



Optimum Fiber Content to Improve Compressive Strength of Glass Fibers Reinforced Cellular Lightweight Concrete for Hollow-core Precast Panel Walls

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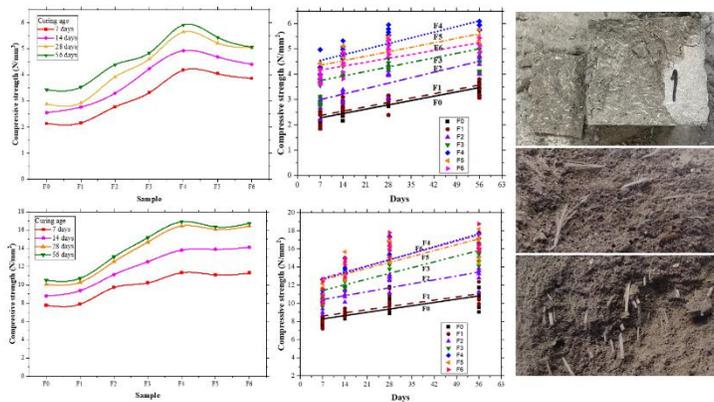
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Abstract

This study aimed to identify the optimal amount of glass fibers to enhance the compressive strength of Glass Fiber reinforced Cellular Lightweight Concrete (GF-CLC). The compressive strength of cellular lightweight concrete with densities of $1.20 \times 10^2 \text{ kg m}^{-3}$ and $1.60 \times 10^2 \text{ kg m}^{-3}$, containing different percentages (1%, 2%, 3%, 4%, 5%, and 6% by weight of cement) of glass fibers, was evaluated using BS EN 12390 Part 1 – 4 tests and compared with non-fiber specimens. The results indicate that 1% glass fiber reinforcement has an insignificant effect on compressive strength, while proportions of 2 – 4% by weight of cement lead to a significant increase in compressive strength at all stages of curing age. The optimum fiber content was found to be 4% by weight of cement, resulting in compressive strength improvements of 2 times and 1.60 times compared to non-fiber reinforced specimens at $1.20 \times 10^2 \text{ kg m}^{-3}$ and $1.60 \times 10^2 \text{ kg m}^{-3}$, respectively. However, adding more than 4% glass fiber by weight of cement leads to a decrease in compressive strength and a constant tendency at higher densities. Compressive strength tends to increase with increased density, curing time, and fiber content because more dense concrete provides higher bonding and pull-out strength between CLC and glass fiber, thereby enhancing the fiber's performance in resisting tensile and shear forces in the cellular lightweight concrete particles, resulting in higher ultimate compressive strength.

Keywords: Glass fiber; Cellular lightweight concrete; Compressive strength



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Introduction

Cellular Lightweight Concrete (CLC) is defined as a form of concrete that can be classified as a lightweight concrete (density of $400 - 1.85 \times 10^2 \text{ kg m}^{-3}$ [1]) with random air-voids created from the mixture of foam agents in mortar. The main advantages of CLC compared to conventional concrete are weight reduction (up to 80%), excellent acoustic and thermal isolation [2 – 5], high resistance to fire [6 – 8], lower costs in raw materials [2], easier pumping and application and finally, it does not need compacting, vibration or leveling.

By density, CLC may be employed in various forms. CLCs

with low densities between $300 - 600 \text{ kg m}^{-3}$ do not have a good mechanical performance, so they are used in thermal and acoustic isolation and fire protection. For densities between 700 and $1.10 \times 10^2 \text{ kg m}^{-3}$ the most extended use is the production of bricks, blocks, and non-structural elements, in specific cases they have been used as a filler material or leveling mortar for flooring. CLC with higher densities between $1.20 \times 10^2 \text{ kg m}^{-3}$ to $1.80 \times 10^2 \text{ kg m}^{-3}$ is used in precast forms, on-site casting, load supports, weight reduction mortars, and slabs where high strengths are required [9 – 12].

Fibers used in the foamed concrete are either synthetic or natural fibers, namely: alkali-resistant glass, kenaf, steel, oil palm fiber, and polypropylene fiber [13 – 16]. It was later revealed that the usage of fiber reinforcement could change the typical behavior of foamed concrete from brittle into ductile elastic–plastic [17]. The key function of fibers is to associate the cracks or fissures that progress in concrete and intensify the ductility of cement concrete elements. It also controls plastic and drying shrinkage of concrete [18]. Even though fiber-reinforced concrete offers various benefits of mechanical properties of the concrete, it is somewhat brittle in nature and remains a handicap for seismic applications [18]. Subsequently, the ductility and strength properties exhibit a contrasting behavior, fiber reinforced concrete is significantly more brittle than common normal strength concretes [19 – 20]. A negative effect of fiber reinforcement is the porosity decline. The reinforcement with glass fiber has been demonstrated to be effective just in part because the capability of the fibers to transmit the strengths did not prevent the progressive collapse of the cellular structure [21]. Other studies have reported an enhancement in the mechanical properties of foamed concretes reinforced with polypropylene fibers [22 – 25].

Glass Fibers Cellular Lightweight Concrete (GF-CLC) is CLC mixed with glass fibers. GF-CLC is a composite material consisting of a matrix containing a random distribution or dispersion of small glass fibers. GF-CLC is reducing material shrinkage, improving the tensile strength of cement-based materials [26]. Due to the presence of these uniformly dispersed fibers, the cracking strength of concrete is increased and the fibers act as crack arresters [26 – 27].

It was thought that dispersed glass fibers would improve the strength of CLC, especially tensile strength because tensile strength is the distinctive feature of glass fibers [26], but it is uncertain how they improve the compressive strength. The purpose of this study is, therefore to investigate the optimum fiber content of glass fibers reinforced cellular lightweight concrete for improved compressive strength. The results of this study can lead to the improvement of lightweight structural applications such as precast walls and slabs.

Materials and Methods

Materials Properties

The composition of the cellular lightweight concrete mixture reinforced with glass fiber comprises Portland cement, sand, a foaming agent, and glass fiber. The essential

properties of these constituent materials, as they pertain to their role in the concrete mixture, are detailed in Table 1.

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Experimental Investigation

The experimental investigation is conducted to obtain the optimum fiber content of glass fibers-reinforced cellular lightweight concrete for improved compressive strength.

Description of Specimens and Mix Design

The experimental work consisted of six cube specimens measuring $10 \times 10 \times 10$ cm. based on BS EN 12390-1:2021 [28] for each GF-CLC mixture, divided into two groups. Group one had specimens with a density of 1.20×10^2 kg m⁻³ which refer to non-load bearing precast panel wall applications, consisting of four sets for specimens cured for 7, 14, 28, and 56 days, with 6 specimens per set. Group two conducted the density of specimens 1.60×10^2 kg m⁻³ which refer to load bearing precast panel wall applications, consisting of four sets by the curing ages of specimens as 7, 14, 28, and 56 days, 6 specimens per set. Each set of specimens was compared to a non-fiber specimen, defined as the control specimen. The 12 mm-long fibers were mixed in ratios of 1%, 2%, 3%, 4%, 5%, and 6% by weight of cement. Therefore, each specimen set consisted of 24 specimens. A total of 336 specimens were tested, as shown in Table 2.

The materials used in the new GF-CLC include Portland cement, sand, water, water-reducing admixture, glass fiber, and liquid foam. CLC mixed design [4] maintains a constant quantity of all proportions to ensure consistency. The sand-to-Portland-cement ratio used was 2:1 while the water-to-cement ratio used was 0.40 and the water-reducing admixture was 1% of cement. Sand's specific gravity and water absorption were, respectively, 2.67 and 4.16. The foam bubbles were generated by using the commercially available chemical foaming agent which has been formulated to generate high-quality foam with strong closed-cell bubbles that are very durable and difficult to break apart during mixing. The foam agent was mixed with water in a ratio of 1:40, and the rate of expansion of the foam bubble was 49 times. The injection time for the liquid foam with concrete will be 448 and 288 seconds per 1 m³ of CLC for densities of 1.20×10^2 kg m⁻³ and 1.60×10^2 kg m⁻³,

Table 1 Materials properties

Materials (Brand)	Properties of Materials	Value
Cement (SCG low carbon)	Portland cement type	1
	Specific gravity of cement	3.15
	Autoclave expansion	0.80%
	Time of setting (Vicat test)	
	Initial set	45 minutes (Min)
	Final set	420 minutes (Max)
	Compressive strength (28 days)	28 MPa (Min)
Sand (From Mekong River)	Specific gravity of sand	2.67
	Fineness modulus of sand	2.64
	Water absorption of sand	2.04%
	Moisture content of sand	4.16%
Form (K Block Foaming Agent)	Rate of foam expansion	49 times
	Flow rate of liquid foam	1.806 l s ⁻¹
Water-reducing admixture (Sika® ViscoCrete®-10 TH)	Recommended Dosage	0.60 – 3% by weight of cement.
	Density	1.050 – 1.070 kg l ⁻¹
	pH-Value.	4.5 – 6.0
Glass fiber (SJ Sinthuphun Trading)	Density of glass fiber	2.50 g cm ⁻³
	Tensile strength of glass fiber	1,200 – 3,500 MPa
	Elongation at break	2 – 3%
	High-temperature applications	1,500°C
	Alkali Resistance	good
	Corrosion Resistance	good
	Non-Combustibility	good
Electrical Insulation	excellent	

respectively, when the flow rate of the liquid foam through the foam syringe is 1.086 l s⁻¹. The duration of liquid foam injection is calculated by dividing the specified volume of liquid foam by its corresponding flow rate. The CLC mixed design shown in Table 3, materials and specimens consist of liquid foam, glass fiber, mixing glass fiber in mortar, and test specimens shown in Fig. 1 (a), (b), (c), and (d), respectively.

In the past experimental studies, CLC with densities of $1.20 \times 10^2 \text{ kg m}^{-3}$ has the compressive strength in the range of 2.69 – 5.50 N mm⁻² [2 – 4, 29 – 31] which is insufficient for the development of non-load bearing precast panel wall applications. Similarly, CLC with densities of $1.60 \times 10^2 \text{ kg m}^{-3}$ has the compressive strength in the range of 7.50 – 11.25 N mm⁻² [2 – 4, 30 – 32] which is insufficient for the development of load bearing precast panel wall applications. However, by appropriately reinforcing with glass fibers, these structural components can be strengthened, opening up possibilities for developing construction technology using prefabricated systems.

Specimens' Preparation and Testing

Casting and curing of test specimens are performed in accordance with BS EN 12390-2:2019 [33]. The curing process prevents freshly placed concrete from drying rapidly. During the first day of its life, to minimize any tendency to crack and allow it to develop concrete strength. The specimens were cured by watering and wrapped with a plastic sheet as shown in Fig. 1(d), to prevent excessive loss of water after casting and consequently increase strength.

At the maturity of the curing age design, the specimens were weighed and measured to calculate their density. After preparing all specimens, compression tests were conducted to investigate the compressive strength according to BS EN 12390-3:2019 [34] using a compression machine as specified in BS EN 12390-4:2019 [35] as shown in Fig. 2. The specimens were tested at curing ages of 7, 14, 28, and 56 days, respectively.

Table 2 Number of specimens

Density (kg m ⁻³)	Specimens	% Fiber by Cement	Number of specimens by curing age				Total
			7d	14d	28d	56d	
1.20× 10 ²	CLC12-F0	0%	6	6	6	6	24
	CLC12-F1	1%	6	6	6	6	24
	CLC12-F2	2%	6	6	6	6	24
	CLC12-F3	3%	6	6	6	6	24
	CLC12-F4	4%	6	6	6	6	24
	CLC12-F5	5%	6	6	6	6	24
	CLC12-F6	6%	6	6	6	6	24
1.60× 10 ²	CLC16-F0	0%	6	6	6	6	24
	CLC16-F1	1%	6	6	6	6	24
	CLC16-F2	2%	6	6	6	6	24
	CLC16-F3	3%	6	6	6	6	24
	CLC16-F4	4%	6	6	6	6	24
	CLC16-F5	5%	6	6	6	6	24
	CLC16-F6	6%	6	6	6	6	24
SUM							336

Table 3 CLC mixed design

Density (kg m ⁻³)	Specimens	By weight
1.20× 10 ²	Cement	350.139 kg
	Sand	715.123 kg
	Water	124.895 kg
	Foam agent	5.840 kg
	Water to mix foam	292.025 kg
	Water-reducing admixture	3.501 kg
	Duration of liquid foam injection	448 s
1.60× 10 ²	Cement	468.781 kg
	Sand	957.437 kg
	Water	167.215 kg
	Foam agent	3.752 kg
	Water to mix foam	187.588 kg
	Water-reducing admixture	4.688 kg
Duration of liquid foam injection	288 s	



(a)



(b)



(c)



(d)



(e)



(f)

Fig. 1 Materials and casting specimens (a) Liquid form (b) Glass fibers (c) Mixing glass fiber in mortar (d) Casting specimens (e) Cube specimens with dimensions of $10 \times 10 \times 10$ cm and (f) Curing process



Fig. 2 The Compression test: (a) the testing specimen in a compression machine (b) the test specimen

Results and Discussions

The compressive strength test results of the lightweight cellular concrete mixed with glass fiber with a design weight of $1.20 \times 10^2 \text{ kg m}^{-3}$ and the actual weight before testing in the range of 1.144×10^2 to $1.285 \times 10^2 \text{ kg m}^{-3}$ are shown in Table 4. These results include the non-fiber-containing test set or the control set (CLC12-F0) of the fiber-containing test set in the percentage of cement weight at 1%, 2%, 3%, 4%,

5%, and 6%, respectively (CLC12-F1, CLC12-F2, CLC12-F3, CLC12-F4, CLC12-F5, and CLC12-F6) at the sample ages of 7 days, 14 days, 28 days and 56 days. The compressive strength test results of cellular lightweight concrete with a design weight of $1.60 \times 10^2 \text{ kg m}^{-3}$ and the actual weight before testing in the range of 1.595×10^2 to $1.658 \times 10^2 \text{ kg m}^{-3}$ are shown in Table 5, which contains the test results, the compression of the non-fiber-containing or control test sets (CLC16-F0), and the fiber-containing

Table 4 Compressive strength test results of group 1 (design density $1.20 \times 10^2 \text{ kg m}^{-3}$)

Specimens	Fibers/Cement (%)	Average Densities (kg m^{-3})	Average compressive strength (N/mm^2)			
			7 days	14 days	28 days	56 days
CLC12-F0	0	1.285×10^2	2.14	2.55	2.88	3.42
CLC12-F1	1	1.276×10^2	2.16	2.77	2.92	3.53
CLC12-F2	2	1.251×10^2	2.78	3.30	4.09	4.39
CLC12-F3	3	1.229×10^2	3.32	4.23	4.61	4.84
CLC12-F4	4	1.195×10^2	4.17	4.93	5.64	5.91
CLC12-F5	5	1.158×10^2	4.04	4.69	5.22	5.44
CLC12-F6	6	1.144×10^2	3.86	4.40	5.05	5.06

Table 5 Compressive strength test result of group 2 (design density $1.60 \times 10^2 \text{ kg m}^{-3}$)

Specimens	Fibers/Cement (%)	Average Densities (kg m^{-3})	Average compressive strength (N mm^{-2})			
			7 days	14 days	28 days	56 days
CLC16-F0	0	1.658×10^2	7.76	8.79	10.06	10.50
CLC16-F1	1	1.651×10^2	7.88	9.30	10.28	10.71
CLC16-F2	2	1.640×10^2	9.71	11.12	12.70	13.22
CLC16-F3	3	1.619×10^2	10.21	12.53	14.68	15.17
CLC16-F4	4	1.612×10^2	11.33	14.01	16.43	16.90
CLC16-F5	5	1.604×10^2	11.10	13.89	16.08	16.34
CLC16-F6	6	1.595×10^2	11.29	14.12	16.44	16.73

samples in the percentage weight of cement 1, 2, 3, 4, 5, and 6 (CLC16-F1, CLC16-F2, CLC16-F3, CLC16-F4, CLC16-F5, and CLC16-F6) at the sample ages of 7 days, 14 days, 28 days and 56 days, respectively. From Table 4 and Table 5, it can be observed that the density of CLC decreases as the fiber content increases. This is because the fibers in the CLC mixture substitute some of the mortar, reducing its consumption and resulting in a lower density.

Regarding the test results, they yielded that the compressive strength of CLC increased with increasing density. The control specimens without fiber addition, CLC12-F0, and CLC16-F0, displayed that when the density of CLC was increased from $1.20 \times 10^2 \text{ kg m}^{-3}$ to $1.60 \times 10^2 \text{ kg m}^{-3}$, the compressive strength at curing age 7 days, 14 days, 28 days and 56 days increased to 3.62, 3.44, 3.49 and 3.07 times, respectively. The incorporation of fibers into the CLC mix enhanced the compressive strength of the test specimens. From the test results, the compressive strength tends to increase with 1 – 4% fiber addition, then decrease with more than 4% fiber addition. The study indicated that when glass fibers were added in the proportion of 4% by weight of cement for the $1.20 \times 10^2 \text{ kg m}^{-3}$ density, the compressive strength of GF-CLC was highest from all curing ages of concrete. According to the test results presented in Table 4 and Fig. 3, it was found that the compressive strength of CLC12-F4 test specimens at 7, 14, 28, and 56 days was higher than that of the control specimens CLC12-F0 in the same age range, with the strength increasing by 1.95, 1.93, 1.96, and 1.73 times, respectively. Therefore, the addition of glass fibers in the CLC mix at a ratio of 4% of the cement weight could increase the compressive strength by approximately 2 times when the test

density of CLC is within the range of $1.112 \times 10^2 \text{ kg}$ to $1.287 \times 10^2 \text{ kg m}^{-3}$.

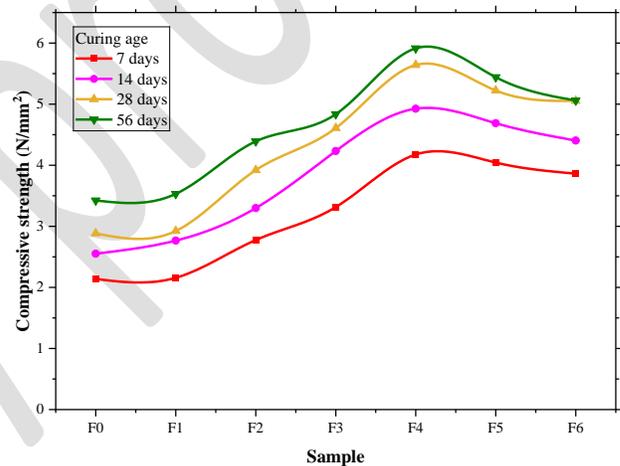


Fig. 3 The compressive strength test results of GF-CLC density $1.20 \times 10^2 \text{ kg m}^{-3}$ for different curing ages.

Fig. 4 displays the linear regression trendline derived from the comparison graph of the compressive strength test results based on the proportion of glass fiber and the curing ages of specimens. It is evident that the compressive strength of GF-CLC increases as the curing age of GF-CLC increases in all test specimens. In summary, when considering the GF-CLC density of $1.20 \times 10^2 \text{ kg m}^{-3}$, the test specimens containing 4%, 5%, 6%, 3%, 2%, and 1% glass fibers by weight of cement (F4, F5, F6, F3, F2, and F1, respectively) exhibit compressive strength values in descending order. Therefore, in this study, the optimal fiber content for this scenario is 4% by weight of cement.

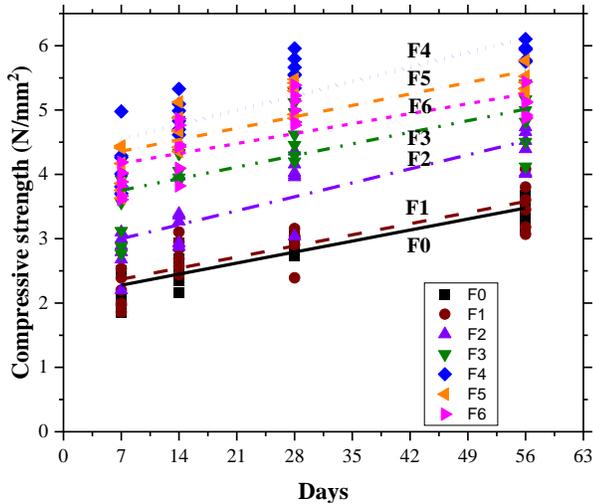


Fig. 4 Compared the linear regression trendline of compressive strength test results of GF-CLC density $1,200 \text{ kg m}^{-3}$ by curing age.

From the test results of the GF-CLC mix with a density of $1.60 \times 10^2 \text{ kg m}^{-3}$, it was found that the compressive strength of the test specimens increased with increasing concrete age. Fig. 5 illustrates the relationship between the compressive strength of test specimens mixed with different proportions of glass fibers. When mixing glass fiber in the proportion of 1% per weight of cement, the average compressive strength of the test specimens changes slightly compared to non-fiber specimens. The average compressive strength of the test specimens significantly increased when the fiber content was in the range of 2 – 4% by weight of cement. Nevertheless, when the proportion of glass fiber was increased in the range of 4 – 6% by weight of cement, the average compressive strength of the test specimens remained relatively constant and the same happens for all curing ages. This is different from the case of testing samples with a density of $1,200 \text{ kg m}^{-3}$, in which the average compressive strength decreased in that range. And when considering the average compressive strength of the test specimens with the proportion of glass fiber at 4% by weight of cement, it was found that the average compressive strength of the tested specimens increased by 1.46, 1.59, 1.63 and 1.61 times of non-fiber specimen at 7, 14, 28 and 56 days, respectively. Therefore, in this study, the addition of glass fibers in the CLC mix at a ratio of 4% of the cement weight could increase the compressive strength by approximately 1.6 times when the test density of CLC is within the range of $1.6580 \times 10^2 - 1.5950 \times 10^2 \text{ kg m}^{-3}$.

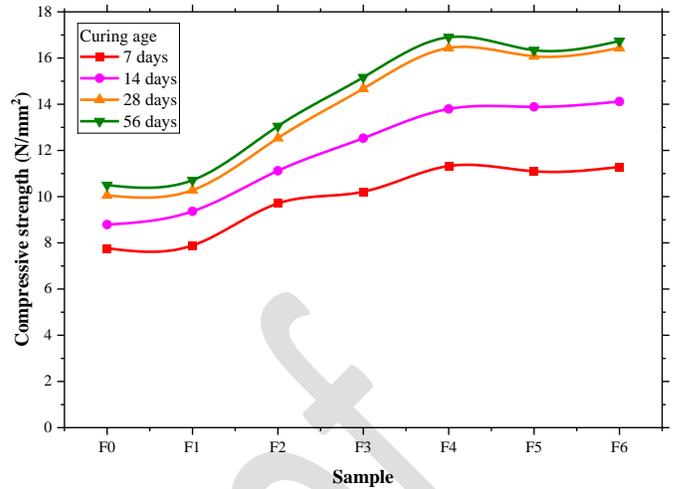


Fig. 5 Compressive strength test results of GF-CLC density $1.60 \times 10^2 \text{ kg m}^{-3}$ by curing age.

Fig. 6 shows the linear regression trendline of the compressive strength test results based on the proportion of glass fiber and the curing age of specimens. It is evident that the compressive strength of GF-CLC increases as the curing age of specimens increases in all test specimens. In summary, by the density of GF-CLC $1.60 \times 10^2 \text{ kg m}^{-3}$, the test specimens containing glass fibers 4%, 6%, 5%, 3%, 2%, and 1% by weight of cement (F4, F6, F5, F3, F2, and F1, respectively) exhibit compressive strength values in descending order. Therefore, the optimal fiber content for this scenario is 4% by weight of cement.

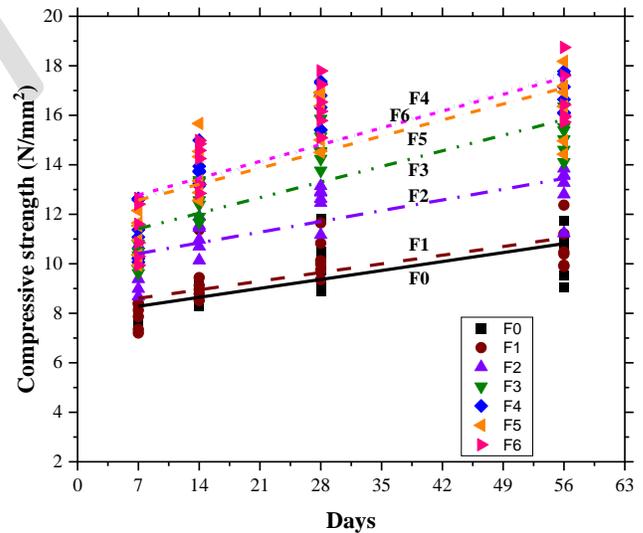


Fig. 6 Compared the linear regression trendline of compressive strength test results of GF-CLC density $1.60 \times 10^2 \text{ kg m}^{-3}$ by curing age.

At both densities, the compressive strength of GF-CLC with a glass fiber content of 4% by weight of cement was found to be higher at the density of $1.60 \times 10^2 \text{ kg m}^{-3}$ than at $1,200 \text{ kg m}^{-3}$ with increases of 2.72, 2.84, 2.91, and 2.86 times at the curing ages of 7, 14, 28 and 56 days, respectively. However, at a fiber content of 5% and 6% by weight of cement, the compressive strength of GF-CLC at a design density of $1,200 \text{ kg m}^{-3}$ decreased compared to that at 4% fiber content, while it remained constant at a density of $1.60 \times 10^2 \text{ kg m}^{-3}$.

The density of cellular lightweight concrete increases, caused by the reduced amount of liquid foam used in the mixture. This causes a decrease in air bubbles and makes the cellular lightweight concrete firmer. As a result, the bonding ability of concrete particles with glass fibers improves with increasing aging of the concrete. This enhances the performance of the fibers in resisting tensile and shear forces in the cellular lightweight concrete particles and leads to higher ultimate compressive strength.

Furthermore, it was observed that the failure surface, as shown in Fig. 7, exhibits the uniform distribution of the glass fiber as shown in Fig. 7(a), but there was a pulled-out failure from the mortar as shown in Fig. 7(b) and 7(c). The tensile strength of glass fiber and the strength of mortar generate the force resistance on the failure surface. Nevertheless, it was observed that, at the failure surface of GF-CLC with density of $1,200 \text{ kg m}^{-3}$, the distribution of pore and pore size are larger than GF-CLC with density of $1.60 \times 10^2 \text{ kg m}^{-3}$, as shown in Fig. 7(b) and Fig. 7(c), respectively. Moreover, the distribution of the glass fibers on failure surface of GF-CLC with density of $1.60 \times 10^2 \text{ kg m}^{-3}$ are denser than GF-CLC with density of $1,200 \text{ kg m}^{-3}$. Similarly, the bundle of glass fiber, on failure surface of GF-CLC with density of $1.60 \times 10^2 \text{ kg m}^{-3}$ are better than GF-CLC with density of $1,200 \text{ kg m}^{-3}$, as shown in Fig. 7(c) and Fig. 7(b), respectively.

Additionally, Fig. 7 illustrates that the failure surface displayed a uniform distribution of glass fibers, as seen in Fig. 7(a). However, there were instances of pulled-out failure from the mortar, shown in Fig. 7(b) and 7(c). The force resistance on the failure surface is influenced by the tensile strength of glass fibers and the strength of mortar. Interestingly, it was observed that GF-CLC with a density of $1,200 \text{ kg m}^{-3}$ had larger pore sizes and a more substantial distribution of pores on the failure surface than GF-CLC with a density of $1.60 \times 10^2 \text{ kg m}^{-3}$, as depicted in Fig. 7(b) and Fig. 7(c), respectively. Furthermore, the distribution of glass fibers on the failure surface of GF-CLC with a density

of $1.60 \times 10^2 \text{ kg m}^{-3}$ was denser than that of GF-CLC with a density of $1,200 \text{ kg m}^{-3}$. However, when considering the effectiveness of glass fibers, the studied results indicate that the compressive strength of GF-CLC increased 2 times for low density specimens and increased only 1.6 times for high density specimens, when compared to those without glass fibers. The reason may be due to the fact that the 1200 kg m^{-3} CLC specimens had very low compressive strength at first.

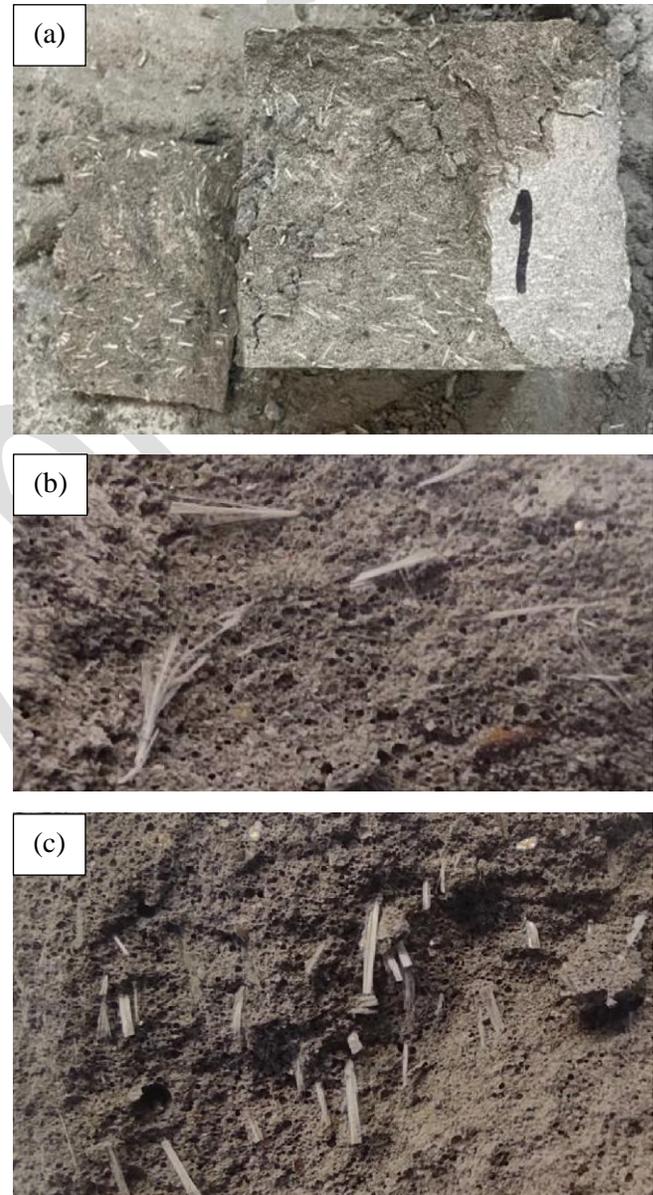


Fig. 7 Failure surface of GF-CLC specimens (a) Failure surface of 4% fiber addition (b) Failure surface of GF-CLC with density of $1.20 \times 10^2 \text{ kg m}^{-3}$ and (c) Failure surface of GF-CLC with density of $1.60 \times 10^2 \text{ kg m}^{-3}$.

Conclusion

The results from this investigation indicate that:

1. Adding 4% glass fiber by weight of cement to cellular lightweight concrete with a design density of $1.20 \times 10^2 \text{ kg m}^{-3}$ results in the highest compressive strength at all curing ages 7, 14, 28, and 56 days. The compressive strength increases by 1.95, 1.93, 1.96, and 1.73 times, respectively, compared to the non-fiber case. Therefore, the optimum glass fiber content for this density of GF-CLC is 4% of the cement weight, which increases the compressive strength by approximately 2 times compared to the non-fiber case.

2. The optimum fiber content for GF-CLC with a density of $1.60 \times 10^2 \text{ kg m}^{-3}$ is also 4% of the cement weight. The compressive strength at the curing age 7, 14, 28, and 56 days increases by 1.46, 1.59, 1.63, and 1.61 times, respectively, compared to the non-fiber case. On average, the increase in compressive strength is about 1.6 times compared to the non-fiber case.

3. Cellular lightweight concrete mixed with 4% glass fiber by weight of cement and a design density of $1.60 \times 10^2 \text{ kg m}^{-3}$ has a higher compressive strength than the case with a design density of $1.20 \times 10^2 \text{ kg m}^{-3}$, at the age of 7, 14, 28, and 56 days, the compressive strength is 2.72, 2.84, 2.91, and 2.86 times higher, respectively.

4. Adding 1% glass fiber by the weight of cement to cellular lightweight concrete has an insignificant effect on the increase in compressive strength. The development of compressive strength increases significantly when the proportion of fiber is in the range of 2 – 4% per weight of cement. However, when the proportion of glass fiber is in the range of 4 – 6% by weight of cement, the compressive strength tends to decrease in the case of $1.20 \times 10^2 \text{ kg m}^{-3}$ design density and remains constant in the case of $1.60 \times 10^2 \text{ kg m}^{-3}$ design density.

5. Compressive strength development tends to increase as the curing ages and fiber content increases in cellular lightweight concrete with higher density. Due to the addition of 4 – 6% fiber by weight of cement in cellular lightweight concrete with a density of $1.60 \times 10^2 \text{ kg m}^{-3}$, the compressive strength shows a constant tendency. Conversely, in the case of cellular lightweight concrete with a density of $1.20 \times 10^2 \text{ kg m}^{-3}$, the compressive strength tends to decrease in the same range of fiber content. Fibers significantly enhance the compressive strength of cellular lightweight concrete (CLC) through several mechanisms. By bridging microcracks, redistributing internal stresses, and mitigating shrinkage-

induced cracking, fibers contribute to the overall durability of the concrete. In higher-density CLC (e.g., $1.60 \times 10^2 \text{ kg m}^{-3}$), fiber inclusion promotes matrix densification, thereby increasing load-bearing capacity and energy absorption, resulting in improved compressive strength. Conversely, in lower-density CLC (e.g., $1.20 \times 10^2 \text{ kg m}^{-3}$), the weaker matrix exhibits reduced effectiveness in anchoring fibers, leading to a decline in compressive performance. Thus, the reinforcing effect of fibers is highly dependent on the matrix density, with higher-density mixtures deriving greater benefit from fiber reinforcement.

6. According to a study, GF-CLC with a glass fiber content of 4% demonstrated compressive strength levels suitable for precast panel wall applications [30]. Specifically, this material achieved the required strength for both load-bearing and non-load-bearing precast wall panels, with densities of $1.20 \times 10^2 \text{ kg m}^{-3}$ and $1.60 \times 10^2 \text{ kg m}^{-3}$, respectively. These findings suggest that GF-CLC may be a superior alternative to CLC for constructing hollow-core precast panel walls.[36]

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