The volume of foam also significantly affected load-carrying capacity in tension. For instance, the load-carrying capacity in tension obtained for the control specimen with a density of 600 kg/m^3 at day-180 was 0.14 N/mm^2, and this load carrying capacity in tension then increased by 229% after the foam volume was reduced to obtain the desired density of 1150 kg/m^3. An increase of 122% in the load-carrying capacity in tension was also achieved for the LFC specimens with a density of 1650 kg/m^3 as only a small amount of foam was needed to achieve this preferred density compared to a density of 1150 kg/m^3. However, the results of the load-carrying capacity in tension obtained for the control specimens were low due to the absence of a reinforcing element in the matrix. Thus, the confinement of the LFC with a different number of layers of fiber mesh improved the performance of the LFC in terms of its load-carrying capacity in tension.

The significant enhancement of the load-carrying capacity in tension of the LFC specimens confined with a different number of layers of fiber mesh is illustrated in Table 8. When the LFC was wrapped in 1 layer of fiber mesh, the load-carrying capacity in tension increased by 186%, 157%, and 150% for the specimens with densities of 650 kg/m^3, 1150 kg/m^3, and 1650 kg/m^3, respectively, compared to the unconfined specimens. For the confinement with 2 layers of fiber mesh, the increases in the load-carrying capacity in tension, which were 279%, 237% and 234% for the respective densities, were double those of the specimens confined with 1 layer of fiber mesh. Superior augmentations of 507%, 343%, and 332% in load-carrying capacity in tension were accomplished when the LFC specimens with densities of 650 kg/m^3, 1150 kg/m^3, and 1650 kg/m^3, respectively were confined with 3 layers of fiber mesh. The incredible enhancement of the load-carrying capacity in tension in LFC proves that fiber mesh has the potential to be used as a reinforcing element in LFC. This performance also improved as the number of layers of fiber mesh for the confinement increased. The fiber mesh used in this study not only had strong fiber-to-matrix bonding but also exceptionally strong fiber-to-fiber bonding, which enabled stretching and prevented the LFC from collapsing. As highlighted by Parveen & Sharma [37], the enhancement of load-carrying capacity in tension is due to the holding capacity of the fibers, which can aid in the splitting of the concrete.

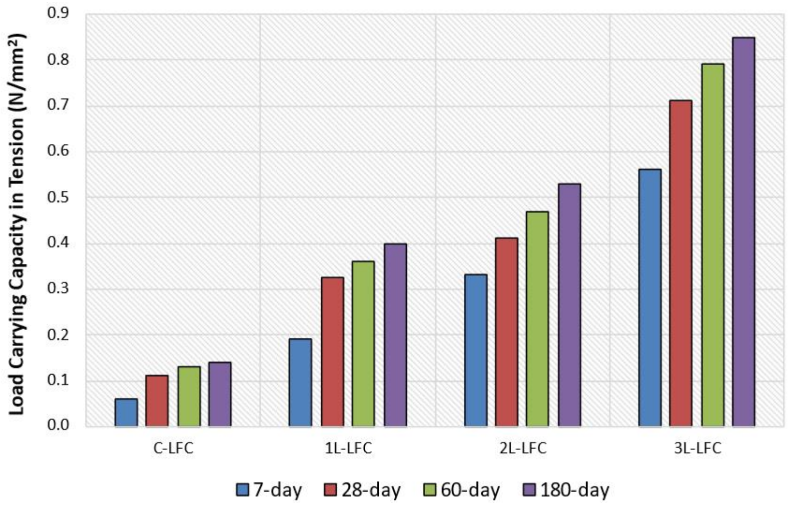


Fig. 15 - Load-carrying capacity in tension of LFC with a density of 650 kg/m^3 strengthened with a different number of layers of fiber mesh

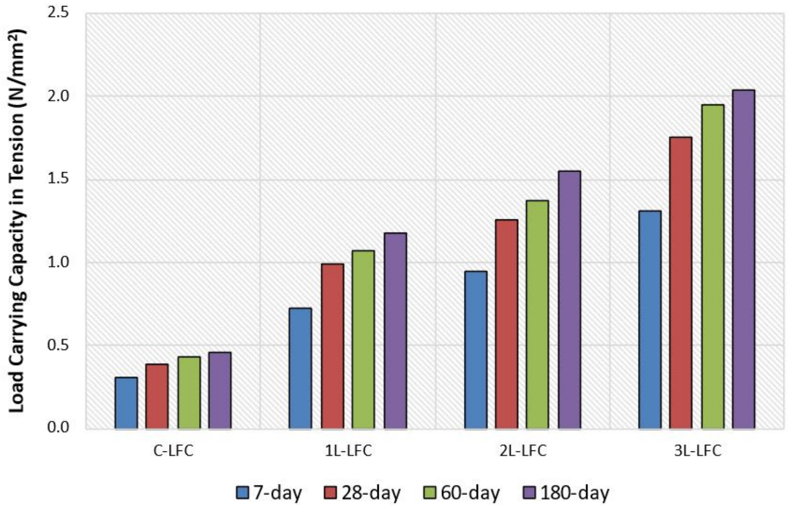


Fig. 16 - Load-carrying capacity in tension of LFC with a density of 1150 kg/m^3 strengthened with a different number of layers of fiber mesh

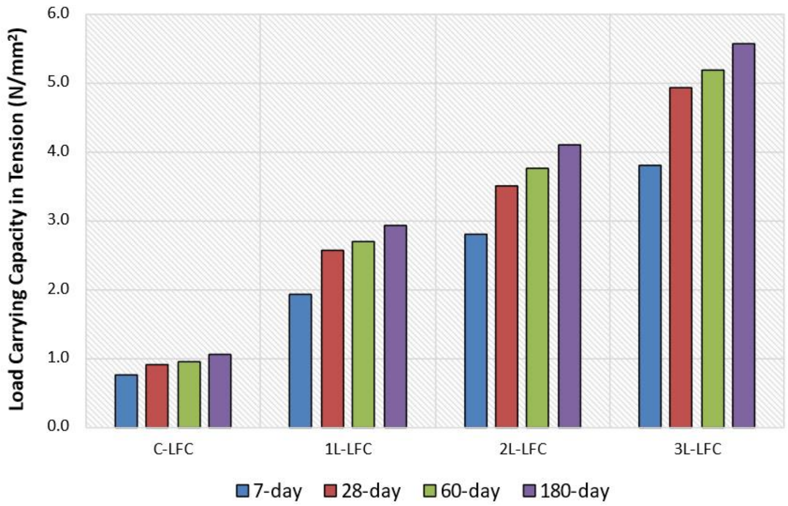


Fig. 17 - Load-carrying capacity in tension of LFC with a density of 1650 kg/m^3 strengthened with a different number of layers of fiber mesh

Table 8 - Percentage increase in tensile strength

Sample	650 kg/m³	1150 kg/m³	1650 kg/m³
1 Layer – LFC	186%	157%	150%
2 Layer – LFC	279%	237%	234%
3 Layer – LFC	507%	343%	332%

3.4 Relationship Between Load Carrying Capacity in Compression and Bending

Fig. 18, Fig. 19, and Fig. 20 present the relationship between the load-carrying capacity in compression and in bending of LFC with densities of 650 kg/m^3, 1150 kg/m^3, and 1650 kg/m^3, respectively, confined with 1 layer, 2 layers, and 3 layers of fiber mesh. As is known, the load-carrying capacity in compression and in bending of LFC showed a similar trend of increase. However, the load-carrying capacity in bending of LFC was lower than its load-carrying capacity in compression due to its good performance with compression but weak behavior with tension. Thus, the confinement with fiber mesh in this study increased both the load-carrying capacity in compression and in bending. Besides, the R2 values obtained from Fig. 18 to Fig. 20 proved that there was a significant relationship between these two parameters, where all the R2 values were close to 1. In general, the development of load-carrying capacity in compression shared the same trend and retained a linear relationship with the development of load-carrying capacity in bending due to the confinement with fiber mesh, which improved the ductility, shear capacity, and energy absorption of the LFC. Besides, the number of layers of confinement also contributed to the high load carrying capacity in compression and in bending of the LFC. The load-carrying capacities in bending were in the range of 53–55% (650 kg/m^3), 58-60% (1100 kg/m^3), and 46-48% (1650 kg/m^3) corresponding to the load-carrying capacities in compression as shown in Fig. 18, Fig. 19, and Fig. 20.

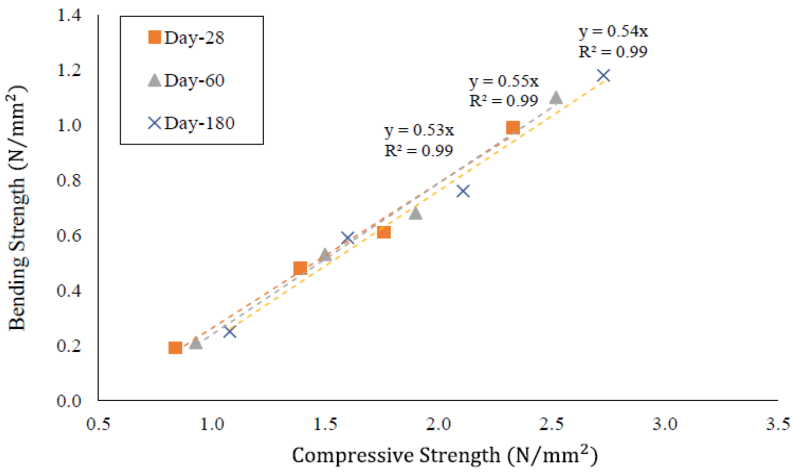


Fig. 18 - Relationship between load-carrying capacity in compression and bending with a density of 650 kg/m³ confined with a different number of layers of fiber mesh

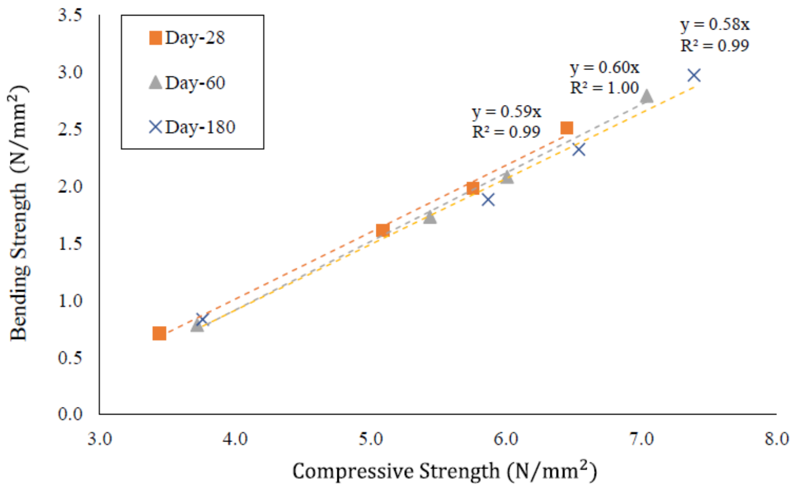


Fig. 19 - Relationship between load-carrying capacity in compression and bending with a density of 1150 kg/m³ confined with a different number of layers of fiber mesh

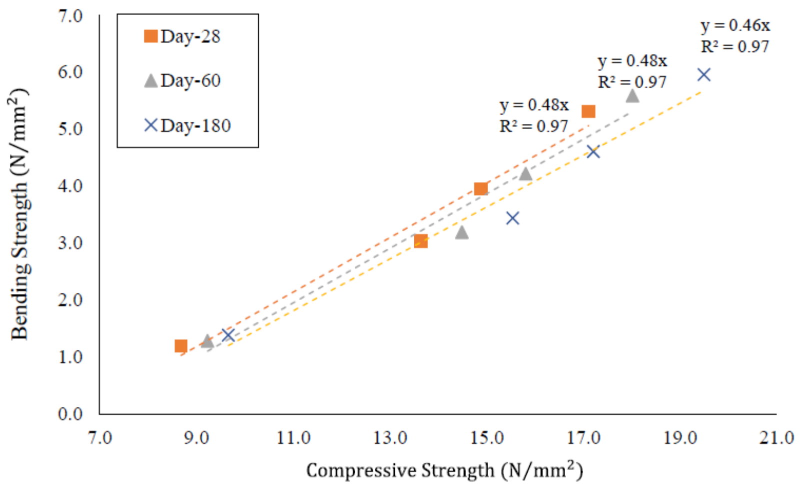


Fig. 20 - Relationship between load-carrying capacity in compression and bending with a density of 1650 kg/m^3 confined with a different number of layers of fiber mesh

3.5 Relationship Between Load Carrying Capacity in Bending and Tension

According to Parra & Gomez [38], the structural properties of concrete such as shear resistance, bond strength and resistance to cracking depend on its tensile strength. Compared to the relationship between the load-carrying capacity in compression and in bending, the correlation between the load-carrying capacity in bending and in tension showed a significant linear relationship, where the R2 value was equal to 1, as shown in Fig. 21, Fig. 22, and Fig. 23. This indicated that the increase in the load-carrying capacity in bending of LFC was parallel with the increase in the load-carrying capacity in tension. This phenomenon was due to the confinement with fiber mesh laid longitudinally to the applied load that prevented the sudden failure of the LFC and acted as a bridge to hold the specimen from separating into two pieces. According to Wong et al. [35], longitudinal fiber laminates always contribute to higher impact strength and more efficient dissipation of impact energy. The load-carrying capacity in tension values was in the range of 74-76% (650 kg/m^3 and 1150 kg/m^3) and 71-74% (1650 kg/m^3) corresponding to the load-carrying capacity in bending values, as shown in Fig. 21, Fig. 22, and Fig. 23.

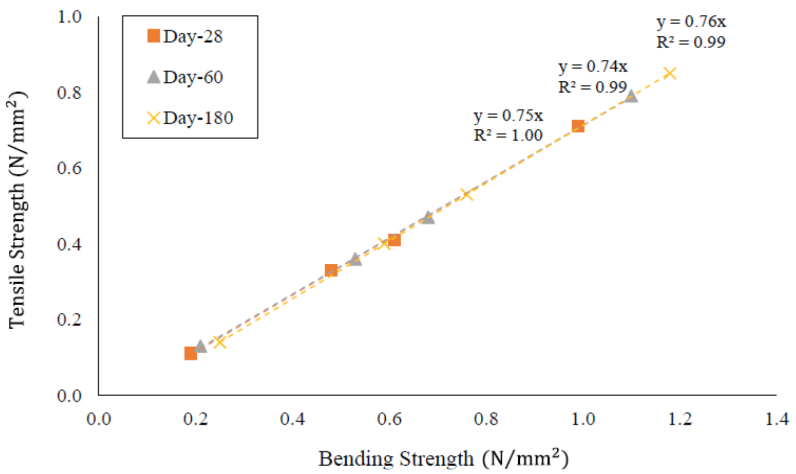


Fig. 21 - Relationship between load-carrying capacity in bending and in tension with a density of 650 kg/m^3 confined with a different number of layers of fiber mesh

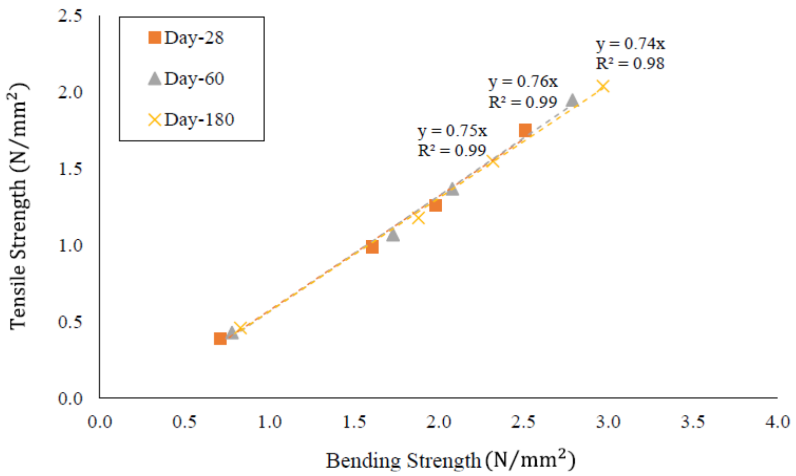


Fig. 22 - Relationship between load-carrying capacity in bending and in tension with a density of 1150 kg/m^3 confined with a different number of layers of fiber mesh

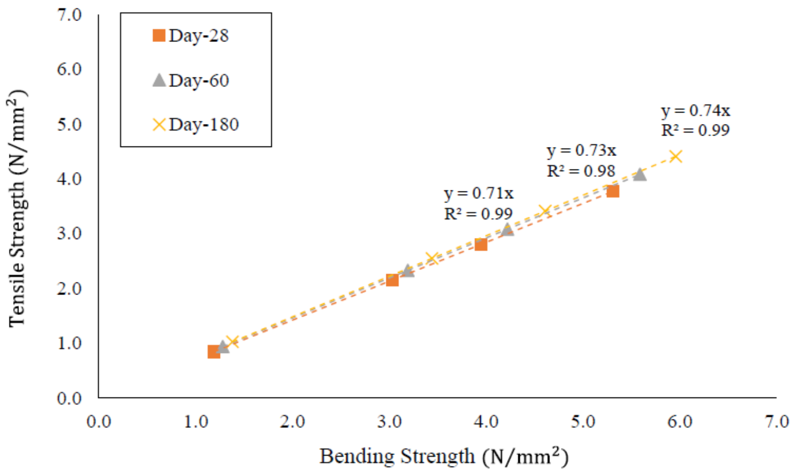


Fig. 23 - Relationship between load-carrying capacity in bending and in tension with a density of 1650 kg/m^3 confined with a different number of layers of fiber mesh

4. Conclusion

The investigation involved the confinement of LFC with 1 layer, 2 layers, and 3 layers of fiber mesh at densities of 650 kg/m^3, 1150 kg/m^3, and 1650 kg/m^3. The maximum load-carrying capacity in compression values achieved at the respective densities were 2.73N/mm^2, 7.39N/mm^2, and 19.5N/mm^2, respectively. Significant improvements of 48% to 153%, 56% to 97%, and 61% to 102% were observed for the LFC specimens with densities of 650 kg/m^3, 1100 kg/m^3 and 1650 kg/m^3, respectively. The load-carrying capacity in bending also showed a similar trend, where it increased as the density of LFC increased. The maximum load-carrying capacity in bending values obtained at the respective densities were 1.18N/mm^2, 2.97 N/mm^2, and 5.96 N/mm^2. The percentage increase in the load-carrying capacity in bending with a different number of layers of fiber mesh compared to the control specimens was 136% to 372% for a density of 650 kg/m^3, 127% to 258%, and 149% to 332%, for densities of 1150 kg/m^3 and 1650 kg/m^3, respectively. Finally, the superior enhancement of the LFC specimens wrapped with a different number of layers of fiber mesh was achieved for the load-carrying capacity in tension. The maximum load-carrying capacity in tension values obtained were 0.85 N/mm^2, 2.04 N/mm^2, and 4.41 N/mm^2 with enhancements of 186% to 567%, 157% to 343%, and 150% to 332%, respectively for the various densities. Thus, this proved that the reinforcement of LFC with fiber mesh improved its mechanical performance.

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