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# Influence of Crisscross Fiberglass Strip on Axial Compressive Strength of Lightweight Foamed Concrete

Md Azree Othuman Mydin[1,*], Mohamad Sukeri Khalid[2], Roshartini Omar[3,4], Hadee Mohammed Najm[5], Shaker Mahmood Abdal Qaidi[6], Paul Oluwaseun Awoyera[7]

[1] School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia
[2] School of Government, College of Law, Government and International Studies, Universiti Utara Malaysia, 06010, Sintok, Kedah, Malaysia
[3] Department of Construction Management, Faculty of Technology Management and Business (FPTP), Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja, Batu Pahat, Johor 86400, Malaysia
[4] Center of Sustainable Infrastructure and Environmental Management (CSIEM), Faculty of Technology Management and Business (FPTP), Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja, Batu Pahat, Johor 86400, Malaysia
[5] Department of Civil Engineering, Z. H. College of Engineering and Technology, Aligarh Muslim University, Aligarh, India
[6] Department of Civil Engineering, College of Engineering, Nawroz University, 42001 Duhok, Iraq
[7] Department of Civil Engineering, Covenant University, Ota, Nigeria

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**ABSTRACT**

Concrete use as a building component is already associated with the global construction sector. Since extensive research on concrete has been conducted for many years, there is a growing interest among researchers to conduct studies to increase the capacity of concrete for use in the building sector. Lightweight foamed concrete is one of the cutting-edge solutions developed for lighter and more sustainable buildings. Although this type of concrete has several benefits, its strength is still viewed as being inferior to that of regular concrete. By limiting the LFC with a crisscross fiberglass strip, the authors of this work will demonstrate improvements in LFC behaviour in terms of its compressive strength (CFS). To examine its improvements, 3 different LFC densities were cast and contained with 1 to 3 layers of 160 g/m$^2$ CFS. For this test, the cement-to-sand ratio was fixed at 1.1:5, and the water content was set at 0.45. The results revealed that the compressive strength of LFC confined with 1 to 3 layers of CFS increased by 153%, 97% and 102% were acquired for 600, 1100 and 1600 kg/m$^3$ densities respectively. This demonstrates that the number of layers used affects how positively the confinement of CFS affects the compressive behaviour of LFC.

## 1. Introduction

Concrete is extremely useful and adaptable when poured into formwork. Since it has been set, the rigidity and strength of concrete have taken precedence. This is due to the fact that concrete functions by carrying a load from a dead load and a live load [1]. Since there has been extensive research on concrete for many years, there is a growing interest among researchers to perform

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[*] *Corresponding author.*
*E-mail address: azree@usm.my*

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studies to raise the capacity of concrete for usage in the building sector. One of the cutting-edge solutions created for lighter and more sustainable buildings is lightweight foamed concrete (LFC). LFC was described by Ramamurthy *et al.,* [2] as a lightweight material made of cement paste with air spaces trapped in the mortar as a result of adding an appropriate foaming agent to the cement slurry [3]. The difference between LFC and conventional concrete, according to research by Zaidi and Li [4], is that homogeneous cells made by air in the form of tiny bubbles are added in place of the conventional aggregates. This is because conventional concrete uses coarse aggregates, which are not used in LFC. According to Jalal *et al.,* [5], LFC is only made up of fine sand mixed with cement, water, and foam and is thought to be a homogenous material because it lacks coarse aggregates, unlike regular concrete. Lowering the density of concrete will lessen the strain placed on building structures, namely the foundation, allowing for the creation of smaller foundations [6].

The growing development of precast concrete systems and components, often known as an Industrialized Building System (IBS), has also piqued the interest of the Malaysian construction industry [7]. There are many different building materials that concentrated on the use of lightweight foamed concrete for non-load-bearing wall systems, for a residential development project in Putrajaya [8]. Because of this, the use of LFC in the construction industry will not only produce an improved and lighter concrete-based material but will also quicken the building process, increase building production, and support the development of infrastructure as a whole [9]. It should be mentioned that LFC has a low density, which is good for compression but insufficient for tension. This disadvantage has limited its use in building construction, particularly for semi-structural and load-bearing components. The cement matrix contains a substantial amount of porosity, which causes numerous microcracks, and as a result, the material has very poor tension and is quite brittle when squeezed. Despite this, LFC is frequently used for level correction in housing complexes and as filler material for load works, as well as being used in construction as a semi-structural element. Nevertheless, a lot of research has been done to improve LFC's performance because it might be employed as a structural building material. Due to its benefits, such as its efficient thermal insulation and acoustic shielding features, especially when low densities of the material are utilized, researchers are becoming more and more interested in LFC [10].

As a result, numerous experiments have been carried out to enhance the mechanical attributes of LFC. According to Hunaiti's [11] study on the contribution of LFC to the strength of cross sections of composite components, it was discovered that LFC is brittle and therefore unable to perform well when it comes to resisting squash loads and bending. LFC cannot be a structural component if it is unable to provide a strength of at least 25 $N/mm^2$. As a result, the addition of fibres to LFC improves its mechanical characteristics. Reinforced lightweight concrete has gained popularity in the building sector over the past several decades [12]. In addition to lowering the cost of construction, the use of fibres in lightweight concrete can also produce certain other improved features, such as a decrease in porosity, water absorption, compressive strength, etc. [13]. Therefore, this study aims to assess the impact of CFS jacketing on the axial compressive strength of LFC.

## 2. Literature Review

LFC's variety of densities is its most obvious feature. Low-density LFC has been said to have a number of disadvantages in addition to its many benefits, which include a reduction in dead load, a faster building pace, and lower haulage and handling costs. According to a study by Hunaiti [11] into the contribution of LFC to the cross-sectional strength of a composite, it was found that the brittle nature of the material prevents LFC from adequately resisting bending stress. Zhu [14] asserts that LFC is composed of soft and fragile elements, and as a result, it has numerous microcracks. These microcracks will therefore spread when it is crushed and result in failure [15]. According to Amran *et al.,* [16], a drop in unit weight has a negative and exponentially increasing impact on the compressive strength of LFC, which is directly connected to its density. According to Ganesan *et al.,* [17], several variables, including the foaming agent, mix proportions, sand particle size, curing technique, additive properties, and additive distribution in the matrix, affect compressive strength. According to Thakrele [18], the reaction between the carbon dioxide (CO2) already present in the surrounding air will cause the compressive strength of LFC to increase indefinitely, but the increase in strength with ageing is essentially linear for the first 12 months. According to Jalal *et al.,* [5], the use of rapid hardening cement enables LFC to reach its high strength at a young age. They also indicated that increasing the amount of sand and cement and decreasing the amount of foam will result in LFC with a higher density and, hence, a higher strength.

As previously mentioned, Zamzani [19] confirmed that LFC's compressive strength is significantly impacted by the density brought on by its porosity. LFC with a lower density will have less strength due to the higher amount of foam due to the development of air gaps caused by the increasing volume of foaming agents. Additionally, the pores, air spaces, and matrix—which typically determine the quality of the microstructure will have an impact on the compressive strength in relation to density.

However, according to Coker *et al.,* [20], the strength gain increases as the LFC takes longer to cure. They claimed that adding foam to concrete causes air voids or pore spaces in addition to increasing the overall amount of water present in the pore spaces inside the concrete mass or the water-to-binder ratio. Calcium silicate hydrate (C-S-H), which is mostly important for the development of strength, is created by the reaction of tricalcium silicate (C3S) and dicalcium silicate (C2S), and the hydration of cement raises the water's alkalinity to pH 13 or even higher.

## 3. Experimental Program

### *3.1 Specimens Preparation*

In this study, three LFC densities specifically 600 kg/m$^3$, 1100 kg/m$^3$, and 1600 kg/m$^3$ were examined. Since a minor alteration in density will result in a small change in the attributes, these three densities were chosen for a comparison study to better understand. Additionally, LFC with a density of 600 kg/m$^3$ stood in for non-structural building components, 1100 kg/m$^3$ for semi-structural building components, and 1600 kg/m$^3$ for structural building components in actual use. All of the mixes had fixed mix ratios, with cement to sand at a fixed ratio of 1:1.5 and water to cement at a fixed ratio of 0.45. This was done to ensure that the confinement with CFS as the key parameter to be evaluated in this research produced comparable results. The woven fiberglass mesh that surrounds the LFC specimen in Figure 1 was used to restrict the LFC specimen after it was set in the matrix. Additionally, different densities of LFC were contained in 1, 2, and 3 layers of woven fiberglass mesh to study their effects on the compressive behaviour of LFC.

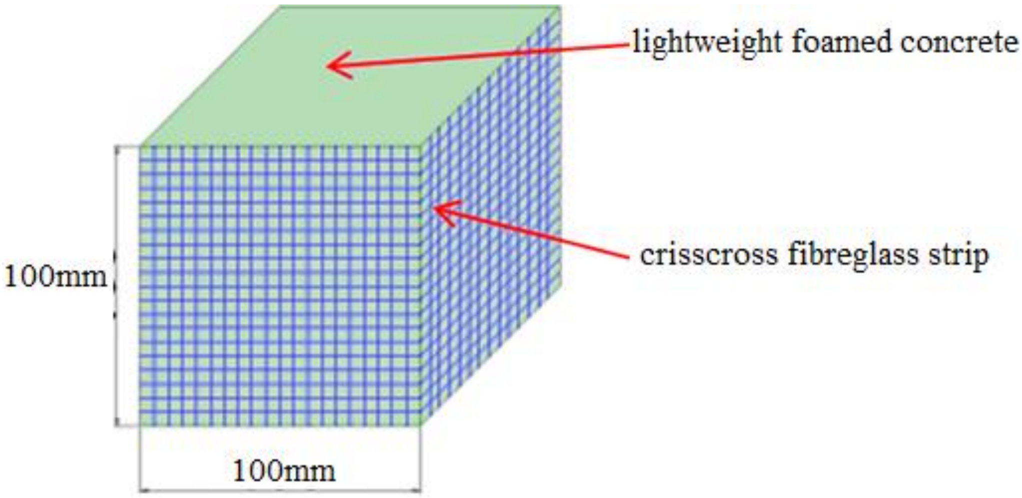


**Fig. 1.** Position of CFS confining LFC

### *3.2 Mechanical Testing*

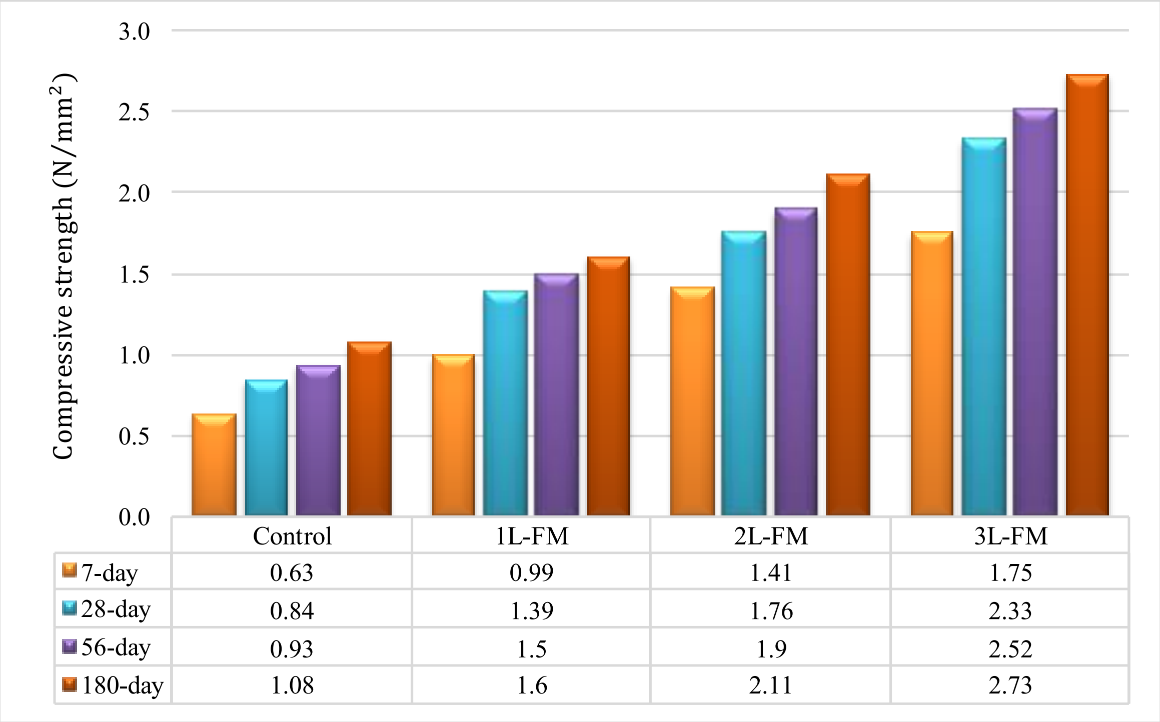
The compressive strength test is crucial for figuring out the highest load the concrete can support before failing. According to British Standard EN12390-Part 3 [21], the axial compressive strength test was conducted. The compressive strength of LFC was measured using three cubed specimens, each measuring 100 mm x 100 mm x 100 mm. Data were collected to track the strength increase of LFC during days 7, 28, 56, and 180 of curing. To guarantee that there was no water left in the LFC specimens after being extracted one day before the curing age, which could have decreased their strength, they were oven-dried for 24 hours. The machine with a 3000 kN capacity for evaluating compressive strength is illustrated in Figure 2, and the test configuration is shown in Figure 3.

**Fig. 2.** Universal Testing Machine (GTECH GT-7001-BS300)

**Fig. 3.** Axial compressive strength test setup

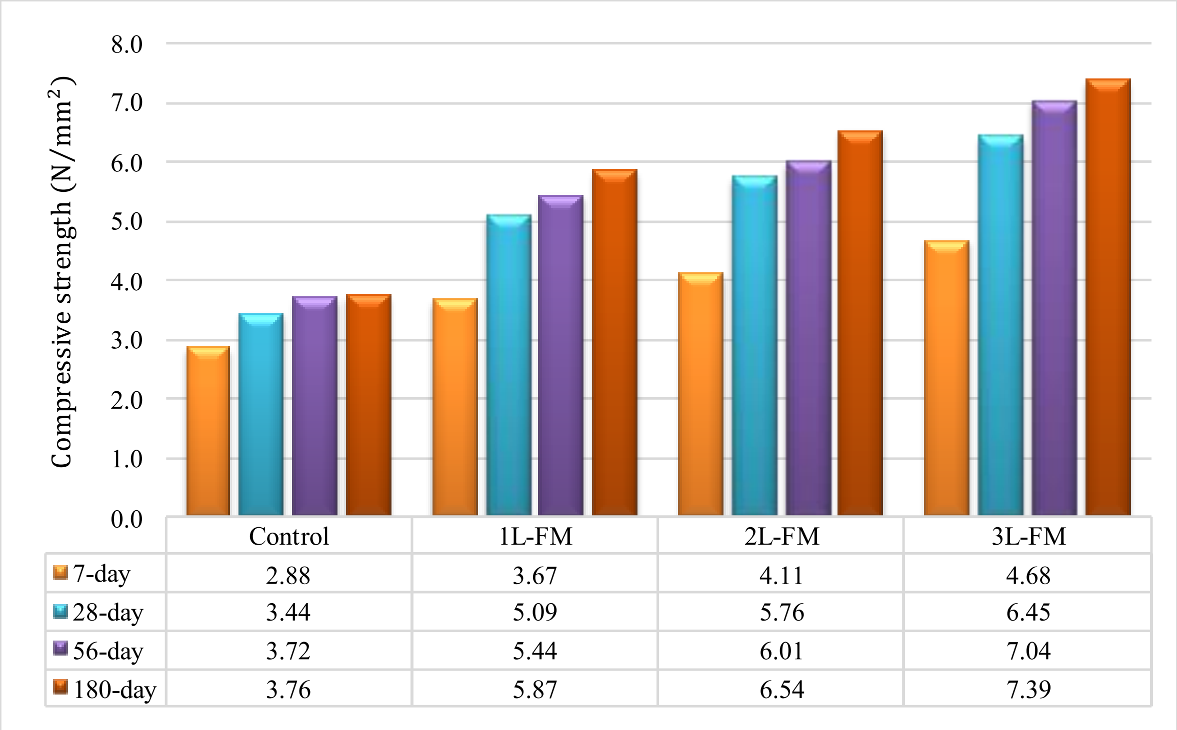
## 4. Results and Discussion

The axial compressive strength findings for LFC with densities of 600 kg/m$^3$, 1100 kg/m$^3$, and 1600 kg/m$^3$ confined with various numbers of layers of CFS are shown in Figure 4, Figure 5, and Figure 6. The three graphs all demonstrate a similar trend of strength development, with all LFC mixes becoming stronger as curing times increased. The LFC's compressive strength considerably rose along with its density. For instance, the compressive strength for the control LFC at day-180 with a density of 600 kg/m$^3$ was 1.08 N/mm$^2$, while the compressive strength for the LFC with a density of 1100 kg/m$^3$ was 3.76 N/mm$^2$, which was 248% higher than the compressive strength for the LFC with a density of 600 kg/m$^3$, and an increase of 157% (9.66 N/mm$^2$) was obtained for the LFC with a density of 1600 kg/m$^3$ According to Raj *et al.,* [22], at the lower density of LFC, the strength is controlled by the amount of foam rather than the physical characteristics of the material. As a result, the density predominantly affects the compressive strength. Additionally, Mohammad *et al.,* [23] pointed out that at greater densities, the distribution of air voids has less of an impact on compressive strength than does a more uniform distribution of voids. The manufacture of LFC with finer sand results in a more equal dispersion of air spaces than with coarse sand, according to Lim *et al.,* [24]. LFC is brittle, hence it needs a reinforcing component to increase its compressive strength. According to Raj *et al.,* [22], adding fibres increases LFC's compressive strength by averting microcracks. As shown in Table 1, this increased the compressive strength of LFC when it was enclosed with 160 g/m$^2$ of CFS. As seen, confinement with a single layer of CFS increased the compressive strength of LFC with a density of 600 kg/m$^3$ by 48% compared to control LFC with the same density, increased the compressive strength of LFC with a density of 1100 kg/m$^3$ by 56%, and increased the compressive strength of LFC with a density of 1600 kg/m$^3$ by 61%. Improvements of 95%, 74%, and 78% were also observed in the LFC specimens with densities of 600, 1100 and 1600 kg/m$^3$ that were consecutively constrained with 2 layers of CFS. Additionally, it was shown that the greatest increase in compressive strength occurred when LFC was contained between three layers of CFS. The CFS has the potential to be exploited as a reinforcing element in LFC, as evidenced by the substantial gains in compressive strength of 153%, 97%, and 102% above the control at the corresponding densities. All the improvements were due to the confinement with CFS in the form of a jacket and the increase in LFC's initial elastic stiffness. The tension in the jacket (CFS confinement) was activated when the lateral distortion arose as a result of the applied load due to the LFC's lateral expansion. In addition, the CFS worked to stop microcracks and slow down crack widening when exposed to greater applied stress [25,26-28]. The fibres, which postpone matrix cracks, are primarily responsible for increased resistance and ductility [29-31]. One of the factors contributing to the enhancement in the compressive strength of LFC is the strong connection between the textile fabric and the cement matrix. Additionally, Noor and Hazren [31] noted in their research that the amount of confinement layers in concrete also affects compressive strength, with an improvement of 54% obtained by using between 1 and 2 layers of textile fabric. Higher ultimate fracture stress is caused by an increase in the load-bearing capacity of concrete [32,33]. The LFC with a density of 1600 kg/m$^3$ that was contained in three layers of CFS for 180 days had the maximum compressive strength as a result of this study.



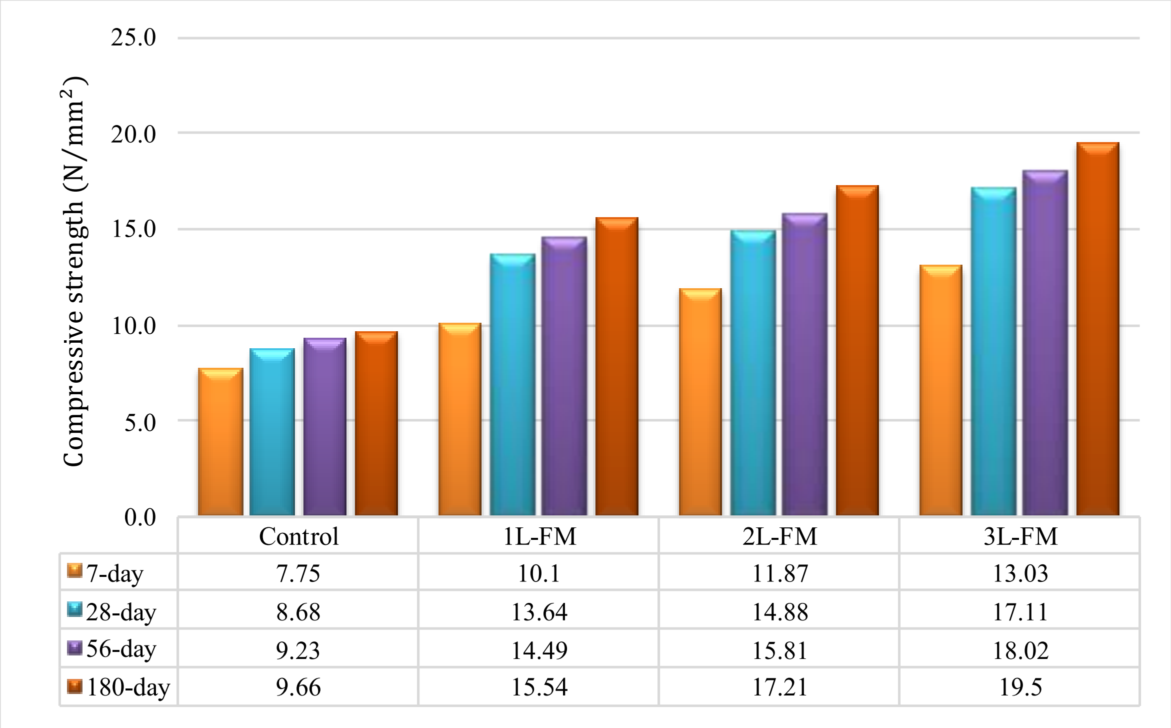
| | Control | 1L-FM | 2L-FM | 3L-FM |
|---|---|---|---|---|
| 7-day | 0.63 | 0.99 | 1.41 | 1.75 |
| 28-day | 0.84 | 1.39 | 1.76 | 2.33 |
| 56-day | 0.93 | 1.5 | 1.9 | 2.52 |
| 180-day | 1.08 | 1.6 | 2.11 | 2.73 |

**Fig. 4.** LFC Axial compressive strength specimens confined in a variety of CFS layers with a density of 600 kg/m$^3$



| | Control | 1L-FM | 2L-FM | 3L-FM |
|---|---|---|---|---|
| 7-day | 2.88 | 3.67 | 4.11 | 4.68 |
| 28-day | 3.44 | 5.09 | 5.76 | 6.45 |
| 56-day | 3.72 | 5.44 | 6.01 | 7.04 |
| 180-day | 3.76 | 5.87 | 6.54 | 7.39 |

**Fig. 5.** LFC Axial compressive strength specimens confined in a variety of CFS layers with a density of 1100 kg/$m^3$



| | Control | 1L-FM | 2L-FM | 3L-FM |
|---|---|---|---|---|
| 7-day | 7.75 | 10.1 | 11.87 | 13.03 |
| 28-day | 8.68 | 13.64 | 14.88 | 17.11 |
| 56-day | 9.23 | 14.49 | 15.81 | 18.02 |
| 180-day | 9.66 | 15.54 | 17.21 | 19.5 |

**Fig. 6.** LFC Axial compressive strength specimens confined in a variety of CFS layers with a density of 1600 kg/$m^3$

**Table 1**
Comparison of LFC specimens confined with one layer, two layers, and three layers of CFS to control specimens at day 180, a percentage increase in compressive strength was observed for each density

| Specimen | Percentage increase (%) | | |
|---|---|---|---|
| | 600 kg/m$^3$ | 1100 kg/m$^3$ | 1600 kg/m$^3$ |
| 1L-FM | 48 | 56 | 61 |
| 2L-FM | 95 | 74 | 78 |
| 3L-FM | 153 | 97 | 102 |

## 5. Conclusion

According to this research, the highest compressive strengths were 2.73N/mm$^2$, 7.39N/mm$^2$, and 19.5N/mm$^2$ at various densities. With the addition of CFS, significant gains of 48% to 153%, 56% to 97%, and 61% to 102%, respectively, were seen for the LFC specimens with densities of 600 kg/m$^3$, 1100 kg/m$^3$, and 1600 kg/m$^3$. The lateral expansion of the LFC encouraged the tension in the jacket (CFS confinement) as soon as the lateral deformation was advanced as a result of the applied load. The CFS worked to stop microcracks and slow down crack spreading when exposed to greater applied stress. This demonstrated that the LFC's mechanical performance was enhanced by the addition of CFS.

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