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Residual Durability Performance of Glass Fiber Reinforced Concrete Damaged by Compressive Stress Loads

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Abstract

Concrete is exposed to a variety of stresses throughout its service life, which can result in cracks and damage. The use of fibers in concrete mixtures is known to improve the mechanical and durability properties of the concrete. In this study, glass fiber-reinforced concrete cube specimens were produced and stressed at 70 and 90 percent of their maximum compressive strength. The effects of stress loading-induced cracks and glass fiber reinforcements on mechanical and durability properties of concrete specimens were investigated using UPV, capillary water absorption, acid effect, and high-temperature effect tests. Glass fibers increased compressive strength and reduced water absorption in specimens that were not stressed. On the other hand, glass fibers increased the durability of stressed specimens at both degrees of compressive load stress. The bridging effects of glass fibers reduced crack creation, resulting in improved UPV test results. Glass fibers did not dissolve in acid solution due to their chemical resistance, resulting in less weight loss and higher compressive strength in concrete specimens. In the high-temperature effect tests, decreasing compressive strength values were observed as the stress load and temperature levels increased. However, such reductions were lower for glass fiber reinforced concrete than for control concrete without glass fiber. As a result of the present findings, glass fiber reinforcements prevent stress-induced cracks, making the concrete more durable and stronger against external forces.

Keywords

GFRC, durability, high temperature, acid effect, fiber-reinforced concrete

1 Introduction

Concrete is the most used construction material in buildings. Cracking occurs in concrete structures over time because of various stresses and external forces. Due to its brittle structure, concrete is prone to cracking. Therefore, fiber reinforcements are used to improve the properties of concrete. Fibers provide more ductile behavior by transferring load-induced stresses due to bridging behavior [1]. Fiber-reinforced concrete is produced by incorporating different types of fiber into the concrete mixture. The use of fibers in concrete has grown in popularity, particularly with the development of chemical admixtures. Glass fiber stands out among fiber types due to characteristics such as high tensile strength, chemical resistance, and resistance to high temperatures. Glass fibers outperform steel in tensile strength. E-glass fibers were the first used type of glass fiber in concrete. However, this type of glass fiber has been adversely affected by the alkaline environment in the concrete structure over time. As a result, the fiber filament structure was damaged and negatively affected the concrete properties. In order to eliminate the weakness of glass fibers in this alkaline environment, zirconium-coated alkali-resistant (AR-Glass) fibers were developed and began to be used in concrete [2]. The AR-glass fibers in concrete have been shown to improve the mechanical and durability properties of concrete [3–6].

Throughout its service life, concrete is subjected to stress at various levels of its strength capacity. Its ability to withstand the stresses to which it is subjected is critical. Since there occur micro-cracks in the concrete structure even without any loading. These cracks expand due to loads and that reduces durability and mechanical properties. There is no expansion up to 30 percent of ultimate stress capacity to be applied to the concrete in these cracks. However, cracks grow as the levels of applied load increase. These cracks expand quickly, and new cracks appear when 70 percent of the ultimate stress (fc)

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is attained. Because cracks formed below this loading level only occur on the surface between the aggregate and cement paste. However, after around 70% loading, these micro-cracks move toward the concrete surface and are connected to each other [7, 8]. When the compressive load is raised to 90–95 percent of the concrete ultimate capacity, the crack formation and expansion rate accelerate significantly, and the material becomes breakable at any time [9, 10]. Popovics and Popovics [11] and Hoseini [12] reported that severe cracks occur at a 70% loading level, adversely affecting concrete properties such as UPV, permeability, and porosity. Furthermore, Yildirim et al. [13] reported that damage occurs at a 70% load level, and these cracks widen significantly at higher loading levels, seriously affecting durability properties at a 90% load level. Besides, it is known that glass fibers reduce the crack formation rate and crack formation [14].

Many studies examining the durability properties of glass fiber are available in the literature, but this study also investigated the residual durability properties of glass fiber-reinforced concrete damaged by compressive loads. Concrete specimens were produced with various ratios of glass fiber to investigate the crack-prevention behavior of glass fiber. These samples were damaged by loading them with compressive stresses of 70% and 90% of their ultimate compressive stress (fc). It aimed to investigate the contribution of glass fibers to semi-cracked samples by performing mechanical and durability tests on 3 different types of samples, which were undamaged and loaded at these two different load levels. Thus, compressive strength, water absorption, ultrasonic pulse velocity (UPV), capillary water absorption, acid effect, and two different degrees of high-temperature effect tests were conducted. These experiments demonstrated the effect of glass fiber reinforced concrete, especially after crack formation, and the glass fiber dosage to be used based on the effect the concrete would be exposed to.

2 Materials and methods

2.1 Materials and mixture proportions

Concrete mixture ratios are provided in Table 1. A water/cement ratio of 0.5 was used in all samples. The polycarboxylate-based superplasticizer (SP) was used at varying doses according to the slump test, and the slump value was kept between 10–15 cm. CEM I 42.5 R Portland cement was used as the binding material in all mixtures. The aggregates used in this study are limestone coarse aggregate with a particle density of 2.75 kg/dm^3 and fine aggregate with a density of 2.65 kg/dm^3. Tap water was used as a mixture of water. The properties of the glass fibers used are provided in Table 2. Glass fiber reinforced concrete specimens were produced by using 0.25%, 0.5%, and 1% AR-glass fibers by volume of concrete, and these specimens were named G0.25, G0.50, and G1, respectively. There is no glass fiber in the control concrete (CC).

2.2 Specimens preparation

The materials given in Table 1 were used in concrete production in accordance with the TS 802 standard [15]. GFRC mixtures were obtained by adding glass fibers at various rates during production. In samples, plasticizer additives were used based on slump values and were poured into molds. Produced samples were all 100 mm × 100 mm × 100 mm concrete cube specimens. After 24 hours, samples taken out of the molds were cured in lime-saturated tap water until the day of the experiment. Three specimens were produced for each test series. The compressive strengths of all samples were determined after 28 days of water curing. 70% and 90% of these determined ultimate compressive stress values were applied to concrete specimens. As a result, stress-induced damage was created on the concrete sample. The concrete samples were then used in the next experiments after this process. In addition, unloaded concrete samples were also used in experiments as a control series. The glass fibers used in this study are shown in Fig. 1.

Table 1 Mix proportions of concrete

Mixture name	Aggregate (kg/m^3)			Water (kg/m^3)	Cement (kg/m^3)	Volume of fiber (%)	Mass of fiber (kg/m^3)	SP (kg/m^3)
	8–16 mm	4–8 mm	<4 mm					
CC	690.07	431.30	603.81	210	420	-	-	0.4
G0.25	687.37	429.60	601.45	210	420	0.25	6.7	1
G0.5	684.65	427.91	599.07	210	420	0.50	13.4	2
G1	679.20	424.40	594,30	210	420	1	26.8	2.7

Table 2 Properties of glass fiber

Material	Length	Diameter	Modulus of elasticity	Specific gravity	Tensile strength	Melting Point
AR-Glass fiber	12 mm	14 µm	72 GPa	2.68	1850 MPa	1050 °C

Fig. 1 The appearance of glass fiber

2.3 Test procedures

2.3.1 Compressive strength

Cube specimens were subjected to compressive strength tests in accordance with TS EN 12390-3 [16]. Three specimens were tested for each mixture, and the average was reported in this paper. Compressive strengths of 7 and 28-day samples were determined. Thus, the effects of glass fibers on compressive strength were investigated.

2.3.2 Water absorption

The water absorption test procedure was conducted according to ASTM C642-06 [17]. At the end of the measurements, water absorption values were calculated with the use of Eq. (1).

$$\text{Water absorption ratio}(\%) = \frac{(W\text{sat} - W\text{dry})}{W\text{dry}} \times 100, \quad (1)$$

where Wdry is the mass of the concrete specimen kept in the oven (g) and Wsat is surface dry mass of the concrete specimen soaked in water (g).

2.3.3 Ultrasonic Pulse Velocity (UPV)

The UPV test procedure was conducted according to the standard ASTM C597-9 [18]. Ultrasonic pulse velocity was calculated with the use of Eq. (2).

$$V = \frac{L}{T}, \quad (2)$$

where V is pulse transmission velocity in concrete (km/sec), L is transmission distance (km), and T is transmission time in the concrete (sec).

The average of five UPV measurements was taken from five different locations on the specimen (4 corners and the middle). To determine the impact of stress, the UPV test was repeated before and after compressive stresses were applied. Finally, a UPV test was performed on the samples that had been exposed to high temperatures to study the damage that had been caused to the concrete and the effect of fibers.

2.3.4 Capillary water absorption

The capillary water absorption test was carried out in accordance with ASTM C1585-13 [19]. Three samples (28 day age) were used for each specimen type. To obtain the capillary water absorption values, specimens with a known dry weight and water-proof side surfaces were weighed at various intervals. Unstressed, 70% stressed, and 90% stressed specimens were used in tests from each series.

2.3.5 Acid effect

An acid effect test was performed to investigate compressive loading-induced cracks and the effects of fiber used on durability. After weighing 28-day-old dry samples, they were immersed in a 5% H_2SO_4 (sulfuric acid) solution for 28 days. Every week, the solution is refreshed. After 28 days, all samples were taken out of the acid solution and immersed in water for 24 hours. After that, the samples were removed from the water and oven-dried for 24 hours at 105 °C. The layer on the samples after they came out of the oven was brushed. The samples were then weighed, and weight losses were calculated. The compressive strength of samples was measured in the following step. Acid-induced weight and compressive strength losses were calculated in this way.

2.3.6 High-temperature effect

A high-temperature effect test was conducted to investigate the effects of different stress levels and fiber ratios on the high-temperature resistance of the concrete. A total of 48 samples (4 samples from each series) were used. Concrete samples were exposed to temperatures of 400 and 600 °C for 2 hours. The temperature increase rate was applied as 10 °C/min. The samples were taken out of the furnace 24 hours after the end of the experiment. The compressive strength of the samples at room temperature was measured. In this way, the effects of high temperatures on concrete samples were investigated.

3 Result and discussion

3.1 Compressive strength

In fact, the effect of fibers on compressive strength is a debatable issue. There are studies in which fibers have a positive effect as well as ineffective or negative effects [20]. However, the good distribution of glass fiber in the mix due to its filament structure increases the strength of the concrete. It performs the load transfer successfully owing to this distribution. Fig. 2 represents the results of compressive strength tests performed at the end of the 7th and 28th days. Increasing fiber ratios resulted in higher compressive strength values. By acting as a bridge between the separated concrete fragments, glass fiber filaments improved the ability to stay together. The effect of glass fiber was observed more effectively at early ages (7 days). The presence of glass fibers in the concrete increased the compressive strength by building a bridge within the concrete, even if the concrete strength has not yet been completed. The behavior was also observed in broken concrete samples and during the compressive test process. When compared to CC samples, the compressive strength increased by 19.74% at 7 days and 13.15% at 28 days in the G1 series with the highest fiber ratio. Greater compressive strengths can be attained by utilizing higher fiber ratios in glass fiber-reinforced concrete with appropriate workability due to the improvement of chemical admixtures [21–24].

The difference between fiber-reinforced and fiber-free control samples broken in a compressive press is seen in Fig. 3. The fiber-reinforced samples were able to maintain physical integrity despite reaching their maximum compressive strength, thanks to the bridging action of glass fibers.

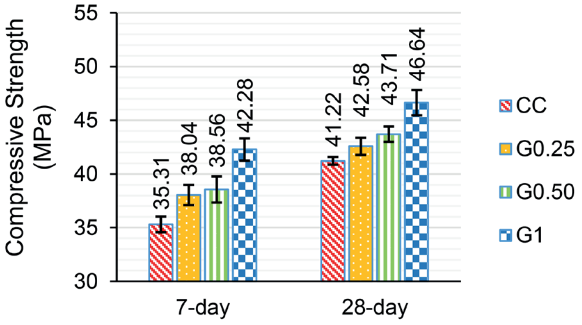

Fig. 2 Compressive strength of concrete specimens at 7 and 28 days

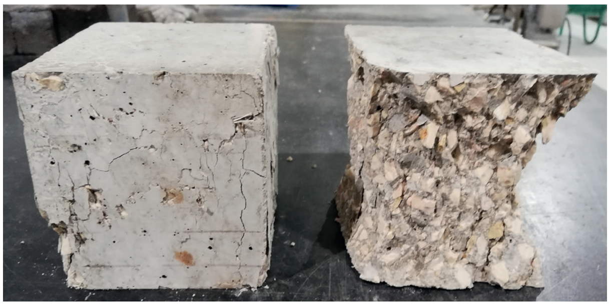

Fig. 3 The appearance of GFRC and control concrete samples after the compressive strength test

3.2 Water absorption

The water absorption test results for 4 different mixtures are presented in Fig. 4. When the results were examined, the G0.25 series absorbed less water than the CC sample. Since glass fibers have good hydrophilic properties. Therefore, it blocked the pores by establishing a strong bond in the cement matrix [25]. More water could not be absorbed owing to the blocked pores. According to the study of Yuan and Jia [26], glass fibers reduce the water absorption value due to this effect. Besides, the water absorption rates increased in the G0.50 and G1 series. The reason for this increase is the gaps formed in the concrete due to the lack of good distribution of glass fiber in these ratios [20]. Even if the slump values of all mixtures are kept constant, the voids in this sample were not prevented. In parallel with this work, Sivakumar et al. [27] report that as the glass fiber ratio increased, the water absorption values increased. For this reason, when a fiber with a thin filament structure, such as glass fiber, is used, the optimum ratio should be determined to reduce the water absorption values by utilizing this thin filament structure. Al-Ghaban et al. [28] reported that while glass, nylon, and carbon fiber are used at a certain rate, they decrease the water absorption rates while increasing them at higher rates.

3.3 Ultrasonic Pulse Velocity (UPV)

All 28-day concrete specimens were subjected to compressive stresses of 70 and 90 percent of the maximum compressive strength (fc) shown in Fig. 2. Before and after this process, UPV values were measured, and the results were compared. UPV test results are presented in Fig. 5. The UPV values of all unstressed samples were observed to be 5.03 km/sec. According to IS 13311-Part 1 classification, no effect of glass fiber was observed in this value, indicating quite a high concrete quality. Glass fiber-reinforced samples, on the other hand, generated higher values in all stressed samples. As can be seen in Fig. 5, the CC samples had the

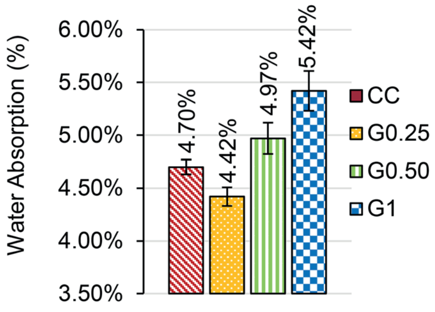

Fig. 4 Water absorption of 28-day concrete specimens

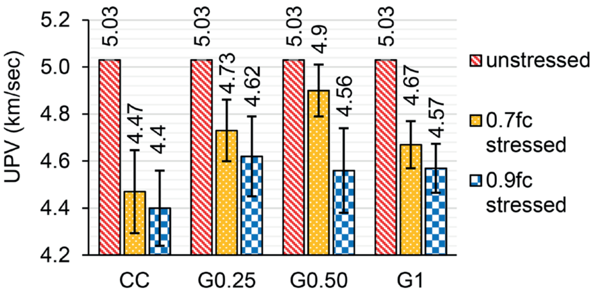

Fig. 5 UPV test results of stressed and unstressed specimens

lowest velocity of the samples subjected to 0.7 fc stress. The greatest velocity detected in G0.5 was 4.90 km/sec, while the CC sample velocity was 4.47 km/sec. In comparison to initial velocity, the CC sample lost 11.13%, while the G0.50 samples lost only 1.2%. When the UPV values of 0.9 fc stress loaded samples were examined, it was observed that CC samples had the lowest value once again. While 0.9 fc was loaded, the concrete had several fractures and spills, causing a reduction in all UPV values. CC samples had a velocity of 4.40 km/sec, whereas G0.25 samples had a velocity of 4.62 km/sec. The capacity of glass fibers to hold the concrete structure together under compressive stresses was impressive at this load level. Although the glass fiber-reinforced samples generated similar results, the G0.25 sample had the highest value. This rate resulted in fewer voids and fibers that performed as predicted. This study, like previous investigations, found no evidence of a positive effect of glass fibers in the UPV test of unstressed samples [29]. However, UPV values were determined to be preserved because glass fibers prevented fracture under stress-applied circumstances. Furthermore, glass fiber has performed this at the rate of each fiber.

This preservation, which is determined in the UPV values, is important for the residual durability properties. Therefore, it was suggested that glass fibers may have a greater impact on residual durability properties than on durability. The appearance of glass fibers in a concrete structure is shown in Fig. 6.

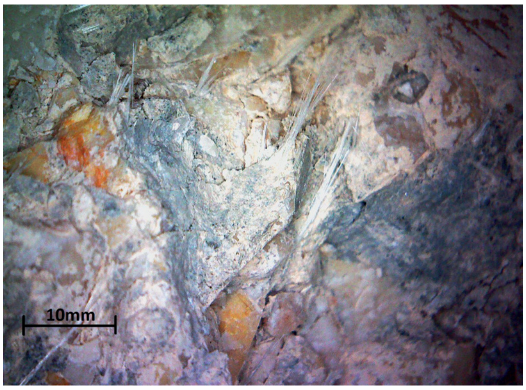

Fig. 6 The internal structure of glass fiber reinforced concrete sample

3.4 Capillary water absorption

Micro and macro cracks that occur in samples when 70 and 90 percent of their maximum compressive strength are loaded were predicted to enhance the concrete's capillary water absorption values. The role of glass fibers in capillary water absorption because of crack prevention using fiber was investigated. First, tests on unstressed 28-day specimens were conducted, and the results are seen in Fig. 7. G1 series, the water absorption rate with the highest water absorption rate in the water absorption tests, also had the highest capillary water absorption. Although CC samples had the highest water absorption values in the first few hours, G1 samples had higher water absorption values than CC samples after the fourth hour and the greatest water absorption after the 16th hour. The voids formed in the concrete samples are the reason that G1 samples have the highest capillary water absorption rate. Since the glass fiber could not provide an optimum distribution at this rate, voids formed in the sample. These gaps showed an adverse effect as the water entered the sample through capillary ways. Following these specimens (G1 and CC), the greatest water absorption was observed in the G0.5 samples and the least in the G0.25 samples. Water absorption values were generally increased while increasing glass fiber ratios [29].

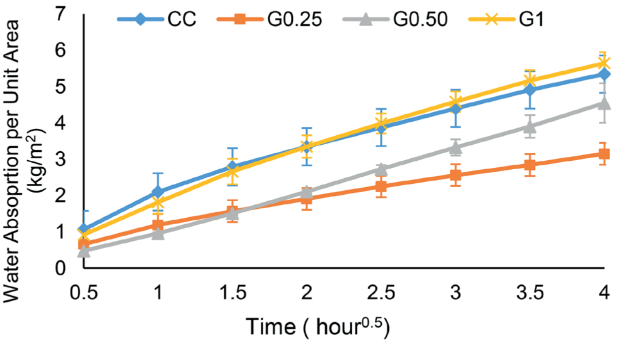

Fig. 7 Capillary water absorption value of unstressed concrete specimens

In parallel with this study, Niu et al. [30] reported that capillary water absorption rates decreased when low fiber was used, while capillary water absorption values increased above the control samples as the added fiber ratio increased. However, some materials that will close the gaps created by these fibers also allow for higher fiber usage. de Gutiérrez et al. [31] reported that the use of pozzolan increased fiber properties by filling the voids created by the fibers. In addition, suitable chemical admixtures such as viscosity-modifying admixtures and advanced hyper-plasticizers can be used to prevent gaps formed by fibers [32].

Capillary water absorption values were observed in parallel to water absorption test results. Since G0.25 samples had the lowest capillary water absorption and normal water absorption values due to a lower void ratio and blocked pores, the optimum fiber content was identified as 0.25% for undamaged specimens.

In Fig. 8, capillary water absorption values of samples exposed to a 70% maximum compressive stress are shown. When compared to unloaded samples, all samples absorbed more water. Load-induced cracks increase capillary water absorption. The effectiveness of the glass fibers was clearly visible here due to their anti-cracking behavior. In unstressed samples, G1 samples with the highest water absorption absorbed less water than CC samples. G0.25 samples were the least water-absorbing sample series once more. By the end of the 16th hour, CC and G0.5 had absorbed a similar amount of water via capillary.

In Fig. 9, capillary water absorption values at 90% fc loading are seen. Capillary water absorption rates increased when the loading rate increased due to deterioration in the concrete structure. Although CC was the most absorbent sample type at the first stage, it reached the same level as G0.5 and G1 samples in the following hours. At this level, G0.25 samples had the lowest water absorption.

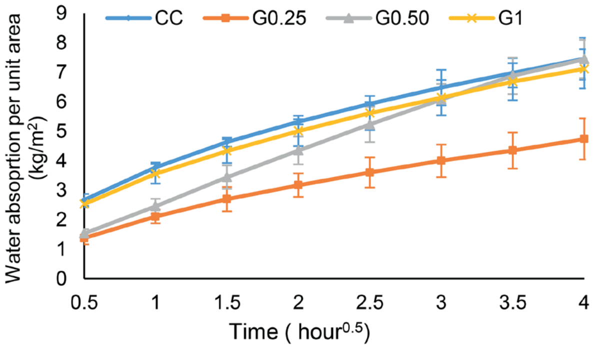

Fig. 8 Capillary water absorption value of 0.7 fc stressed concrete specimens

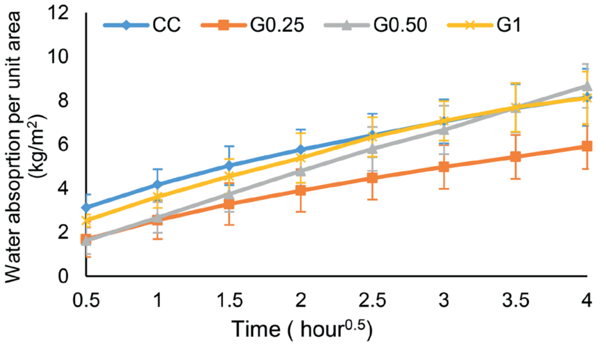

Fig. 9 Capillary water absorption value of 0.9 fc stressed concrete specimens

Capillary water absorption tests revealed that G0.25 had the lowest water absorption at all stress levels. Parallel to the water absorption test results, 0.25% glass fiber was identified as the optimum ratio for capillary water absorption. However, the use of glass fiber at higher rates was also found to have a positive effect on loaded samples. Thus, it has been demonstrated that glass fibers not only provide mechanical strength by bridging cracks but also reduce these capillary cracks. In general, fibers exhibit unfavorable results in experiments based on absorption or permeability due to voiding problems. However, it was observed that the situation was reversed when exposed to damage. While glass fibers increased the capillary water absorption rates in undamaged samples, as the damage levels increased, the absorption also decreased thanks to their crack-prevention capabilities.

3.5 Acid effect

The acid effect was first clearly visible on the surface of the samples. Fig. 10 shows the concrete sample removed from the acid solution. The acid solution significantly damaged the exterior surfaces of the concrete.

Weight losses were determined to identify the rate of this destruction. Weight loss ratios of the samples taken out of the acid solution are presented in Fig. 11. The greatest weight losses were observed in CC samples. The acid solution leaking from the cracks penetrated the internal structure of the concrete and caused it to dissolve. Therefore, weight loss increased while stress levels increased. Thanks to the acid resilience of glass fibers, GFRC has lower acid-related weight losses [21]. With increasing glass fiber ratios, unstressed samples observed gradually decreasing weight losses. All glass fiber-containing series demonstrated lower weight losses in stressed samples than in CC samples. G0.5 samples had the lowest weight loss at both stress levels (0.7 fc and 0.9 fc) of the glass fiber-containing

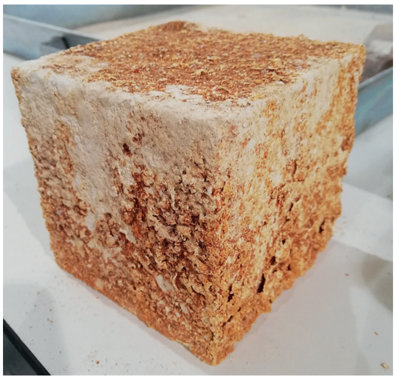

Fig. 10 Acid effect on cubic concrete specimens

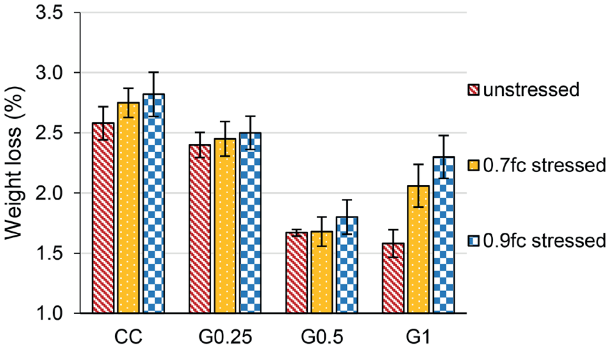

Fig. 11 Weight loss ratios of specimens after acid effect

series. Based on the weight losses of the acid effect test, 0.50 percent glass fiber by volume was determined to be the optimum value in terms of its contribution to the prevention of voids and cracks in concrete.

Since glass fibers do not dissolve in acid, higher values were observed in compressive strengths as well as weight losses by keeping the concrete pieces together. Compressive strength values of concrete samples exposed to acid are provided in Table 3. The G0.25 series has the maximum compressive strength in unstressed samples, followed by CC samples. When compared to CC samples, the influence of glass fiber resulted in a 7.63% increase in compressive strength. When 0.7 fc stress was applied, however, severe reductions in CC samples were observed, while reductions in the other glass fiber-containing samples were minimal. In CC samples, the compressive strength was 25.71 MPa, but in the G0.25 series, it was 31.59 MPa. In this approach, the influence of glass fiber resulted in a 22.87% increase in compressive strength in 0.7 fc stress applied to loaded samples. On the other hand, in 0.9 fc stress-loaded samples, the CC series had only 17.40 MPa of compressive strength, while the G0.25 series had 31.66 MPa. Thus, the use of glass fiber increased compressive strength by 82%. Such a value is of great importance for a structure that will be exposed to acid. Also, when compared to CC samples, the G0.5 series had a 55% higher compressive strength and the G1 series had a 54% higher compressive strength.

Besides, glass fiber reinforced concrete samples had higher compressive strength and also better preserved 28-day compressive strength values in Fig. 2. In Fig. 12, the percentages of losses compressive strength by acid effect from their 28-day strength are presented. The rate of compressive strength loss in CC samples increased dramatically as the loading level increased. On the other hand, stress-induced compressive strength losses were minor in glass fiber-containing samples. At 0.9 fc loading, the CC samples with the lowest compressive strength lost nearly 58% of their 28-day compressive strength. The G0.25 samples with the highest compressive strength lost just 26% of their initial compressive strength. As a result, while glass fiber-reinforced concrete had greater compressive strength values, it also conserved its current compressive strength at a considerably higher percentage.

Table 3 Compressive strength of concrete samples after acid effect (MPa)

Sample name	Unstressed	0.7 fc stressed	0.9 fc stressed
CC	30.25	25.71	17.40
G0.25	32.56	31.59	31.66
G0.50	28.54	27.59	26.93
G1	28.22	26.90	26.88

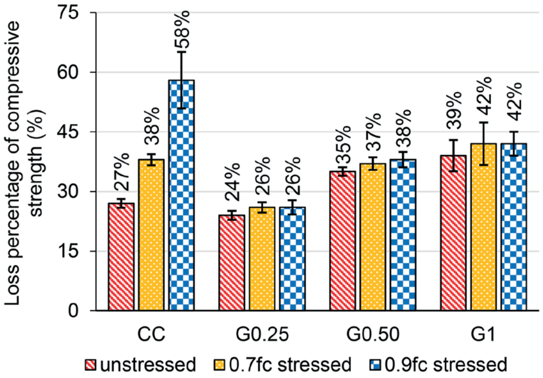

Fig. 12 Acid effect-induced losses in compressive strengths of the specimens

The chemical resistance of glass fiber is principally responsible for the favorable benefits of glass fiber on acid resistance. Because the glass fiber did not dissolve in the acid, it was able to keep the concrete together. As a result of minimizing acid penetration into the concrete, reduced weight loss and increased compressive strength values were observed. Nonetheless, in unstressed samples, glass fibers were less affected by acid attacks in parallel with previous studies [33–35]. However, in this study, it was determined that the contribution of glass fibers was much higher in damaged samples. As the damage rate increased, the durability protection provided by the glass fiber against acid was determined in the compressive strength values. Thus, the presence of glass fibers in concrete was found to be important, especially in damaged samples.

3.6 High-temperature effect

Glass fibers are the ones that are resistant to high temperatures among the fiber types. High-temperature experiments were carried out to determine its impact on damaged samples [36]. Firstly, The UPV values of 28-day samples were determined after they had been exposed to

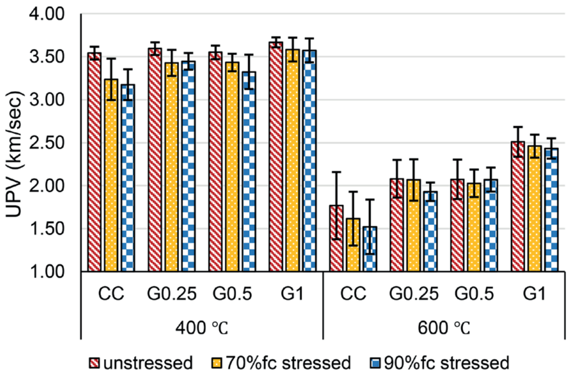

Fig. 13 UPV results of concrete specimens exposed to 400 °C and 600 °C temperatures

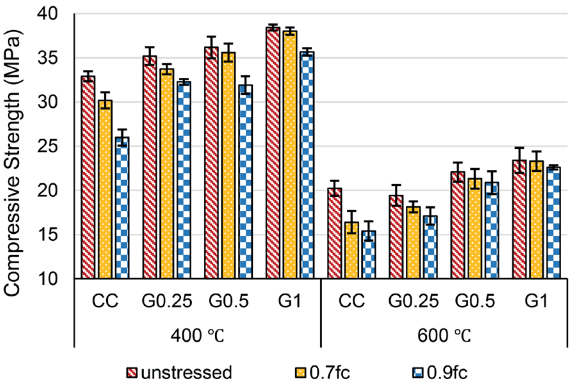

Fig. 14 Compressive strength of concrete specimens exposed to 400 °C and 600 °C temperatures

two different temperatures (400 °C and 600 °C). Fig. 13 presents the results of all UPV tests. As with increased stress levels, UPV values decreased in all samples. G1 samples yielded the highest values at both temperatures, while CC samples had the lowest results. As the load level increased, CC had significant decreases, whereas the glass fiber-containing series showed more minimal declines. When the temperature was increased from 400 to 600 °C, the UPV values of the CC samples were reduced by half. At both temperatures, higher values were obtained in glass fiber-containing samples. UPV values increased while glass fiber ratios increased. Thus, the glass fibers demonstrated their anti-crack properties against loading and high temperatures.

Following the UPV test, the compressive strengths of concrete samples exposed to high temperatures were determined, and the results are presented in Fig. 14. Parallel to UPV values, the G1 series had the highest compressive strength values at all stress levels and both temperature levels. Compressive strength values increased when increasing glass fiber ratios. In all samples, lower values were obtained as the stress load level increased, but the decrease rates were much higher in CC samples than in all other G series. At 400 °C, the lowest compressive strength value was measured as 25.97 MPa in CC samples and 35.66 MPa in G1 samples. Thus, glass fiber reinforcement increased compressive strength by 37.31% at 400 °C. When the samples were heated up to 600 °C, there were remarkable decreases in compressive strength values. At 0.9 fc stress loading at this temperature, the CC and G1 series had compressive strength values of 15.4 MPa and 22.6 MPa, respectively. Thus, G1 is 46% greater than CC samples.

The present findings are consistent with the results of previous studies reporting that the compressive strength of concrete exposed to high temperatures increases with increasing fiber reinforcement ratios [5]. Glass fiber prevents the strength loss of concrete by preventing heat-induced stresses [37, 38]. In addition, it was determined that the glass fiber effect increased even more in the samples exposed to stress before being exposed to the temperature effect. Because the fibers preserved the integrity of the concrete against stress load and prevented the high temperature from entering the internal structure and disrupting the concrete. As a result, they were able to demonstrate higher compressive strength as the fiber ratio increased.

4 Conclusions

In this study, GFRC was produced using various proportions of glass fibers. Then, these samples were damaged by loading two different levels of compressive stress. Residual durability properties were investigated by conducting experiments on these damaged samples. The conclusions are described below:

1. As the glass fiber ratio increased, compression strength results also increased in undamaged samples. In addition, while the water absorption values were the lowest in the G0.25 series, the use of glass fiber above this ratio increased the water absorption.
2. The response of glass fibers to stress was measured by UPV tests before and after compressive loading. As the loaded compressive stress level increases, dramatic decreases are observed in CC samples, while it is much less in glass fiber-reinforced samples. Thus, glass fiber reduced stress-induced concrete damage, resulting in less segregation and cracks, which improved concrete integrity.
3. The effect of crack prevention behavior against loading was observed in capillary water absorption tests. While more water was absorbed in high glass fiber ratios in undamaged samples, even less water

absorption was detected after loading than in the control sample. Thus, despite the voids they create, high-rate glass fibers have been found to reduce capillary water absorption after load damage.

4. This behavior, which reduces absorption, was also detected in the acid attack tests. Concrete samples lost weight and compressive strength due to more acid entering through cracks formed after loading damage. As the compressive loadings increased, the CC samples' weight loss and compressive strength were affected dramatically. However, owing to acid resistance, glass fiber reinforced concrete had 22.87% and 82% higher compressive strengths at 70 percent and 90 percent load levels, respectively. Besides high compressive strengths, G0.25 and the other glass fiber-containing series preserved their 28-day compressive strength much higher against acid effects. While the CC series lost 58% of its 28-day compressive strength, G0.25 lost only 26%.
5. In high-temperature experiments, the resistance of glass fibers to high temperatures was also observed in undamaged samples, but the main effect was observed in damaged concrete. While CC samples were severely damaged at both load levels, glass fiber-reinforced concrete samples preserved their compressive strength to a large extent at both temperatures. Under the most adverse conditions (600 °C and 0.9 fc stress loaded), the CC sample had a compressive strength of 15.40 MPa, while G1 had a compressive strength of 22.6 MPa, which was 46.75 percent higher than the CC sample.

According to the findings of this study, compressive stress loads at various levels severely damage the durability properties of concrete. These damages have been observed to be largely prevented due to the superior durability properties of glass fiber. In further studies, a hybrid system could be generated by adding different fibers to glass fibers at different stress levels, and the durability properties of the concrete could further be improved.

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