ORIGINAL RESEARCH

Experimental study of fiber concrete slab behavior against high electric heat

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Abstract

Concrete structures may be exposed to high heat. In such a way that high heat in the vicinity of concrete structures causes damage in concrete. The aim of this study is assessment of effect of electric high heat on the bending capacity, energy absorption, fracture type and crack distribution of circular fiber concrete slab under monotonic loading. The concrete aggregates with a fracture percentage of 45% are from the mines around Tehran and the fibers used in the concrete are of macrosynthetic type. The concrete mixing design was based on the target compressive strength of 45 MPa and the amount of fibers equal to 0.5% of concrete volume. The heating of the concrete samples was done by a 2400-liter device with a power of 90 KW and maximum temperature of 550 degrees Celsius. To perform slab tests, Dartec9600 device was used with monotonic loading at a rate 0.004 mm/s. based on the Experimental studies conducted on the fiber concrete slab, the application of high heat did not cause concrete peeling but it reduced the capacity of the slab by 89.3% and decreased the energy absorption of the slab compared to the control sample. Also, SEM photos have shown the aggressive destruction of macrosynthetic fibers and the creation of cracks under the effect of high heat in fiber concrete.

Key words: Concrete Slab, Macrosynthetic Fiber, Electric Heat, Bending Capacity, Energy Absorption

1. Introduction

The primary objective of structural engineering across the world has been to protect structures against environmental elements, including high temperature, which is an environmental component that may harm people's lives and financial security. One technique of putting out a fire in a building is to use water, but as soon as the water reaches the heated part, a considerable temperature differential arises and causes damage (1). In addition to other variables like earthquakes, it may shorten the usable life of the structure. Heat produces a considerable reduction in concrete's strength, according to the findings, and it also generates small cracks in the material (2).

Temperatures in tunnels may rise quickly and stay high for a long period as a result of fires. The temperature in the majority of the recorded tunnel fires rose beyond 1000 degrees Celsius and persisted for days, mostly owing to the ineffective typical ventilation in them (3).The findings of the investigations conducted in the Plasco building demonstrate that the truss floor system would deflect at high temperatures. The severe main and out-of-plane bending of the beam-to-column sheets causes the floor to partially collapse in place. At roughly 650 degrees Celsius, it destroys this column (4).

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Generally speaking, aggregate and hydrated cement paste are the two main components of concrete. Concrete's distinctive behavior is influenced by the interactions between its component ingredients and their behavior (5). Along with improving the ductility, toughness, and strain of cement, the usage of various fiber kinds also significantly lowers shrinkage and heat fractures (6). Laboratory tests have shown that the fibers in mortar and concrete act as a bridge on the crack (7). In another research, punch shear failure occurred in damaged continuous slabs and also peeling concrete due to heat. The middle spans in continuous slab had shown a better performance in ductility due to the presence of the supports on the sides. (8) The durability of the structure against high heat is defined as one of the main factors of the building to withstand fire and protected it. The amount of damage caused by has a direct relationship with the mortar and the temperature created in it. (9)

The design rules' guidance on dealing with fire in concrete components is mostly based on a number of dated, irrational tests on individual sections and beams.(10) Research on the behavior and mechanical properties of geopolymer mortar after applying heat has shown that bending and tensile strengths have decreased at high temperature, but the bonding and compressive strengths have decreased less compared to normal concrete.(11) heat effect resistance tests on reinforced concrete slabs repaired with CFRP fibers have shown that when temperature in epoxy resin reaches the Tg value, the performance of the composite between CFRP fiber and concrete has started to disappear. also shown that the correct construction of a suitable system can increase the effective time of the CFRP reinforcement system to the reinforced concrete member during a heat. (12-13)

In the research, it has been shown that the use of CFRP fibers in beams has increased the bending stiffness by 30% (14), and using it as a double layer by about 70% (15), and these results have brought relatively good agreement with the numerical model. (16) On the other hand, The reinforced concrete slabs in the study on the assessment of fire resistance of unreinforced concrete slab system and reinforced with CFRP against fire shattered in a very short amount of time. (17) It has been shown that adding more concrete to slabs reinforced with CFRP rebars increases the thermal protection for the slab rebars but only marginally improves fire resistance. (18) The addition of polypropylene fiber to the slab concrete mix has prevented the concrete form segregation against heat and had been observed peeling of Concrete slabs with steel fibers and plain concrete slabs. (19) Tests in the pore pressure mode on reinforced concrete slabs with high performance and high temperatures reveal that the pace at which concrete slabs progressively warm up is not the sole factor that contributes to flaking as depth from the heated surface increases.(20) According to studies, the impact of high temperatures on geopolymeric concrete's resistance parameters has revealed that changes in the samples' weight, length, and compressive strength depend on the behavior of the nanostructures, which begins with the decomposition of C-A-S-H nanostructures under the influence of high heat. It has been seen that the weight and compressive strength both decrease, and the cracks also become larger. (21)

Based on previous research, heat can affect the performance and properties of various structural members such as slabs. In this experimental study, the behavior of fiber concrete slab a circular slab against high temperature has been investigated. fiber concrete slab made based on ASTM C1550, was heated at 550 degrees Celsius for 47 hours, with 24 hours of preheating at 80 degrees Celsius. After cooling and transfer to the laboratory, the slab was exposed to monotonic loading, and its behavior, including its bending and compressive capacities, energy absorption and The kind of failure of the slab in its unheated and heated states were examined and compared.

2. Experimental Procedure

In this research, circular samples have been used for the slab. For sampling, cubic samples with dimensions of 100 and 150 mm were used. After processing and determining the compressive strength, the slab has been subjected to monotonic test and its desired parameters have been extracted. The flowchart of the laboratory work, including the stage of making samples, curing samples and conducting experiments, was shown in figure 1, and the Materials physical properties, the plan of mixing and making samples, maintaining and curing sample and heating samples are given below.

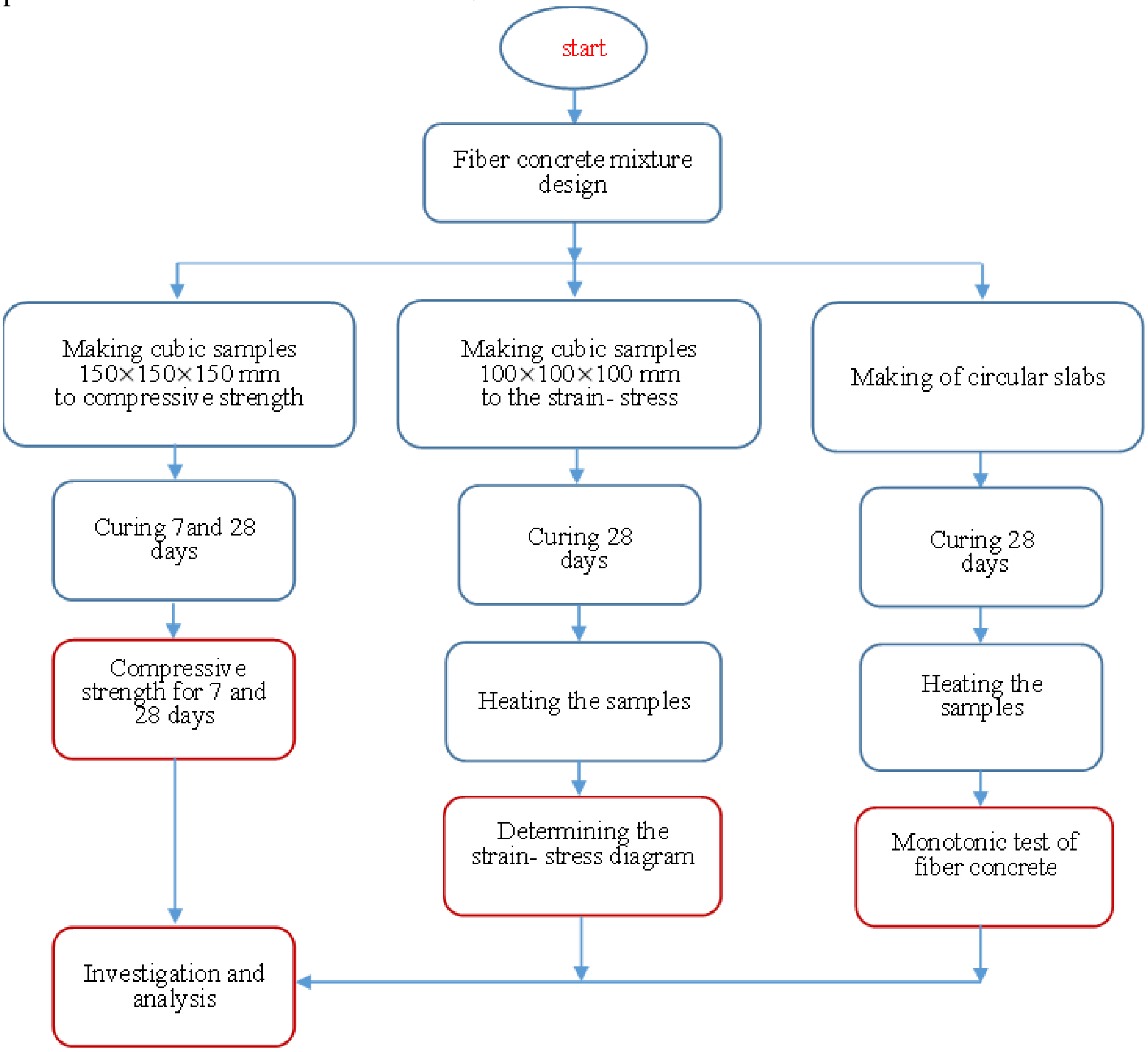


Figure 1: Flowchart of the laboratory

2.1. Materials Physical Properties

Cement, stone materials, water, macrosynthetic fibers, and super plasticizer ingredients in the amount of 0.5 percent of the weight of cement are used to create fiber concrete. The cement used was Portland type I, which was obtained from the Dilijan cement facility, and its specifications are shown in Table 1.

Table 1: Specifications of Portland cement

Type of cement	Specific gravity (kg/m^3)	Fineness (cm^2/kg)
Cement 425 –1	3090	3299000

The stone materials used to prepare concrete comes from a mine west of Tehran with a 45% fracture percentage. Tables 2 and 3 include the granulation requirements, specific weight, and percentages of moisture and softness.

The water used to obtain concrete is drinking water of Tehran and the third generation superplasticizer based on modified ether carboxylates with the brand name PS-10 was applied.

The macrosynthetic fibers indicated in figure 2 and the specifications given in table 5 were applied to reinforce the slab concrete.

Table 2: Granulation of Gravel and Sand

Size(mm)	19	12.5	9.5	4.75	2.38	1.19	0.6	0.3	0.15
Passing Percentage of Gravel	100	64	25.1	5.5	-	-	-	-	-
Passing Percentage of Sand	100	100	100	95.9	65.1	45.3	30.8	15	4.2
50% Sand and 50% Gravel	100	82	62.55	50.7	32.55	22.65	15.4	7.5	2.1
Authorized domain	100	75-90	62-84	38-70	23-56	14-43	8-31	4-20	2-10
Effective Percentage for Softness	-	-	37.45	49.3	67.45	77.35	84.6	92.5	97.9

Table 3: Specific gravity, percentage of moisture and softness of stone materials

Stone Materials	**Water absorption percentage**	**Moisture percentage**	**Special Weight Kg/m$^{3)}$(**	**Softness**
Gravel	1.9	0.942	2582	5.07
Sand	3.2	2.35	2536	3.4

Table 4: Specifications of superplasticizer

Chemical compounds	**Ionic nature**	**Color**	**physical state**	**density (kg/m^3)**	**chloride(ppm)**
Modified Copolymers of Poly-carboxylate acid	Ionic	light brown	Liquid	C°at 20 1090	Max 500

Table 5: Specifications of macrosynthetic fibers

Color	**Special Weight (Kg/m^3)**	**Shape**	**Tensile strength (MPa)**	**length (mm)**	**Ultimate strain (%)**
Gray	910	Monofilament and fiber	693	54	11.2

Figure 2: Macrosynthetic fibers

2.2. Specimen and Mixture Design

Using a compressive strength of 45 MPa, a fiber percentage of 0.5% of the volume of the concrete at a rate of 4.55 kg/m3, a water-cement ratio of 0.43, 179 Liters of free water, and a material rate of superplasticizer 0.5% of cement weight for a concrete equal to 2300 Kg/m^3 with the workability 120 mm with, concrete mixture design was developed. The characteristics and quantity of components employed in table 6 served as the design methodology for Iran's concrete mixture (22). Figure 3 illustrates the circular shape and geometric specifications of the fiber concrete slab are based on ASTM C1550 (23), which have dimensions of 750 mm in diameter and 75 mm in thickness.

Table 6: Specifications and amount of materials used for one cubic meter of fiber concrete

ROW	Type of material	Quantity (Kg)
1	Gravel	873
2	Sand	856
3	Cement	400
4	Water	179
5	Macrosynthetic fibers	4.55
6	Superplasticizer	2

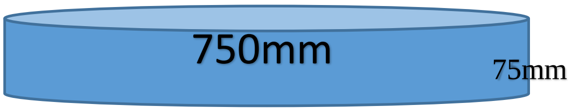


Figure 3: Schematic of geometric characteristics of circular fiber concrete slab

2.3. Preparing and Curing of Specimens

After molding, the 150 × 150 × 150 mm samples were maintained in a humid environment for 24 hours, and then the samples were taken out of the mold and located in water with a constant temperature of 20±1°C based on Figure 4 to reach their ultimate strengths. After the samples reached their ultimate strengths of 28 days, they were deleted from the water and subjected to compression and bending tests. Fiber concrete slab has been cured utilizing a sack and soaking with water for 28 days.

2.4. Electric Heating of Fiber Concrete Slab

2400-liter oven device of Noshirvani University of Technology, Babol, was applied to heat the fiber concrete samples. The present device has a power of 90 kW, and the samples were preheated for 24 hours at 80^{0}C.

Figure 4: Preparing and curing of fiber concrete samples

Then, it is heated up to 550 degrees Celsius. Figure 5 indicates the heating device and Figure 6 reveals the heating diagram of the fiber concrete samples.

Figure 5: 2400 liter oven device

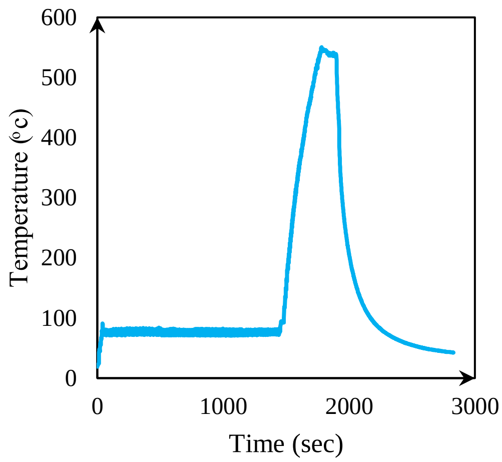


Figure 6: Heating diagram of fiber concrete samples

2.5. Bending Strength of Fiber Concrete Slab

To determine the bending strength of the fiber concrete slab, was used The Dartec9600 machine of Amirkabir University's rock mechanics Laboratory with a loading capacity of 100 tonnes. During the experiment, the computer will have access to it. The sensors on the moveable jaw measure the force-displacement information (upper jaw). The perspective of the loading device from above is shown in Figure 7. The monotonic mode of displacement control and a moving jaw displacement rate of 0.004 mm/s were used to load the circular fiber concrete slab. The circular fiber concrete slab's bending test based on standard ASTM C1550 is shown in Figure 8.

Figure 7: A view of Dartec9600 self-control loading device

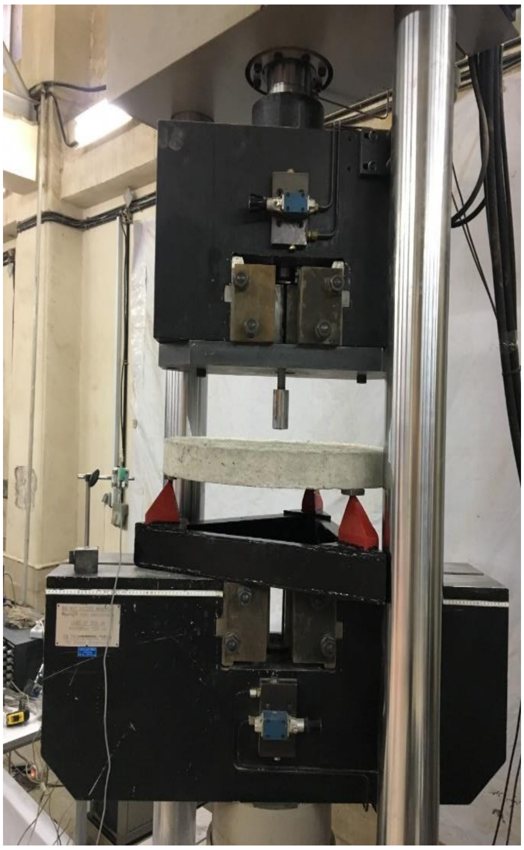


Figure 8: Bending test of circular fiber concrete slab

3. Results and discussion

The findings of compressive strength tests of samples of 150×150×150 mm fiber concrete for days 7 and 28 are given in table 7, and the stress-strain curves of fiber concrete in unheated and heated states and their comparison are indicated in figure 9.

The circular fiber concrete slabs in the unheated and heated situations were subjected to monotonic loading, and the parameters of the vertical displacement of the center of slab, the shape of the crack distribution and the values of the crack width during loading were studied. The findings of the tests are given in Tables 8 and 9 and Figures 10, 11 and 12.

Table 7: Compressive strength of fiber concrete (MPa)

ROW	Type of test	Sample dimensions (mm)	7 days	28 days
1	compressive strength	150×150×150	38.5	49.4

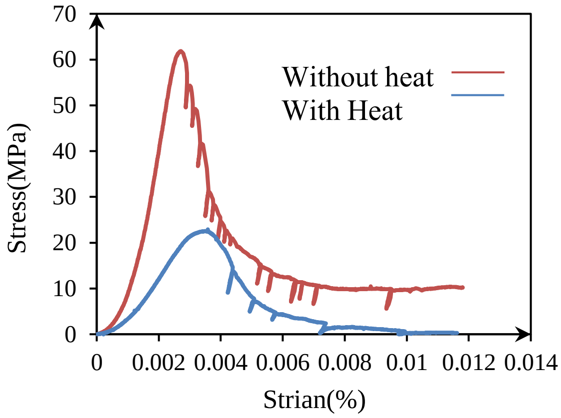


Figure 9: Comparison of stress-strain diagrams of unheated and heated cubic samples

Table 8: Values of time, force, displacement and crack width of circular fiber concrete slab in unheated condition

ROW	Force (KN)	Displacement (mm)	Time (s)	Crack Width (mm)
1	37.26	1	19	The beginning of crack
2	17.89	4	68	1
3	17.5	4.7	80	2
4	16.82	5.5	93	3
5	15.56	6.5	110	4.5
6	14.27	7.5	127	5.5
7	13.6	8	136	7
8	12.43	9	152	8
9	10.78	10	169	9
10	9.35	11	186	10.5
11	8.6	12	202	12
12	7.69	13	219	14

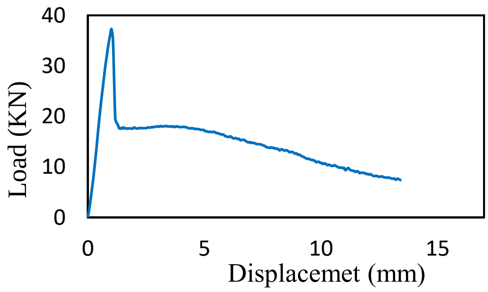


Figure 10: Diagram of force- Displacement of circular fiber concrete slab in unheated state

Table 9: Values of time, force, displacement and crack width of circular fiber concrete slab in heated state at 550⁰C

ROW	Force (KN)	Displacement (mm)	Time (s)	Crack Width (mm)
1	3.97	1.16	288	The beginning of crack
2	1.85	3	755	1
3	1.33	4	994	2
4	0.59	5	1245	2.5
5	0.44	6	1498	3
6	0.16	7	1761	3.2
7	0.53	8	1999	3.4
8	0.09	9	2234	3.7
9	0.01	10	2520	4

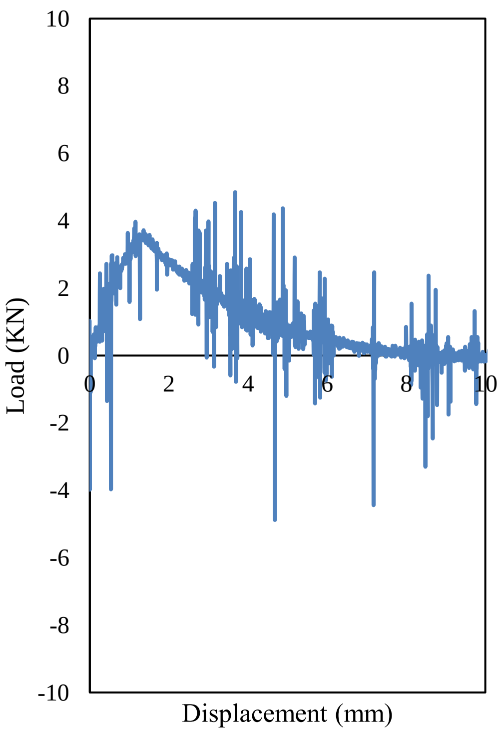


Figure 11: Diagram of force-Displacement of circular fiber concrete slab in heated state at 550⁰C

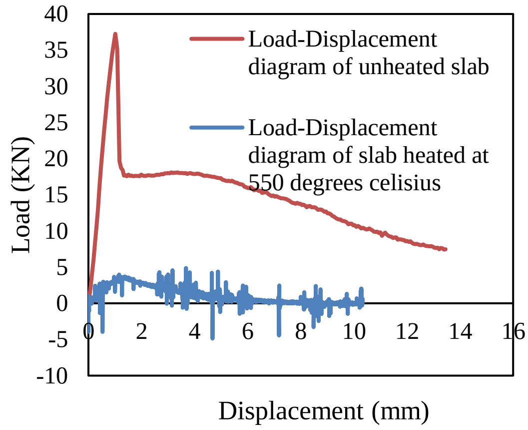


Figure 12: Comparison of force-Displacement diagrams of fiber concrete slabs in unheated and heated state

The maximum stress in the fiber concrete sample, according to the stress-strain curve, is 61 MPa at a strain of 0.0028 in the unheated condition, and 22 MPa at a strain of 0.0036 in the heated state, showing a 64% decrease in stress. The influence of macrosynthetic fibers is reduced by 64% relative to the unheated condition at 14 of the stress-strain diagram's points as opposed to 5 of the points in the heated state. Also, for the unheated sample, for strain values greater than 0.006, the stress value was constant and no decrease was observed. The ultimate strain for the unheated sample was equal to 0.012 at a stress of 10 MPa, but for the heated sample, the ultimate strain was equal to 0.01 at zero stress. According to the fact that the maximum strain of ordinary concrete is the range of 0.002, for unheated fiber concrete this figure is equal to 0.0028, that is, about 40% more, and the maximum strain for heated fiber concrete is equal to 0.0036, that is, about 80% more than the strain of ordinary concrete.

The maximum force in the circular fiber concrete slab in the unheated state is equivalent to 37.26 KN in the change of vertical displacement equal to 1 mm and duration of 19 seconds, and the force then decreases with a reasonably rapid rate. Slab's behavior has been brittle. According to figure 13, there were 3 cracks reported radially from the slab's center at a 120 degree angle, which conformed to the ASTM C1550 standard.

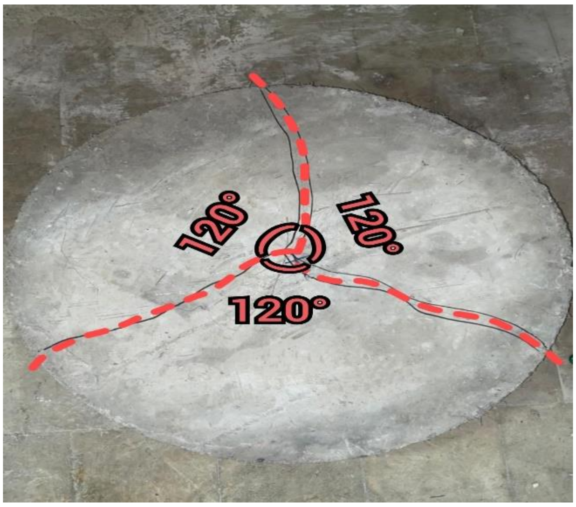


Figure 13: Shape and propagation of radial crack in circular fiber concrete slab in unheated state

The maximum force in the heated condition of the circular fiber concrete slab is 3.97 kN, with a vertical displacement of 1.16 mm, and the duration is 288 seconds. Thereafter, the force is lowered with a gradual slope, and the slab ultimately behaves as if it were crispy and brittle. Figure 14 shows the number of 3 cracks that have been seen radiating outward from the slab's center and having 140, 120, 100 degree angles. The capacity of the circular fiber concrete slab has been lowered by 89.3% as a result of heating. Also, by examining the radial cracks formed in the slabs, it has been determined that the application of high heat has changed the propagation angles of the cracks.

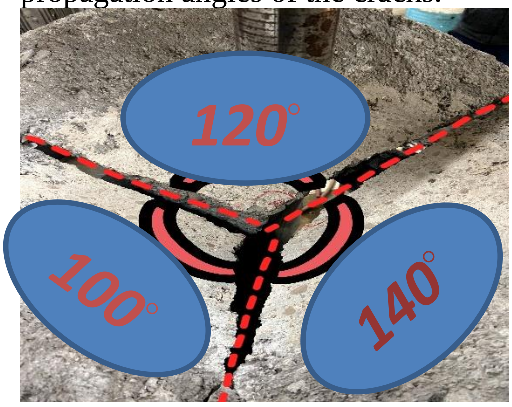
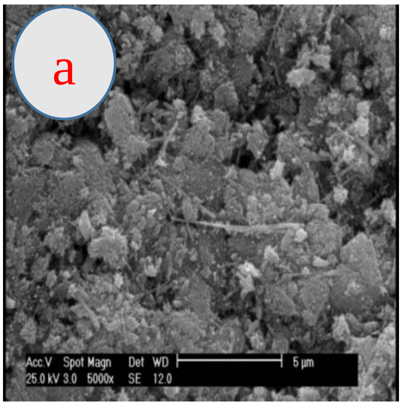


Figure 14: Shape and propagation of the radial crack in the circular fiber concrete slab in the heated state at 550 degrees Celsius.

The amount of energy absorbed by the slabs has been measured in two states: initial energy absorption (up to initial cracking) and total absorbed energy.
The amount of initial energy absorption of fiber concrete slab in unheated state is equal to 23j and in heated state equal to 0.68j and the total amount of absorbed energy of fiber concrete slab in unheated state is equal to 184j and in heated state is equal to 14j. Investigations have shown that the energy absorption of fiber concrete slabs due to heat has decreased by 92.4%.
In order to further investigate the effect of heat on fiber concrete slabs, SEM photographs of heated and unheated samples have been prepared.
Examining the SEM photos of the unheated sample shows the good quality of composite materials of fiber concrete and the photos of heated fiber concrete have shown that the high heat caused the destruction of the macrosynthetic fiber and part of the cracks were caused by the chain destruction of the macrosynthetic fiber. Also, high heat has caused deep cracks caused by asymmetric expansion between components.SEM images of fiber concrete samples in unheated and heated state at 550 degrees Celsius are indicated in Figure 15.



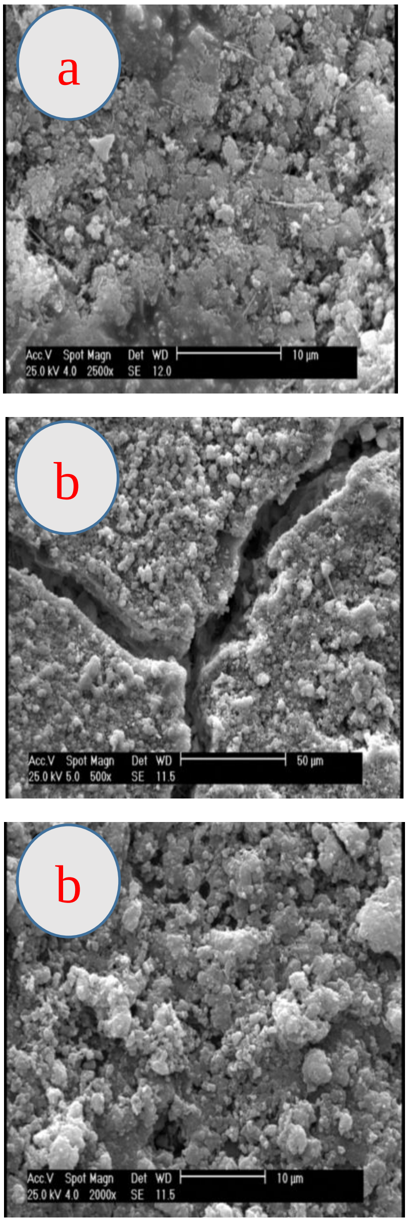


Figure 15: SEM images of fiber concrete samples: a) in unheated condition, b) in heated condition at 550 degrees Celsius

4. Conclusion

The experimental study has been conducted on a circular concrete slabs with a diameter of 750 mm and a thickness of 75 mm, made of macrosynthetic fibers in unheated and heated at 550^{0}C conditions. The heat applied by the electric oven is with a maximum temperature of 550^{0}C and the behavior of fiber concrete slabs including displacement, crack distribution, capacity and energy absorption under monotonic loading has been studied. The results showed:

1-Applying high heat to the samples has caused the maximum strain of fiber concrete to be about 29% higher than the heat state.

2- The amount of reduction in the bending capacity of the fiber concrete slab in the heated state compared to the unheated fiber concrete slab was equal to 89.3%.

3-The energy absorption of the fiber concrete slab in the heated state showed a decrease of 92.4% and the presence of small cracks with a small width, had a small effect on the energy absorption of the fiber concrete slab.

4-The peeling of concrete has not been observed in heated fiber concrete.

5-The SEM photos of the samples show the good quality of the fiber concrete composite materials, but applying high heat has destroyed the macrosynthetic fibers and created cracks due to the chain destruction of the macrosynthetic fibers in fiber concrete samples.

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