Mechanics of Advanced Composite Structures 5 (2018) 103 – 113

Semnan University

Mechanics of Advanced Composite Structures

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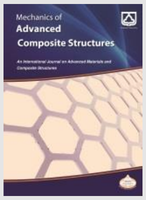

Experimental investigation of the strength of glass fiber-reinforced concrete exposed to high temperature

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PAPER INFO

Paper history:
Received 2017-03-13
Received in revised form
2017-11-13
Accepted 2018-03-04

Keywords:
High temperature
Glass fiber
Concrete
Experimental investigation

ABSTRACT

This study investigated the effects of high temperature exposure on the compressive, tensile, and flexural strengths of concrete containing glass fiber. A total of 108 cubic specimens (150 mm × 150 mm × 150 mm), cylindrical specimens (300 mm × 150 mm), and prismatic specimens (500 mm × 150 mm × 150 mm) were prepared for compressive, tensile, and flexural strength testing, respectively. The specimens were incorporated with 1%, 2%, and 3% glass fiber and cured for 28 days to derive the desired strengths. The specimens were then annealed and subjected to experiments in which they were exposed to high temperature (600°C) for 30 minutes, one hour, and two hours. The specimens were cooled via slow cooling (exposure to air) and fast cooling (water spraying immediately after exposure to heat). Results showed that the presence of glass fiber exerted different effects on specimen strength and that heat caused the formation of numerous cracks in the specimens.

1. Introduction

Nowadays, the use of fibers to enhance the performance of steel structures [1–8] and concrete [9, 14] is being considerably developed. Fiber incorporation into concrete has improved many of concrete's properties, including its compressive strength, and has eased its preparation and fabrication. However, studies have provided mixed findings regarding temperature tolerance, with some assuming that concrete is resistant to high temperatures and others asserting concrete's vulnerability under such conditions. Several studies investigated the remaining capacity of reinforced high-strength concrete [15, 16], reinforced concrete frames [17], reinforced concrete walls [18], reinforced concrete slabs [19], and steel members filled with concrete [20] after exposure to high temperatures. The findings showed that concrete is non-resistant to high temperatures as such conditions reduce the remaining strength of the material. Demirel and Kelestemur [21] explored the temperature resistance of pumice-microsilica and pumice-reinforced concrete samples that were exposed to temperatures of 400°C to 800°C and slowly cooled. The authors found that unlike exposure to room temperature, exposure to 400°C increases the compressive strength of concrete. Beyond this temperature, however, compressive strength declines. This decline is also more significant in concrete containing pumice and microsilica than in concrete comprising pumice alone.

Yang et al. [22] reported that an increased duration of exposure to high temperatures (the curing of air-heated samples) does not contribute to the improvement of compressive pressure. In a study of the mechanical properties of highly resistant concrete samples exposed to heat, Gyu-Yong et al. [23] observed slight increases in compressive strength at 100°C to 400°C but detected a considerable decrease at 400°C to 700°C.

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DOI: 10.22075/MACS.2018.1264.1056

At 100°C to 300°C, the elasticity module of the samples moderately declines and then decreases by half at 700°C.

Bastami et al. [24] probed into the effects of temperature on the compressive strength, spalling, and mass loss of high-strength concrete. The authors indicated that increasing the water-to-binder ratio at room temperature reduces the compressive strength of high-strength concrete. By contrast, increasing such ratio under heating conditions increases the relative compressive strength of the material. The authors also discovered that the concentration of fine aggregates provides the highest contribution to the compressive strength and reduction in spalling ratio of high-strength concrete.

Nadeem et al. [25] examined the compressive strength of concrete samples exposed to high temperatures under two conditions: fast cooling with water and slow cooling with airflow. The findings indicated that fast cooling causes thermal shock in concrete layers, thereby considerably reducing strength to levels lower than those achieved during cooling via airflow. A loss in strength also occurs under both cooling systems at above 400°C.

Behnood and Ghandehari [26] studied concrete samples that were incorporated with polypropylene fiber and exposed to high temperatures. As reported by the authors, compressive strength rises at 200°C but decreases at other temperatures. This reduction is associated with the melting of the polypropylene fiber and the formation of blank spaces at all the temperature conditions implemented in the experiments. A comparison of compressive and tensile strengths under exposure to heat showed that the latter is more sensitive to temperature. Finally, the presence of polypropylene fiber improves compressive pressure.

Dugenci et al. [27] scrutinized the compressive strength of steel fiber-reinforced concrete samples that were exposed to temperatures of 900°C, 1000°C, 1100°C, and 1200°C and then cooled slowly through exposure to air. The control samples exhibit the highest rate of decline in compressive strength. At temperatures above 1000°C, the presence of steel fiber minimally affects compressive strength, which contrasts with its substantial effects at 900°C and 1000°C.

Kamal et al. [28] delved into the effects of steel and polypropylene fibers on the fresh and hardened mechanical properties of self-compacting concrete, including its compressive, flexural, and impact strengths. The results showed that the optimum concentrations of steel and polypropylene fibers are 0.75% and 1.0% of cement content, respectively.

Al-Qadi and Al-Zaidyeen [29] inquired into the effects of specimen shape on the residual mechanical properties of polypropylene fiber-reinforced self-compacting concrete exposed to high temperatures (from 200°C to 600°C). The authors indicated that the thermal shock induced by air cooling causes greater losses in compressive strength in cylindrical concrete samples than in cubic samples. Additionally, polypropylene fiber can increase the residual strength and fracture energy of concrete subjected to thermal shock from air cooling at room temperature up to 600°C.

Zhu et al. [30] experimentally investigated the effects of organic modified polypropylene fiber on the compressive strength of concrete specimens aged seven and 28 days. The results demonstrated that at seven days, the concrete combined with organic modified polypropylene fiber has a significantly lower compressive strength than that exhibited by plain concrete—a condition that remains at day 28. The peak value of the concrete's flexural strength when it is combined with organic modified polypropylene fiber is lower than that of plain concrete; such strength corresponds with the compressive strength of the material. Finally, the organic modified polypropylene fiber significantly increases toughness, especially the residual flexural strength of the concrete specimens.

Tassew et al. [31] probed into the effects of chopped glass fibers on the mechanical and rheological properties of ceramic concrete produced using a phosphate cement binder. The researchers investigated two ceramic concrete matrices, namely, one containing sand and another containing lightweight expanded clay aggregates. They also examined fiber volume fractions between 0% and 2% and found that the addition of glass fibers into ceramic concrete minimally influences the material's compressive strength and modulus of elasticity. The compression, flexure, and shear toughness of the material increase with rising fiber content, but its workability decreases. The authors demonstrated that it is possible to manufacture glass fiber-reinforced ceramic concrete with workability and mechanical properties that are suitable for application in building members.

As can be seen, considerable explorations have been devoted to the mechanical properties of concrete samples exposed to high temperatures. To the best of our knowledge, however, no independent research has been conducted to examine the strength of glass fiber-reinforced concrete subjected to high temperatures. The results of previous studies likewise reflected that no independent experimental research has been performed to illuminate the effects of increased duration (from 30 to 120 minutes) of high temperature exposure on the compressive, tensile, and flexural strengths of concrete containing glass fiber. The current study was aimed at filling these voids. To this end, cubic specimens (150 mm × 150 mm × 150 mm), cylindrical specimens (300 mm × 150 mm), and prismatic specimens (500 mm × 150 mm × 150 mm) were prepared by combining concrete with 1%, 2%, and 3% glass fiber. The specimens were then exposed to a temperature of 600°C for 30 minutes, one hour, and two hours to test their compressive, tensile, and flexural strengths. The specimens were then cooled under slow and fast modes, after which the effects of increased exposure were determined.

2. Materials

2.1. Cement

In this study, Portland cement of Type II (Qayen factory cement: the location of Qayen cement factory is in Qayen, the South Khorasan province, Iran) with a specific gravity of 3.15 g/cm^3 was used. The oxides of the materials of this cement were SiO_2, Al2O3, Fe_2O_3, CaO, MgO, and SO_3 which had the quantities of 21.5%, 4.92%, 4.31%, 63.4%, 1.3%, and 1.8%, respectively. The cementitious compounds of this cement were included C_3S, C_2S, and C_3A, and their quantities in the cement materials were 52.1%, 22.1%, and 5.8%, respectively. The material's weight loss at extreme temperatures (loss on ignition) was 1.7%.

2.2. Gravel and sand

Coarse aggregates, including granite crushed gravel, and fine aggregates containing river sand were employed. A grading test was performed according to the ASTM C136 standard. The largest nominal dimension of the aggregates and the fineness module of sand were 12.5 and 3.54 mm, respectively. The ASTM C566 standard was used as reference in determining the relative moisture content of the aggregates. The specific gravity and water absorption of the coarse and fine aggregates were calculated on the basis of the ASTM C127 and ASTM C128 standards, respectively. The bulk density and sand equivalence of the aggregates were determined using ASTM C29 and ASTM D2419, respectively. The specific gravity, water absorption, and bulk density of gravel were 2693 kg/m^3, 0.8%, and 1575 kg/m^3, respectively. The specific gravity, water absorption, relative moisture content, and sand equivalence of sand were 2650 kg/m^3, 2.2%, 9.3%, and 78, respectively.

2.3. Super plasticizer

As recommended in ASTM C494, sulfonate melamine formaldehyde was used as the super plasticizer. It had a specific gravity of 17.1 g/m^3, a pH of 8 to 9, and a bright brown color.

2.4. Glass fiber

E-glass chopped strand glass fiber was used as the reinforcing material for the concrete specimens. The length, diameter, specific gravity, elasticity module, tensile strength, and fracture strain of the glass fiber were 12 mm, 0.013 mm, 2.6 g/m^3, 80 GPa, 2000 MPa, and 2% to 3.5%, respectively. Its SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, B_2O_3, Na_2O, K_2O, and Li_2O concentrations were 54.2%, 14%, 0.4%, 13.8%, 4.6%, 10.6%, 0.8%, 0.8%, and 0.8%, respectively.

3. Experiments

3.1. Design and preparation of concrete mixtures

The concrete slump was set at 8 to 10 cm, following the ASTM C143 recommendation. The ratios of water to concrete and gravel to sand were 0.45:1.0 and 0.82:1.0, respectively, and the concentrations of glass fiber in the concrete mixtures were 1%, 2%, and 3%. When the fiber was incorporated into the concrete specimens, the workability of concrete sharply decreased. This problem was solved through the use of the super plasticizer. According to the manufacturer's instructions and the trial-and-error method, the super plasticizer added to the specimens was 0.6% of cement weight.

3.2. Molding and curing of concrete specimens

To increase the accuracy of the results, three samples were tested in each category. Cubic molds with dimensions of 150 mm × 150 mm × 150 mm were used to fabricate concrete specimens for compressive strength testing. On the basis of BS 1881-108, the concrete mixture was poured into the molds in three layers, which were each compacted using 35 hits. Cylindrical molds with dimensions of 300 mm × 150 mm were used to fabricate concrete specimens for tensile strength testing, and prismatic molds with dimensions of 500 mm × 150 mm × 150 mm were used to fabricate concrete specimens for flexural strength testing. After the fresh concrete specimens were molded, they were covered with a wet sack and a nylon sheet to prevent drying. After 24 hours, the concrete molds were carefully transferred to a 25±2°C water pool for 28 days of curing.

3.3. Heating process

Following the 28-day curing, the specimens were heated in a furnace whose temperature was increased at increments of 3.8°C per minute. The temperature was then kept constant at 600°C. Subsequently, the specimens were exposed to heat for 30 minutes, one hour, and two hours. At the end of each of these periods, the furnace was switched off and opened to slowly cool off some of the specimens. The rest, first, were taken out of the furnace, and then, water was sprayed on them for 20 minutes (for rapid cooling). Twenty-four hours after heating, all the specimens were transferred to a laboratory for the strength tests.

3.4. Compressive strength test

The average compressive strength of the cubic specimens was recorded; after which they were labeled in accordance with the concentrations of glass fiber in them. Thus, a GF0 specimen (control) is one that contains no glass fiber, a GF1 specimen has 1% glass fiber, and so on. The compressive strength testing of the cubic specimens was based on BS 1881-116:1983. Loading speed ranges from 0.2 to 0.4 MPa/second, out of which a speed of 0.3 MPa/second was chosen as the parameter for testing 27 glass fiber-reinforced cubic specimens (nine each from the GF1, GF2, and GF3 groups) and nine GF0 specimens.

3.5. Tensile strength test

The average tensile strength of the specimens was documented; after which they were labeled in the same manner done for the cubic specimens. The tensile strength test of the cylindrical specimens was based on ASTM C496. Loading speed ranges from 0.7 to 1.4 MPa/minute, out of which 0.9 MPa/minute was chosen as the condition for testing 27 cylindrical specimens containing 1%, 2%, and 3% glass fiber and nine specimens containing no glass fiber.

3.6. Flexural strength test

The average flexural strength of the specimens was recorded, after which they were labeled in the same manner done for the cubic and cylindrical specimens. The flexural strength test of the prismatic specimens was carried out on the basis of ASTM C293, with loading imposed on the middle span of the specimens. Loading speed ranges from 0.9 to 1.2 MPa/minute, so the test was loaded at a constant speed of 0.9 MPa/minute for 27 prismatic specimens containing 1%, 2%, and 3% glass fiber and nine specimens containing no glass fiber. Figs. 1a to 1c illustrate the compressive, tensile, and flexural testing and the devices used in tests.

4. Results and discussion

As previously stated, no independent experimental research has been conducted to investigate the effects of increased duration of exposure (up to 120 minutes) to high temperatures on the compressive, tensile, and flexural strengths of concrete containing glass fiber. Accordingly, the current study addressed this deficiency to bridge the knowledge gap in this field.

4.1. Compressive strength

4.1.1. Compressive strength under slow cooling

A total of 27 GF1, GF2, and GF3 cubic specimens and nine GF0 specimens were exposed to a temperature of 600°C for 30 minutes, one hour, and two hours and then subjected to slow cooling. As Fig. 2 shows, increasing the duration of heating decreased the compressive strength of the slowly cooled specimens. The GF3 specimens exhibited the lowest compressive strength at a heat exposure lasting 30 minutes. The lowest compressive strength of the control specimens was obtained at a heat exposure of two hours. The GF1 specimens had the highest remaining compressive strength at all the heating durations.

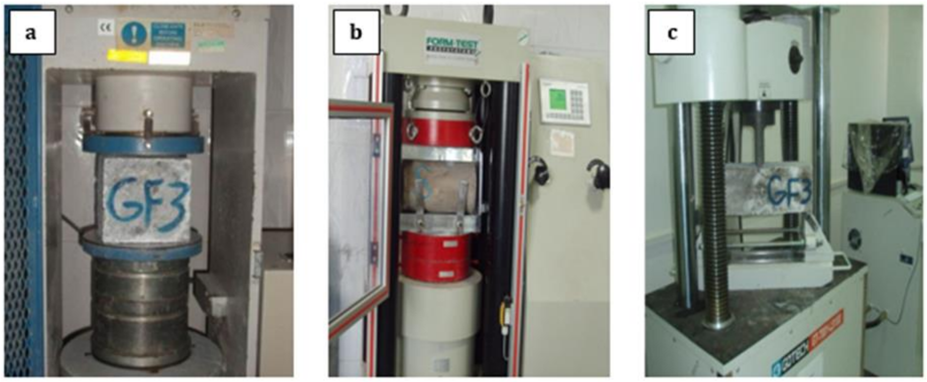

Figure 1. Hydraulic jack for determining specimen strength: (a) Compressive test, (b) tensile test, (c) flexural test.

The results also indicated that the reduction in compressive strength was higher in the control specimens than in the other samples at all the heating durations. The findings further reflected that the GF2 and GF1 specimens had the lowest reductions in compressive strength at exposures of 30 minutes and two hours, respectively. The reductions in compressive strength in the control specimens amounted to 15.76%, 27.99%, and 37.77% at 30 minutes, one hour, and two hours of exposure, respectively. Nine cubic specimens incorporated with glass fiber (three each of GF1, GF2, and GF3) and three GF0 specimens were tested at laboratory temperatures. The results showed that adding glass fiber to concrete did not contribute to the improvement of compressive strength under these temperatures (Fig. 2). Adding 1% glass fiber to concrete increased compressive strength by only 1.06%, but adding 2% and 3% glass fiber to concrete decreased compressive strength by 9.24% and 13.51%, respectively.

Because an average value of specimen strength was calculated, a necessary step was to check the standard deviation of the data. Standard deviation is an indicator of data distribution. The standard deviation of the results of compressive testing at high temperature and slow cooling was 0.11 to 0.36, and the standard deviation of the results of testing at laboratory temperatures was 0.08 to 0.24.

4.1.2. Compressive strength under fast cooling

A total of 27 cubic GF1, GF2, and GF3 specimens and nine GF0 specimens were exposed to a temperature of 600°C for 30 minutes, one hour, and two hours and then subjected to fast cooling. Increasing heating time decreased the compressive strength of the specimens (Fig. 3).

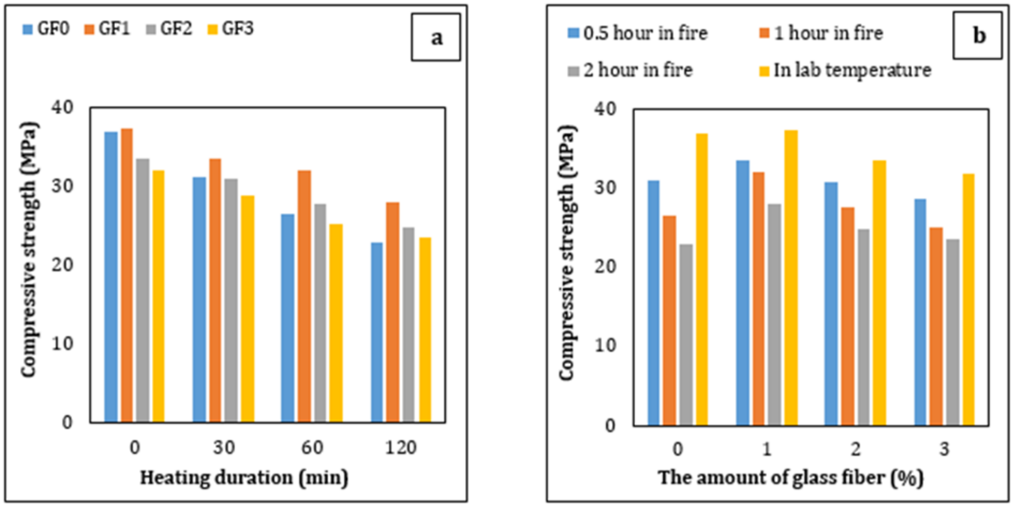

Figure 2. Slow cooling of cubic specimens: Curves of (a) compressive strength–heating duration, (b) compressive strength–fiber concentration.

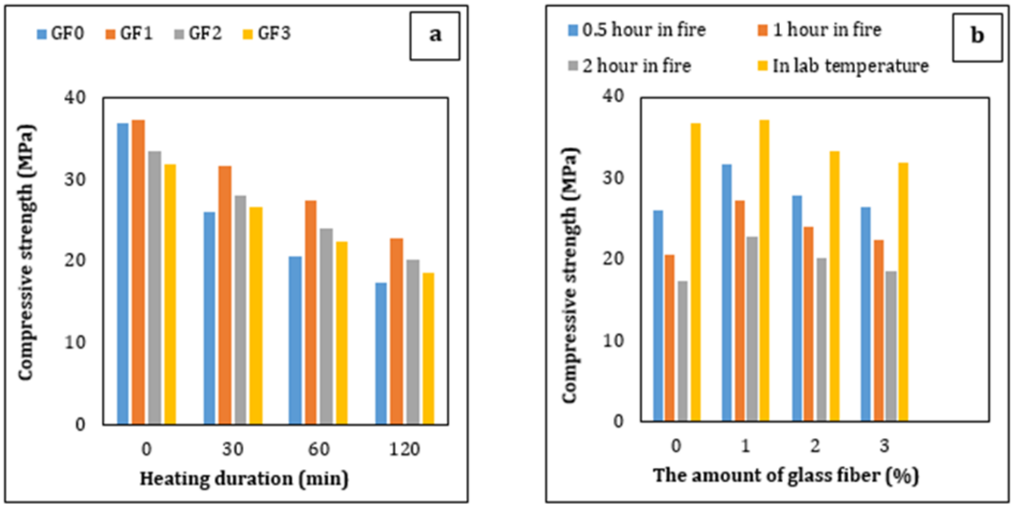

Figure 3. Fast cooling of cubic specimens: Curves of (a) compressive strength–heating duration, (b) compressive strength–fiber concentration.

The lowest compressive strength and the highest reduction in such strength occurred in the control specimens, whereas the highest remaining compressive strength and the lowest reduction in such strength were observed in the GF1 specimens. The compressive strength of the control specimens at 30 minutes, one hour, and two hours of exposure decreased by 29.16%, 44.29%, and 52.72%, respectively. The reductions in the GFI specimens were 14.76%, 26.59%, and 38.69%, respectively. The standard deviation of the results of compressive testing at high temperature and fast cooling was 0.12 to 0.42.

Figs. 2 and 3 indicate that all the slowly cooled specimens exhibited a higher remaining compressive strength and a lower reduction in compressive strength than did the rapidly cooled specimens. The specimens containing 1% glass fiber had a compressive strength superior to that of all the other specimens. The strength of the specimens heated at 30 minutes, one hour, and two hours, which were slowly cooled, decreased by 10.19%, 14.22%, and 24.71%, and the strength of the heated specimens, which were rapidly cooled, decreased by 14.76%, 26.59%, and 38.69% (at exposures lasting 30 minutes, one hour, and two hours), respectively. The differences in strength reductions is due to the variances in heating between internal and external layers and the expansion of lime existing in the concrete specimens as they were cooled.

Many cracks were observed in all the specimens after heating and cooling, but they occurred primarily in the samples cooled with water. Fig. 4 shows the cracks in the specimens.

4.2. Tensile strength

4.2.1. Tensile strength under slow cooling

A total of 27 cylindrical specimens containing 1%, 2%, and 3% glass fiber and nine specimens comprising no glass fiber were exposed to a temperature of 600°C for 30 minutes, one hour, and two hours. The specimens were then slowly cooled. Increasing heating time decreased the tensile strength of the slowly cooled concrete (Fig. 5). The control specimens achieved the lowest tensile strength at heating for 30 minutes, one hour, and two hours. The specimens containing 1% glass fiber had the highest tensile strength across all the heating durations. The reduction in tensile strength was higher at one and two hours of heating for the control samples and at 30 minutes of heating for the samples reinforced with 1% glass fiber. The specimens containing 2% glass fiber exhibited the lowest reduction in tensile strength reduction across the three exposure periods. The tensile strength of the control specimens decreased by 25.63%, 33.94%, and 43.68%, and the tensile strength of the specimens containing 1% glass fiber decreased by 17.48%, 22.01%, and 27.51% at 30 minutes, one hour, and two hours of temperature exposure, respectively. Nine cylindrical specimens containing 1%, 2%, and 3% glass fiber and three specimens containing no glass fiber were tested at laboratory temperatures. Fig. 5 indicates that at laboratory temperatures, adding glass fiber to the concrete specimens improved tensile strength to levels higher than those observed in the control specimens. Specifically, incorporating 1%, 2%, and 3% glass fiber to concrete increased its tensile strength by 11.55%, 6.5%, and 3.61% over the strength of the controls. Note that adding more than 1% glass fiber to concrete decreased tensile strength, although the obtained value was still higher than that of the control specimens.

Figure 4. Cracks resulting from heating.

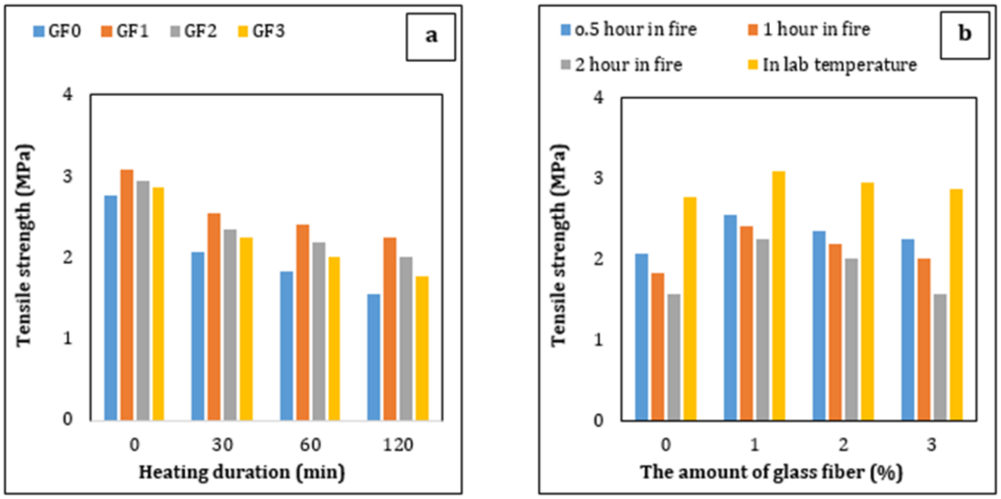

Figure 5. Slow cooling of cylindrical specimens: Curves of (a) tensile strength–heating duration, (b) tensile strength–fiber concentration.

The standard deviation of the results of tensile testing at high temperature and slow cooling was 0.10 to 0.30, and the standard deviation of the results of testing at laboratory temperatures was 0.09 to 0.24.

4.2.2. Tensile strength under fast cooling

A total of 27 cylindrical specimens containing 1%, 2%, and 3% glass fiber and nine specimens comprising no glass fiber were exposed to a temperature of 600°C for 30 minutes, one hour, and two hours and then subjected to fast cooling. Increasing heating time decreased the tensile strength of the rapidly cooled concrete specimens (Fi. 6). During all the heating times, the lowest tensile strength was observed in the controls, and the highest was observed in the specimens containing 1% glass fiber. The control specimens underwent the highest reduction in tensile strength at one and two hours of exposure, whereas the specimens containing 1% glass fiber achieved the highest reduction in tensile strength at 30 minutes of exposure. The tensile strength of the control specimens decreased by 31.41%, 40.43%, and 55.60%, and that of the specimens containing 1% glass fiber decreased by 28.80%, 35.28%, and 42.39% at 30 minutes, one hour, and two hours of exposure, respectively.

The standard deviation of the results of tensile strength testing at high temperature and fast cooling was 0.12 to 0.36.

4.3. Flexural strength

4.3.1. Flexural strength under slow cooling

A total of 27 prismatic GF1, GF2, and GF3 specimens and nine GF0 specimens were exposed to a temperature of 600°C for 30 minutes, one hour, and two hours and then subjected to slow cooling. Increasing heating time reduced the flexural strength of the slowly cooled concrete (Fig. 7).

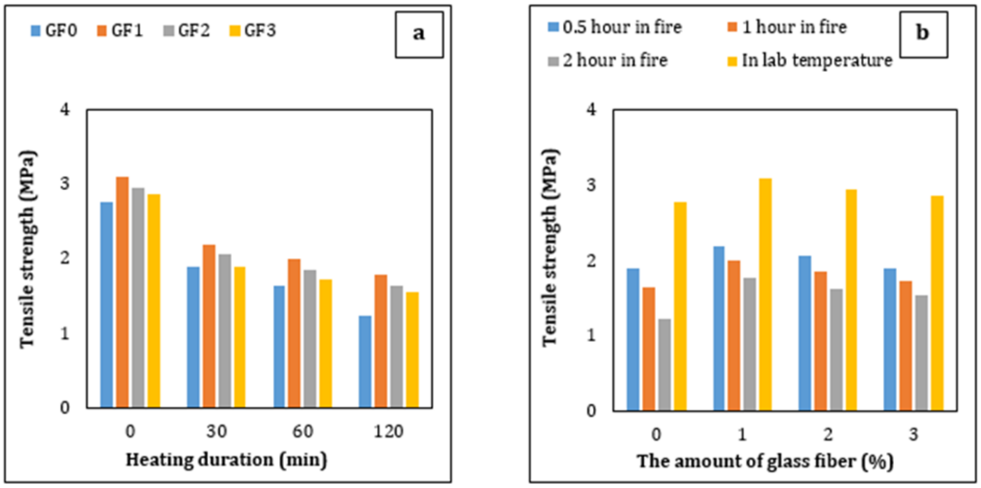

Figure 6. Fast cooling of cylindrical specimens: Curves of (a) tensile strength–heating duration, (b) tensile strength–fiber concentration.

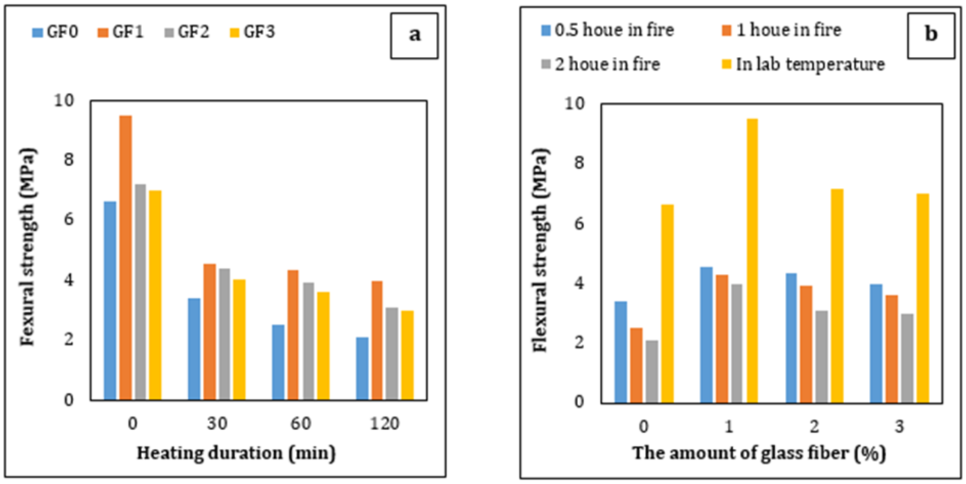

Figure 7. Slow cooling of prismatic specimens: Curves of (a) flexural strength–heating duration, (b) flexural strength–fiber concentration.

According to Fig. 7, at all the exposure durations, the control specimens exhibited the lowest flexural strength, whereas the GF1 specimens exhibited the highest. The results revealed that the reduction in flexural strength of the controls was higher at one and two hours of exposure and that of the GF1 specimens was higher at 30 minutes of exposure. The lowest reduction in flexural strength occurred in the GF2 specimens in all the exposure durations. Such reductions were 48.64%, 61.93%, and 68.28% in the controls and 39.36%, 45.48%, and 57.02% in GF2 at 30 minutes, one hour, and two hours, respectively. Nine prismatic GF1, GF2, and GF3 specimens and three prismatic GF0 specimens were tested at laboratory temperatures. Adding glass fiber to the concrete specimens improved the flexural strength to levels higher than that observed in the control specimens (Fig. 7). To be specific, incorporating 1%, 2%, and 3% glass fiber to the concrete specimens augmented their flexural strength by 43.66%, 8.61%, and 5.59% over the levels achieved in the control specimens, respectively. Note that adding more than 1% glass fiber to the concrete specimens decreased their flexural strength, although the obtained value was still higher than that achieved by the control specimens.

The standard deviation of the results of flexural testing at high temperature and slow cooling was 0.09 to 0.31, and that of the results of testing at laboratory temperatures was 0.10 to 0.26.

4.3.2. Flexural strength under fast cooling

A total of 27 prismatic G1, G2, and G3 specimens and nine GF0 specimens were exposed to a temperature of 600°C for 30 minutes, one hour, and two hours and then subjected to fast cooling. Increasing heating time resulted in diminished flexural strength among the rapidly cooled concrete specimens (Fig. 8). Across all the heating times, the lowest flexural strength was generated by the control specimens, whereas the highest was achieved by the GF1 specimens. The highest reduction in flexural strength occurred at one and two hours of exposure for the control specimens and at 30 minutes of exposure for the GF1 specimens. The flexural strength of the controls declined by 63.14% and 71.30% at one and two hours of exposure, respectively, whereas that of the GF1 specimens decreased by 61.83% at 30 minutes of exposure. The lowest reductions in flexural strength were 59.67%, achieved by the GF2 specimens at two hours of temperature exposure, and 49%, realized by the GF3 specimens at one hour of temperature exposure.

The standard deviation of the results of flexural testing at high temperature and fast cooling was 0.11 to 0.38.

4.4. Comparison of reductions in compressive, tensile, and flexural strengths

The results indicated a considerable reduction in the tensile and flexural strengths of the specimens, unlike their compressive strength, which declined only to a moderate degree. This finding is attributed to the numerous cracks that formed in all the specimens after temperature exposure for 30 minutes, one hour, and two hours and subsequent cooling. The cracks formed mainly in the specimens cooled with water. The emergence and development of new cracks decreased the resistance of the specimens, and they tended to close under pressure but open under tensile conditions. Finally, steam pressure and differences in temperature among the samples influenced the development of cracks and caused their transformation into micro and macro cracks (Fig. 4).

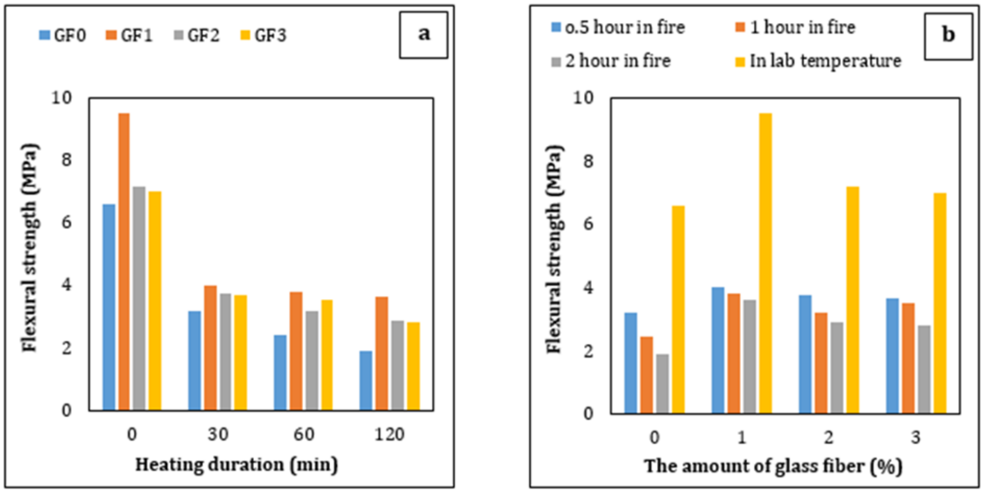

Figure 8. Fast cooling of prismatic specimens: Curves of (a) flexural strength–heating duration, (b) flexural strength–fiber concentration.

5. Conclusion

In this study, 1%, 2%, and 3% glass fiber was incorporated into concrete to prepare specimens for the investigation of the effects of high temperature on the compressive, tensile, and flexural strengths of glass fiber-reinforced concrete. The specimens were cooled quickly using water or slowly using airflow. The core test results are summarized as follows:

- The analysis of compressive strength at laboratory temperatures reflected the minor influence of glass fiber on improvements in compressive strength. However, glass fiber considerably affected tensile and flexural strengths, particularly in the specimens containing 1% glass fiber.
- Compressive strength decreased with increasing exposure. Slow cooling resulted in a reduction in compressive strength that was lower than that observed under fast cooling.
- With fast cooling, the remaining compressive strength of the control specimens substantially decreased. The specimens containing 1% glass fiber exhibited the highest remaining compressive strength and the lowest strength reduction.
- Slow cooling was less effective than fast cooling on tensile strength. Similarly, compressive and tensile strengths decreased with increasing exposure.
- The results indicated that the tensile and flexural strength of the specimens were more sensitive to both cooling methods (fast cooling and slow cooling) than the compressive strength. In fact, the cracks created in the heated concretes tremendously influenced in the decrease of the tensile and flexural strength of these concretes
- The control specimens had the lowest remaining tensile and flexural strengths, and the reduction in these variables was higher in the controls than in the glass fiber-reinforced samples.
- Glass fiber did not melts at 600°C, and despite its reduced characteristics with heating at this temperature, glass fiber remained effective in improving the tensile and flexural strengths of the concrete specimens.
- Fast cooling was inappropriate because it caused heating shock and markedly decreased strength. This problem requires a solution.
- Among all the specimens, those containing 1% glass fiber exhibited the best compressive, tensile, and flexural strengths.
- Incorporating glass fiber into concrete sharply decreased the concrete's workability. This issue was resolved using a super plasticizer.

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