



Research Article

Effect of steam–curing on the glass fiber reinforced concrete

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ABSTRACT

Due to the increased need to use precast concrete to reduce construction duration and to accelerate the cement reaction process to achieve the required concrete resistance that enables the elements to gain the required strength to handle the loads generated by the transportation process, many companies use steam curing methods to expedite the hydration process. The steam curing process negatively affects the concrete strength, especially in the long term. Fibers of different types are used to improve the interior composition of concrete and increase its crack resistance. The purpose of the current study was to determine the effect of the glass fiber on the behavior of steam-cured concrete. In this study, 90 concrete cubes were used with 15cm dimensions, three different weight ratios of glass fibers (0%, 0.12%, and 0.24%) with two curing methods standard curing in the water tank (water curing - WC) for 3, 7, and 28 days, and steam curing (SC) for 4 and 8 hours. Nine specimens of each mix were cast in 12 mm and 24 mm fibers length and tested for each curing duration and method. The results of this study indicate that fiber glass addition to the steam-cured concrete has a positive effect on the concrete unit weight and the ultrasonic pulse velocity. Moreover, the result showed that the tensile and compressive strength of the concrete has been positively affected by the length of the fiber more than the fiber weight percentage.

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1. Introduction

Nowadays the need for precast concrete buildings has increased as some countries are facing severe housing shortages and labor shortages as well (Liu et al. 2020). Due to rising construction costs and the increasing importance of quality and timely delivery, many developers are choosing innovative construction techniques such as precast concrete structures, which can speed up the construction process in less time (Zeyad et al. 2021; Canbaz et al. 2022). Precast concrete needs a long time, up to days, to reach the resistance that enables it to withstand the stresses resulting from the transportation process from the precast concrete supplier to the construction site, which causes an increase in the duration of project implementation and reduces the production capacity of the precast concrete (Liu et al. 2019). However, Steam curing is mainly used to produce prefabricated compo-

nents in many concrete structures. The steam curing method is characterized by improving the mechanical properties of concrete at an early age (Yang et al. 2021). On the other hand, this process has negative effects as the accelerated hydration reaction of concrete results in poor durability and long-term load-bearing capacity (Yoo et al. 2016). Recently, researchers focused on ways to improve the mechanical properties and durability of steam-cured concrete by various methods such as mechanical treatment by reducing the rate of temperature change and also improving mechanical properties by adding concrete additives or fibers to the concrete mix (Yu et al. 2016; Vairagade et al. 2012).

Fiber additives play a major role in mechanical properties improvement, such as toughness and crack growth resistance abilities (Brandt 2008; Won et al. 2012). Fibers improve concrete in all directions since fibers are scattered randomly in the concrete during mixing

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(Tassew and Lubell 2014; Balaguru and Shah 1992). Previous research has established that improving the post-peak ductility by adding fibers also improves eliminating temperature and shrinkage cracks, pre-crack tensile strength, impact strength, and fatigue strength (Vandewalle 2000; Vairagade and Kene 2012). Traditionally, many types of fibers have been used in fiber reinforcement concrete, each of these types has a different impact on the concrete mechanical behavior based on fiber shape, size, strength, and type, common types are carbon, steel, glass, and natural fibers. Several applications of FRC use fibers that make up about 1% of the concrete volume (Tan et al. 2012; Banthia 2003).

The use of fiber glass in concrete reinforcement was first introduced by researchers in Russia in the 1940s then used in the construction industry in 1970 in the United Kingdom. Chandramouli et al. (2010) and Shah and Rangan (1994) observed increases in compressive strength of 20–25 percent and flexural and splitting tensile strength of 15–20 percent in their studies on glass fiber reinforcement concrete. Similar results were found by Tassew and Lubell (2014) who found that regardless of the mix composition or fiber length, the volume proportion of glass fiber (GF) increased the flexural strength of ceramic concrete. Regardless of the fiber length or mix composition, ceramic concrete's compression toughness index, flexural toughness, and shear toughness all significantly increased with an increase in fiber content (Tassew and Lubell 2014; Shende and Pande 2011).

Several attempts have been made to research the effect of glass fiber on the mechanical properties of the GFR. Previous research on the effect of steam curing (Kohno et al. 2009) examined the mechanical properties of GFR samples that were steam-cured for 1–5 hours and then kept in standard curing for 90 days. In our study, however, micro glass fibers were incorporated into the GFR sample mix, and the effect of longer steam curing (such as 8-hour curing) was investigated. Micro-fibers are important in controlling microcracks that may occur especially in long-term steam curing applications. This paper attempts to focus on the effect of glass fiber on the steam cured concrete. In this study cube specimen of 15 cm dimensions was used to examine the effect of different fiber lengths and weight percentage on the unit weights, the ultrasonic pulse velocity, the compressive strength, and the split tensile strength of the concrete.

2. Experimental Study

2.1. Materials

Concrete cube specimens were created by using three types of crushed aggregates. Fig. 1, shows an analysis of the particle size of the aggregate mixture. The commercial quartz sand as fine aggregate (specific gravity of 2.65). Further, the densities of the fine aggregates were 2.69, 2.70, and 2.71 g/cm³, for fine aggregate sizes of (0–4 mm), (4–11.2 mm), and (11.2–22.4 mm) respectively.

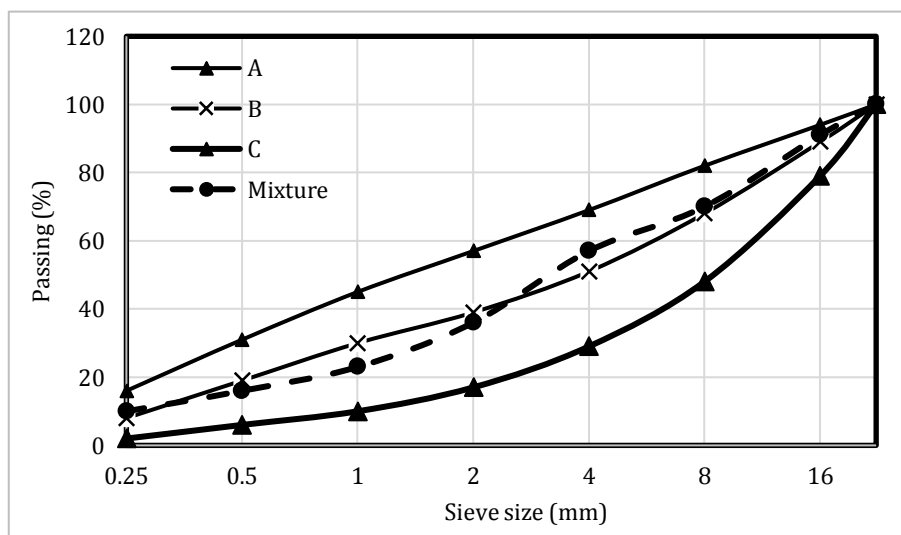


Fig. 1. Granulometry of the aggregate mixture according to EN 12620.

To improve the workability of concrete and avoid the loss in strength during the excess use of water, superplasticizers were used as an admixture and the properties of the new generation of superplasticizers are shown

in Table 1. Furthermore, the physical and chemical properties of tap water used in mixing the specimens are given in Table 2.

Table 1. Properties of admixture.

Chemical structure	Appearance	Cl, %	pH	Density, g/cm ³	Alkali, %
Polycarboxylic ether	Brown	≤ 0.10	5–7	1.069–1.109	≤ 3.00

Table 2. Properties of mixing water.

Chemical property, mg/l						Physical property	
Al	0,04	Cu	0,016	Ni	5,07	Conductivity, $\mu\text{S}/\text{cm}$	628
NO_3	11,1	Fe	0,007	K	6,8	Hardness, Fd^0	30,11
NH_4	0,06	Mn	0,015	As	1,19	pH	7,35

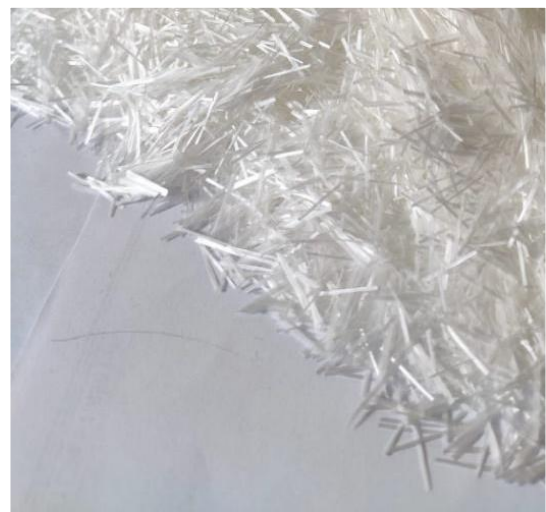
The mechanical properties of the glass fiber reinforcements (Fig. 2) used in the concrete mix were as follows, 3400 MPa tensile strength, 77 GPa modulus of elasticity, and a density of $2.60 \text{ kg}/\text{dm}^3$, however, the diameter of the glass fiber was 13-15 μm with two different lengths 12, and 24 mm.

Portland cement type CEM I 42.5 R was provided by a local supplier with physical and chemical properties shown in Table 3.

2.2. Method and tests

Cube specimens of 15 cm were created to examine the effect of glass fiber with different lengths and weights, three different weight ratios of glass fibers (0%, 0.12%, and 0.24%) were used in two different lengths 12, and 24 mm. Table 4 shows the mix ratio of 1 m^3 concrete mixture by weight. Two curing methods were implemented in the study, standard curing in the water tank (water curing - WC) for 3, 7, and 28 days, and steam curing (SC) for 4, and 8 hours. The group of WC was demolded 24 h after casting and then put in a water tank at 20 C and was taken out of the tank 3 hours before the test. Nine specimens of each mix were cast in 12 mm, and 24 mm fibers length and tested for each curing duration and method, eventually reaching 90 specimens.

To examine the changes in the unit weight, ultrasonic pulse velocity, splitting tensile strength, and compressive strength, tests were carried out for each fiber ratio, length, curing condition, and duration, as can be seen in Figs. 3 and 4. However, the test results will be discussed in further sections.

**Fig. 2.** Glass fiber.**Table 3.** Properties of cement.

Chemical properties				Physical properties	
SiO_2	19.2	K_2O	0.63	Density, g/cm^3	3.09
Al_2O_3	4.56	Na_2O	0.31	Specific surface, cm^2/g	3190
Fe_2O_3	3.09	SO_3	3.21	Setting time (initial), min	163
CaO	62.9	Cl-	0.01	Setting time (final), min	228
MgO	1.88	LOI	3.8	Soundness, mm	1

Table 4. A mix ratio of 1 m^3 of concrete mixture by weight.

Cement (kg)	Water (kg)	Superplasticizer (kg)	Aggregate (kg)		
			0-4 mm	4-11.2 mm	11.2-22.4 mm
435	125	3.5	967	333	555

3. Discussion

The effect of glass fiber length and fiber ratio on the unit weight of concrete is shown in Fig. 5. When the fiber ratio increases, the unit weight of the concrete increases as well. Depending on the fiber rate of increase, the increase in unit weight increased by 1.8% in the samples

with 12 mm fiber, while the increase rate reached 1.4% when the fiber size reached 24 mm. On the other hand the increase of the curing time, causes the decrease in the unit weight with the addition of fiber. Depending on the time of curing, the unit weight increased up to 2.08% regardless of fiber ratio and fiber length. Concrete unit weight is expected to decrease due to water loss in con-

crete exposed to drying in construction site conditions. However, during the experiment, the samples are kept in water to simulate standard curing conditions, as a consequence of the samples being removed from the curing tank 2-3 hours before the test and the surface is allowed to dry, which caused an increase in the unit weight due to the water it contains.



Fig. 3. Mechanical tests.



Fig. 4. Ultrasonic pulse velocity and mechanical tests.

Fig. 6 shows the change in UPV (ultrasonic pulse velocity) depending on fiber ratio, fiber length, and curing time. The UPV is increased by 11%, with the increase in the fiber content. The bridging of gaps and cracks induced by the fibers causes the UPV to increase as the waves caused by UPV have passed through the gaps in a short time. Since it takes time for the gaps to fill and the internal structure to gain strength during hydration, fibers with 24mm length were more effective in passing through these gaps at an early age. This effect disappeared on the 28th day, and similar results were obtained with an increase in the UPV which was dependent on the fiber ratio and independent of the fiber length.

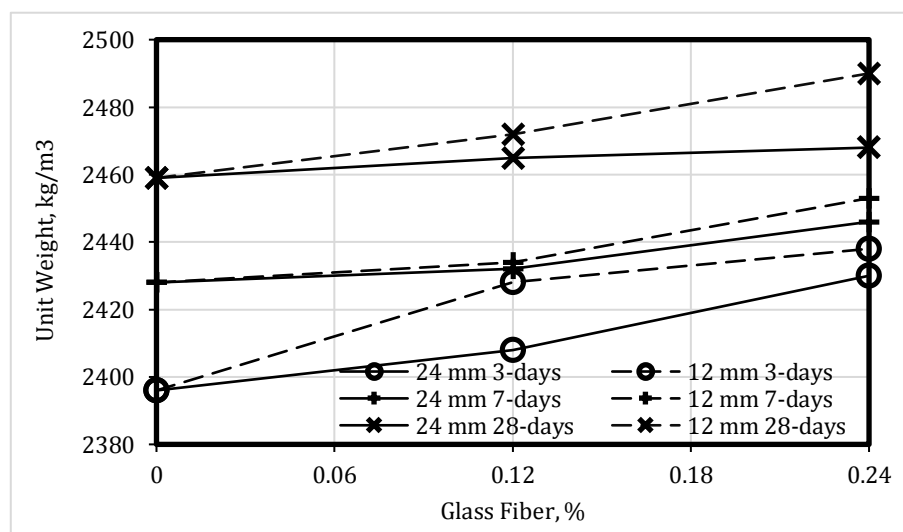


Fig. 5. Unit weight of glass fiber concrete.

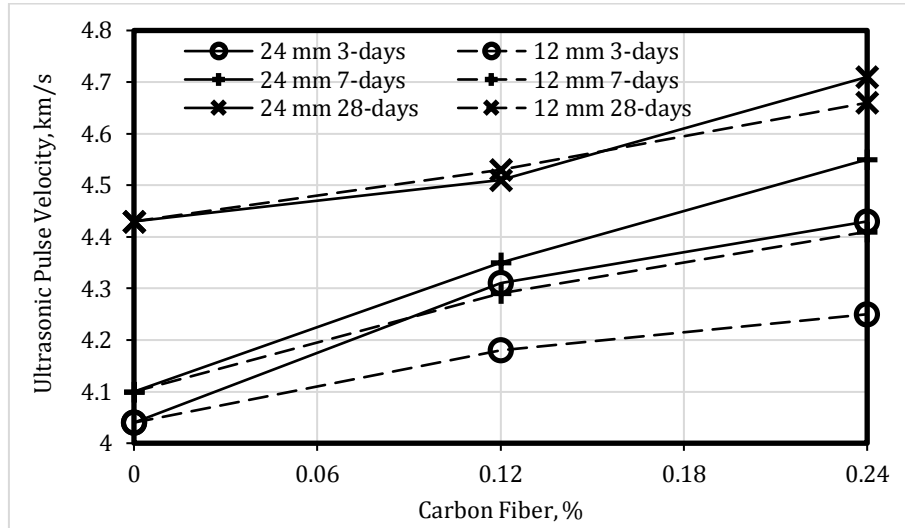


Fig. 6. UPV test results of glass fiber concrete.

The compressive strength of the glass fiber concrete samples is given in Fig. 7. It can be seen that when the short fiber was used with the concrete, the compressive strength of the 3-day curing increased by 13%. However, the increase rate decreased by 11% and 5.6% in the 7-day and the 28-day curing respectively. In the case of using long fiber, the compressive strength of concrete increased by 37%, 42%, and 17% in the 3-day, 7-day, and 28-day respectively. The fibers caused an increase in compressive strength by controlling the growth of microcracks in the concrete under pressure stress with the effect of bridging. Since these fibers have a smooth surface, they cannot

show sufficient adherence. For this reason, the compressive strength of the concrete increases depending on the length of the fiber. Due to the concrete not gaining enough strength at an early age, glass fibers can withstand more stress, where the contribution to strength is more in these fibers. Additionally, compared to the 28-day reference samples, the compressive strength of the 3-day and 7-day were 63% and 72% respectively. On the other hand, when the fiber was added the compressive strength of the samples reached 74% on the 3-day and 89% on the 7-day. Therefore, using glass fiber in concrete caused a significant increase in strength, especially at an early age.

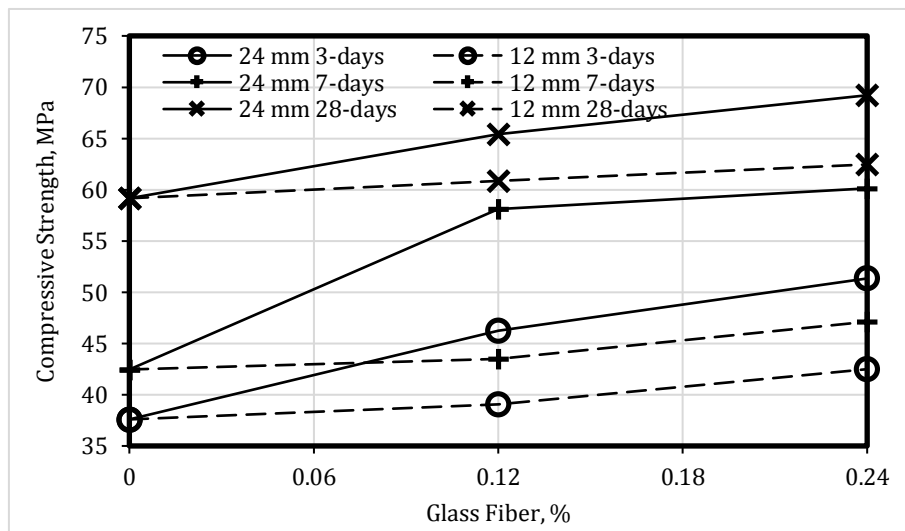


Fig. 7. Compressive strength of glass fiber concrete.

Fig. 8 illustrates the result of splitting tensile strength of glass fiber reinforced concrete under the indirect method of assessing the tensile strength (Brazilian test), the result shows that the splitting tensile strength increased by 24% when the short fibers were added to the concrete. Moreover, this increase reached 40% in the case of long fibers. Generally, when the Brazilian test is carried out to determine the splitting tensile strength,

the concrete cracks, and splits under the effect of linear load, although the glass fibers limit this crack by the effect of bridging. However, this positive effect of the fibers is being gradually lost because the fiber was partially ruptured with the increase in the load and due to the loss of adherence. Since adherence is increased with the increase of the length of the fibers, the tensile strength of the samples reinforced by the long fibers witnessed bet-

ter results. Compared to the 28-day reference sample of the splitting tensile strength, the reference samples gained 65% and 81%, while the samples with fiber gained 81% and 93% in 3-days and 8-days respectively.

It is observed that it is possible to counteract tensile stresses that occur in the internal structure due to mechanical impacts or effects such as shrinkage at early ages by using glass fibers.

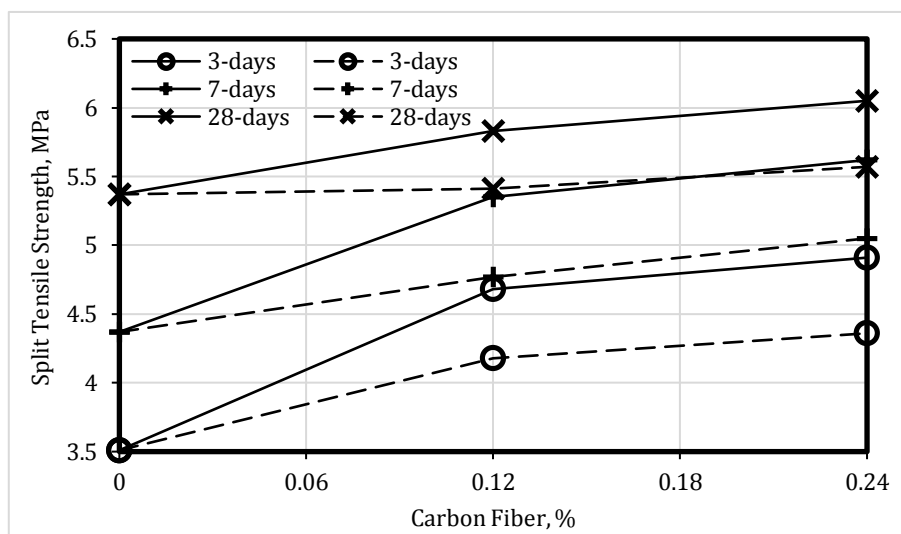


Fig. 8. Splitting tensile strength of glass fiber concrete.

The behavior of fiber-reinforced concrete in the unit weight under the effect of steam curing is given in Fig. 9. The figure shows that the unit weight has increased due to the increase of the fiber under steam curing. However, the unit weight reached 2.4% and 0.7% when using short and long fiber respectively. By contrast, when the samples are compared according to the unit weights of the reference sample, it has been found that the concrete

sample without fibers under the steam curing has been decreased by 1.87%, as opposed to the samples with fibers which were reduced by 0.8% and 1.5% for short fibers and long fibers respectively. Overall, the fact that the formation of the internal structure could not be completed in a short time under the effect of steam curing and that it did not provide sufficient filling caused a slight decrease in the unit weights of the reference concrete.

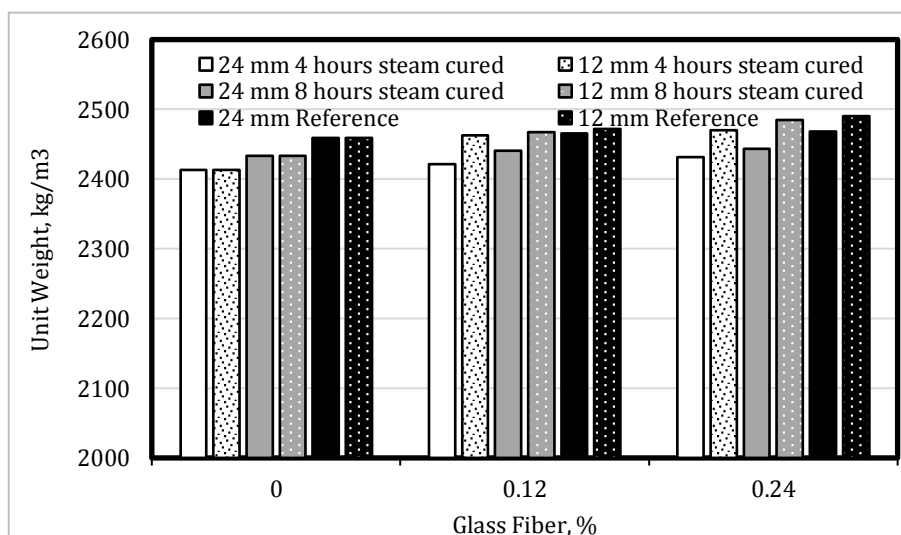


Fig. 9. Unit weight of steam-cured glass fiber concrete under various curing durations.

The variation of UPV values with fiber content and fiber size of reference concretes under steam curing is demonstrated in Fig. 10. It can be seen that when the 12 mm fiber length was used, the samples without steam curing increased by 5.2% compared to the reference sample without fibers, however the percentage of in-

crease was decreased by 2.5% in case of steam curing. On the other hand, when the 24 mm fiber length has used the samples without steam curing increased by 6.3%, and as opposed to the short fibers, the long fibers caused an increase by 8.1% in UPV compared to the reference samples. UPV can take low values due to cracks or gaps

in the concrete. However, fiber addition increases the UPV values as it makes it easier to overcome these gaps. Since steam curing is aimed to accelerate the hydration reaction to gain early strength in the concrete, which ul-

timately increases the UPV, further, these values can be increased with the addition of fibers. However, the irregularity in the fiber distribution causes the UPV increase to occur in different ways in the samples.

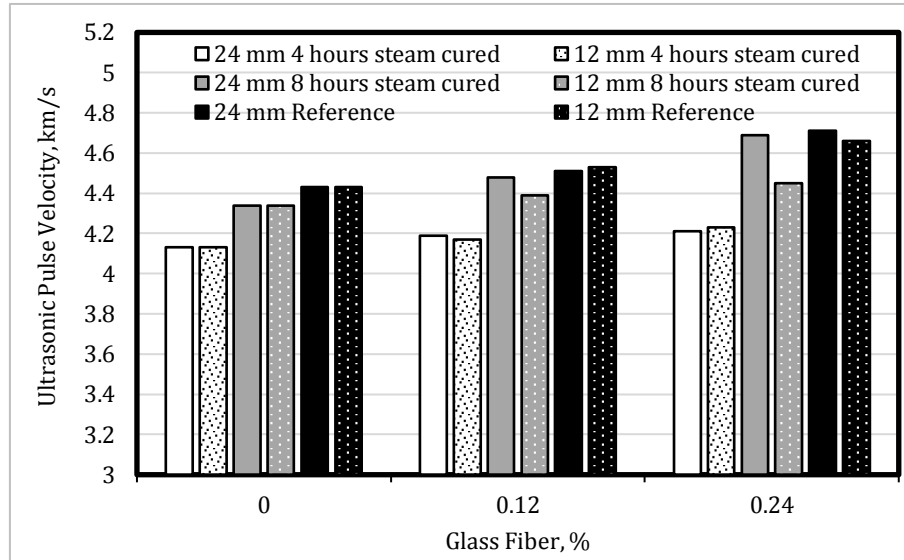


Fig. 10. UPV test results of steam-cured glass fiber concrete under various curing durations.

The variation of steam cured fiber reinforced concrete with compressive strength of 28-day reference fiber concrete is demonstrated in Fig. 11. In the case of using short fibers, the compressive strength of the reference samples under standard curing has increased by 57%, although in the case of steam curing this increase reached 63%. On the other hand, when the long fiber was used, the compressive strength of the reference samples increased by 17%, while this increase was 30% in the steam-cured samples. Furthermore, the glass fibers were used to control the micro cracks that may occur in the internal structure during the early strength gain phase in the steam curing application, and it has caused

a great increase in the compressive strength as well. Additionally, in standard curing, it was observed that the glass fiber size and distribution have an effect on the concrete compressive strength, and since the amount of glass fibers is higher when using short fibers with the same ratio as long fibers, the increase in the amount of fibers causes better distributing of the fibers in the internal structure of the concrete which enhances the compressive strength. It can be seen that with the application of 8 hours of steam curing, the samples without fibers gain reached 64% in compressive strength, while the samples with short and long glass fibers gained 98% and 71% respectively.

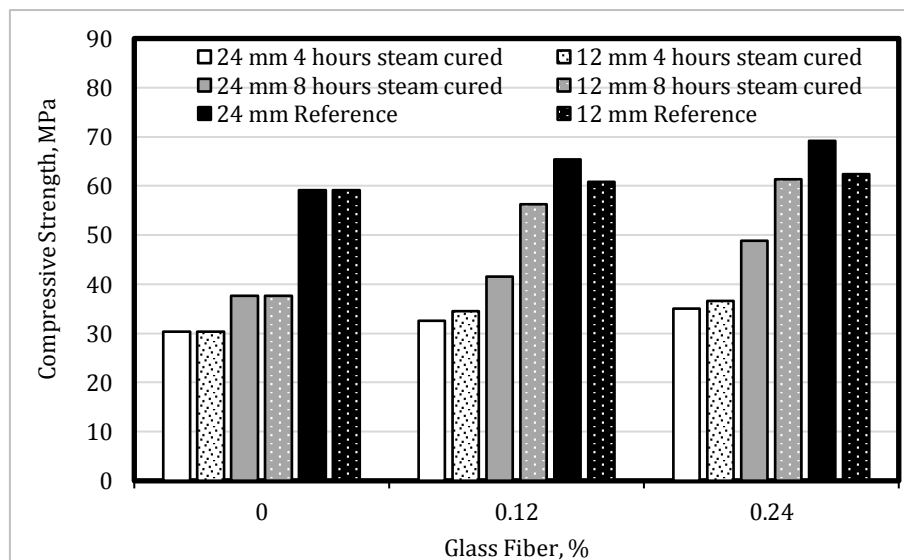


Fig. 11. Compressive strength of steam-cured glass fiber concrete under various curing durations.

Split tensile values with variations of fiber ratio and size of reference concrete under steam curing are given in Fig. 12. It can be seen that with the addition of short glass fiber in the reference concrete without steam curing, the splitting tensile strength increased up to 3.7%, however, with the application of steam curing the increase rate reached 45.9%. And in the case of long glass fiber, the splitting tensile strength of the reference samples increased by 12.7%, while this rate increased to 35.8% in the steam-cured samples. Fiber has been especially effective in steam curing applications, as it prevents the increase of microcracks and voids that occur during the

hydration of cement in a short time steam curing application. On the other hand, when the steam curing time was increased, a comparison between the steam curing samples and the 28-day reference samples was conducted, and it has been found that the splitting tensile strength reached 65.4%, 95.3%, and 64.3% without fiber, with short fibers and long fibers respectively. Although it has been found that long fibers did not increase the tensile strength gain with steam curing effect as much as short fibers, the number of fibers is more effective than the fiber length, especially since there are micro-cracks, and short fibers are effective in preventing these cracks.

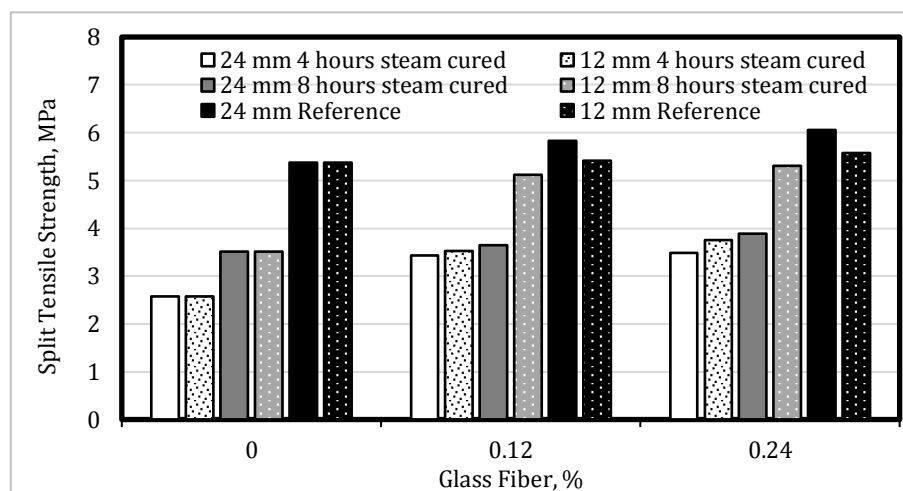


Fig. 12. Splitting tensile strength of steam-cured glass fiber concrete under various curing durations.

4. Conclusions

The conclusions of the study are summarized as follows:

- At the end of the experimental study, considering the glass fiber ratios, when 0.24 % of the fiber is used, the highest values are found in unit weight is around 2490 kg/m³, 4.71 km/h in UPV, additionally compressive and splitting tensile strength were found to be around 69.2 MPa and 6.05 MPa respectively. However, when comparing the mechanical and physical properties between the 0.12 % and 0.24 %, it has been found that using 0.24% fiber was advantageous. Therefore, it is recommended to use 0.24% fiber.
- When the study is conducted in terms of fiber length, it has been found that the highest values of samples reinforced with short glass fiber are 2468 kg/m³ in unit weight, 4.71 km/h in UPV, 69.2 MPa in compressive strength, and 6.05 MPa in split tensile strength, on the other hand, the highest values of samples reinforced with long glass fiber are 2490 kg/m³ in unit weight, 4.66 km/h in UPV, 62.5 MPa in compressive strength, and 5.57 MPa in splitting tensile strength. Therefore, long fibers are recommended due to their advantages in mechanical properties.
- For prefabricated building applications where steam curing is inevitable, and when curing time and fiber ratio are taken into account, the increase in fiber ratio is advantageous, and it has been observed that an 8-hour curing application is advantageous if 0.24 % fi-

- ber is used. The results of 8-hour steam curing reached 2485 kg/m³ in unit weights, 4.69 km in UPV/h, 61.3 MPa compressive strength, and 5.31 MPa in splitting tensile strength. The experiments have shown that using fibers with steam curing had a positive effect on the mechanical properties, especially in compressive strength which is the most effective parameter in the application of prefabricated buildings.
- Considering the steam curing and fiber length, it was observed that the mechanical properties of the samples increased significantly in the 8-hours steam curing compared to the 4-hours steam curing. In the case of 8-hour steam curing, the compressive strengths of short fiber samples reached 61.3 MPa, while it reached 48.9 MPa in long fiber samples. On the other hand, the splitting tensile strength reached 5.31 MPa in short fiber samples, while it reached 3.89 MPa in long fiber samples. It can be said that it is more advantageous to use short fiber for a fixed ratio in steam curing applications.

As a result of the study, it has been revealed that fiber use is important in steam curing applications and fiber size was as effective as fiber ratio. For steam curing application, using 0.24% short glass fiber in samples is recommended. However, for further studies, it is recommended to repeat the experiments by increasing the fiber ratio and shortening the fiber size, especially for cost optimization. In addition, it is recommended to carry out studies not only in terms of short-term properties but also in terms of long-term properties.

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Conflict of Interest

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