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EFFECT OF FIRE ON REINFORCED CONCRETE BEAMS WITH FRP AND CONVENTIONAL STEEL AT LIMITED TIME OF FIRE

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Abstract

The aim of this study is to investigate the behavior of RC concrete beams reinforced with basalt, carbon, glass fiber reinforced polymer bars and conventional steel. A comparison between the results has been performed to investigate and study the effect of fire on reinforced concrete beams considering the following items: (flexural capacity, deflection behavior and crack pattern). It is noticeable that the use of FRP bars significantly increased the ultimate load of the specimens, where the percentage of increase ranged between 34 - 73 % of the ultimate load of the specimen C-S under static load. The greatest ultimate load was reached the beam that was reinforced with carbon bars (CFRP). It was also noticed able that the use of FRP rods significantly increases the deflection of the beams. The percentage of increase was between 45 - 170 % of the final deflection of the C-S specimen under static load. It was noted that the effect of the fire on the beams reinforced with fiber bars (FRP), where the efficiency of bearing capacity of beams after fire decreases by 11 to 18 % of the actual efficiency of bearing capacity of beams control. As for the beam reinforced with conventional steel bars, its efficiency was reduced by 15 % from the actual capacity.

Keywords:

BFRP;
CFRP;
GFRP;
Fiber volume friction;
Fire.

1 Introduction

The use of corrosion resistant material or increasing concrete cover or reducing the permeability of concrete by adding pozzolanic materials seems to be the effective solution to protect the steel bars against corrosion [1, 2, 3]. Several measures have been adopted, to enhance the corrosion resistivity of steel such as epoxy coating of steel, use of stainless steel and galvanization of steel bars [4, 5, 6]. Despite the application of these measures, none of them is successful in completely elimination of the corrosion. In recent years, the use of fiber reinforced polymer (FRP) as a replacement of steel, in RC structures has proved to be effective in complete eliminating corrosion due its non-corrodible nature, for the construction of RC structures for using in the strengthening and retrofitting of structural elements. Because of its desired properties such as high tensile strength, low weight, and corrosion resistance [7]. Commonly three types of FRP composites are used which includes: carbon fiber reinforced polymer (CFRP), glass fiber reinforced polymer (GFRP) and basalt fiber reinforced polymer (BFRP). All those types have beams used and compared to steel reinforcement [8, 9, 10]. The properties of the fiber bars manufactured in the laboratory of the faculty of engineering at Al-Azhar University were studied. Then these manufactured bars (FRP) and conventional steel were used to reinforce concrete beams and results were compared. Then the effect of fire on them is studied. There is a change in the material's microstructure when fibers are added to concrete in the ideal ratio, resulting in greater compressive strength, ductility, splitting tensile capacity, and bending tensile strength [11].

2 Experimental program

2.1 Production of basalt, carbon and glass fiber reinforced polymer (BFRP & CFRP and GFRP)

The fiber yarns were prepared with the appropriate number to obtain the required diameter and the required density. The basin was filled with resin or matrix. The yarns were passed with resin until saturation. Then the yarns were passed through the guide 1 and then the guide 2 to wipe the excess of the resin and until the bars take the circular shape. Then the bar was passed through the die and then the Equipment for the production of rough bar surface is performed. Fig. 1 and 2 show the shape of FRP bars after production.

The content of the yarns in the fiber bars was determined in relation to the resin. Three samples with a length of 10 cm of each type were prepared. The samples were weighted. Whereas, the values in the tables are the average readings. Then the sample was burned as shown in Fig. 3 until only yarns were left and then it was weighed and the fiber volume fraction is determined from the properties that have been calculated according to each of the Tables 1a and 1b. The fiber volume fraction was found to be 57.6 % for CFRP and fiber volume fraction in the BFRP and GFRP were equal to 55.6 %. Table 2 shows the properties of FRP bars. A tested in the laboratory Fig. 4 shows the test setup to measure tensile strength and failure of bar FRP and conventional steel bars and Fig. 5 shows comparison between of FRP (stress-strain curve) and conventional steel.

Fig. 1: The equipment used in the production of fiber bars (stand & resin bath & guide & die & motor and equipment for the production of rough bar surface).

Fig. 2: BFRP & GFRP and CFRP shape after production.

Table 1a: Calculations of volume fraction of FRP.

Comp	Density of fiber [g/cm^3]	Density of matrix [g/cm^3]	Mass of composite specimen [g]	Mass of fiber [g]	Mass of matrix [g]
Ter	ρ_f	ρ_m	M_c	M_f	M_m
Equ	-	-	$M_c = M_f + M_m$	-	-
CFRP	1.9	1.29	15	10	5
BFRP	2.1	1.1	17	12	5
GFRP	2.1	1.1	17	12	5

Table 1b: Calculations of volume fraction of FRP.

Comp	Volume of fiber [cm^3]	Volume of matrix [cm^3]	Volume of composite specimen [cm^3]	Fiber volume fraction	Matrix volume fraction
Ter	V_f	V_m	V_c	FVF	MVM
Equ	$V_f = M_f / \rho_f$	$V_m = M_m / \rho_m$	$V_c = V_f + V_m$	$FVF = V_f / V_c$	$MVF = V_m / V_c$
CFRP	5.263	3.875	9.138	57.59 %	42.4 %
BFRP	5.714	4.545	10.259	55.69 %	44.3 %
GFRP	4.714	4.545	10.259	55.69 %	44.3 %

Table 2: Properties of steel & FRP (BFRP, GFRP and CFRP).

Parameters	Steel	BFRP	GFRP	CFRP
Area [mm^2]	78.5	78.5	78.5	78.5
Diameter [mm]	10	10	10	10
Weight per meter [g]	617	170	170	150
Yield stress [N/mm^2]	410	-	-	-
Ultimate stress [N/mm^2]	520	1469	1160	1582
Strain	.02	.026369	.02284	.0117252
Young's modules = stress/strain [MPa]	200000	55268.47	50093.64	133922.06
Thermal expansion [10^{-6} m/m·°C]	1.2	15 - 20	15 - 20	15 - 20
Elongation [%]	9 - 11 %	1.8 %	2 %	1.6 %
Density [g/cm^3]	7.85	2.1	2.1	1.9
Ultimate stress ratio between FRP and conventional steel	1	2.825	2.2309	3.0422

Fig. 3: Specimens of FRP (BFRP & CFRP and GFRP), during fire and shape of specimens after fire.

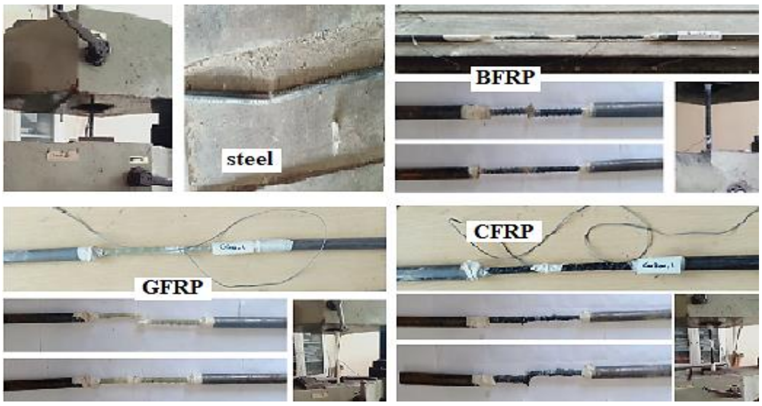


Fig. 4: Test setup to measure tensile strength and failure of (steel, BFRP, CFRP and GFRP).

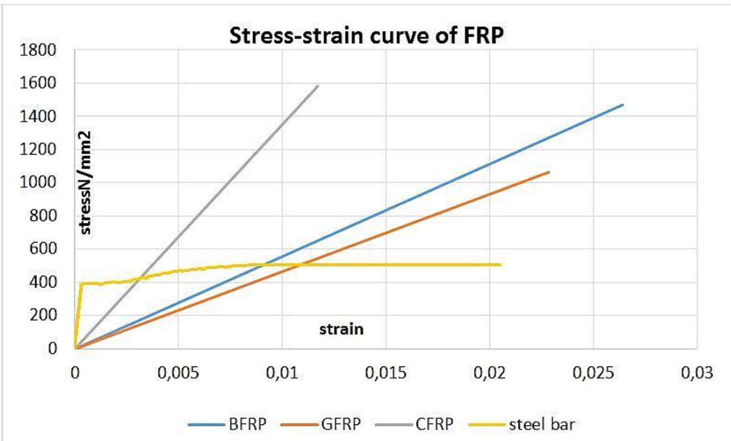


Fig. 5: Comparison between of FRP (stress-strain curve) and conventional steel.

2.2 Beams experimental program

The experimental program consisted of 8 beam specimens divided into two groups and all tested specimens had the same cross-sectional dimensions, as shown in Fig. 6 and Table 3. The beams had a rectangular cross section with a 120 mm width, 250 mm height and the length of the beam was chosen to be 2000 mm, with distance of 1800 mm between the supports, the beams were tested in 4-point bending. The loading system was designed to produce a constant moment region in the middle of the beam specimen. Concrete in all specimens had a characteristic strength of 35 N/mm^2 and clear cover of all beams was 25 mm.

- The first group: Group (1) is a control group that consisted of four reinforced concrete beams reinforced by (CFRP, BFRP, GFRP and conventional steel). These beams were tested to measure maximum load capacities and failure modes under static load.
- The second group: Group (2) is a group consisted of four reinforced concrete beams identical to those in group (1). The beams were tested according to the following three stages: First stage: The beam was tested to about 33.33 % of ultimate capacity as recorded for Group (1), and the effect is made with a value of 1/3 of the beam's loading capacity. Second stage: The beam was removed from the load cell and placed in the fire oven at a temperature of 300 degrees for 30 minutes. The thermocouple was read to know the temperature transferred to the bottom reinforcement during the fire. Finally, third stage: the beam was taken out of the fire oven and loaded up to failure. The following reads were taken: (deflection, load capacity and failure mode).

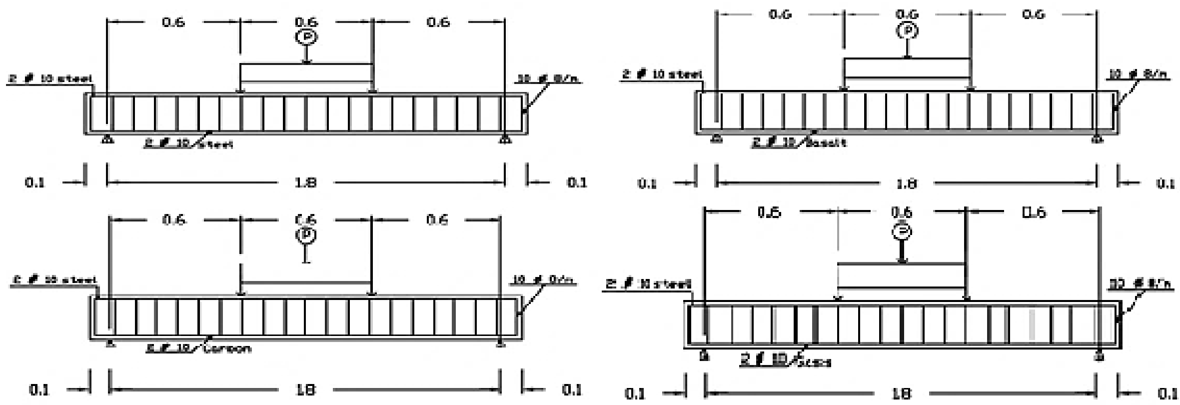


Fig. 6: Beams specimens.

Table 3: Experimental program specimens.

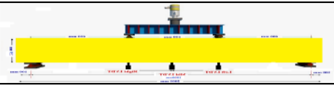
No	Group	Beam no.	Ter	Top RFT	Bottom RFT	Fire
1	Group (1)	B1	(C-S)	2 Φ10 – steel bar	2 Φ10 – steel bar	-
2		B2	(C-B)		2 Φ10 – basalt fiber bar	
3		B3	(C-C)		2 Φ10 – carbon fiber bar	
4		B4	(C-G)		2 Φ10 – glass fiber bar	
5	Group (2)	B5	(F-S)	2 Φ10 – steel bar	2 Φ10 – steel bar	300 ˚C at 30 min.
6		B6	(F-B)		2 Φ10 – basalt fiber bar	
7		B7	(F-C)		2 Φ10 – carbon fiber bar	
8		B8	(F-G)		2 Φ10 – glass fiber bar	

3 Results and discussion

3.1 Group (1)

Ultimate load: It was noted that the beams reinforced with different fiber rods FRP (basalt, carbon and glass) achieved much higher loads than the beams reinforced with conventional steel bars. As the percentage of the loads in the beams reinforced with fiber rods reached 34 - 73 % above the load resulting from the beams reinforced with conventional steel rebar under static load. The values and rates of increase in the values of ultimate load of specimens are shown in Table 4 and Fig. 7.

Table 4: The values and rates of increase in the values of ultimate load of specimens.

Group (1)	Ultimate load [kN] 	Ultimate capacity of beams / Ultimate capacity of steel reinforced beam
C-S	77.37	1
C-B	110.6395	1.42
C-C	133.577	1.72
C-G	103.713	1.34

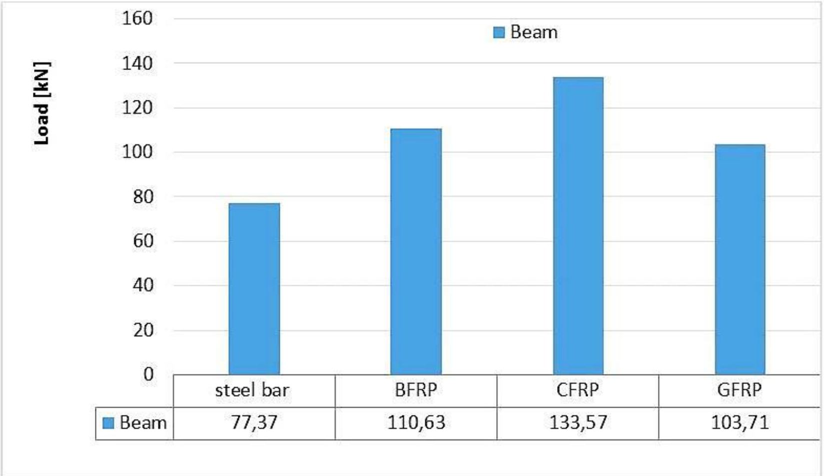


Fig. 7: Ultimate load of group (1).

Deflection behavior: It was found that the behavior of the beams reinforced with fiber rods had a very high deflection compared to the beams reinforced with conventional steel bars. Also, it was found that the highest deflection value occurred in the beams reinforced with basalt and glass bars, where the increase rate reached 170 % over the deflection resulting in the beams reinforced with conventional steel bars. As for the beams reinforced with carbon bars, the resulting deflection was less valuable compared to the deflection produced in the beams reinforced with basalt and glass bars, and the rate of increase was 66 % compared to the deflection produced in the beams reinforced with conventional reinforcing steel bars. As a result of this deflection resulting in the beam reinforced with fiber bars (FRP), it produces wider cracks and is clearly noticeable, and for this reason, it gives a feeling of insecurity as a result of the appearance of a large number of cracks and the occurrence of deflection with very high values. It is noticeable that the use of FRP rods significantly increases the deflection of the samples. The percentage increase is between 45 - 170 % of the final deflection of the C-S specimen under static load.as shown in Table 5. Fig. 8 shows effect the deflection on length of beam. Fig. 9, 10, 11 and 12 shows the failure shapes of group (1).

Table 5: The values and rates of increase in the values of deflection at three points in the specimen's.

Group (1)	Deflection-left		Deflection-mid		Deflection-right	
	Value [mm]	Rate [%]	Value [mm]	Rate [%]	Value [mm]	Rate [%]
C-S	15.9462	Ref	20.70158	Ref	15.3083	Ref
C-B	41.126	257.90	48.037	232.05	40.298	263.24
C-C	26.4727	166.01	30.1206	145.50	25.7636	168.30
C-G	35.19	220.68	41.71	201.48	34.43	224.91

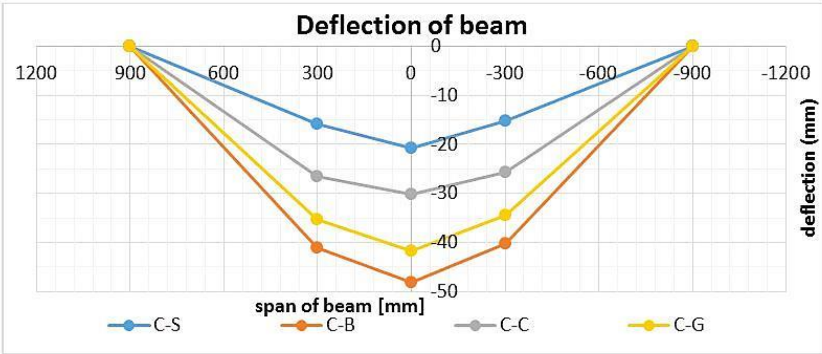


Fig. 8: Effect the deflection at length of the beams.

Fig. 9: Cracks pattern and failure mode of the beam (C-S).

Fig. 10: Cracks pattern and failure mode of the beam (C-B).

Fig. 11: Cracks pattern and failure mode of the beam (C-C).

Fig. 12: Cracks pattern and failure mode of the beam (C-G).

3.2 Group (2)

Figs. 13 and 14 show three load and deflection values of beams. Figs. 15 - 26 the three stages of the beams are presented (F-S, F-C, F-B and F-G). It was found that after the exposure to fire. The flexural capacity of beam (F-S) was reduced by 15 % compared to beams (C-S). The flexural capacity of beam (F-B) was reduced by 11.2 % compared to beams (C-B). The flexural capacity of beam (F-C) was reduced by 12.95 % compared to beams (C-C). The flexural capacity of beam (F-G) was reduced by 17.59 % compared to beams (C-G). Fig. 27 shows the rate of absorbing RFT (heat & time) at the specimen's group (2). Whereas, it is noted that the temperature resulting from the fire in the conventional steel bars reached 140 co. Also, the temperature in the fiber bars reached from 133 to 136 °C. Table 6 shows the values of ultimate load and deflection of group (2) according to cases (control, before fire and after fire).

Table 6: The values of ultimate load and deflection of specimens after fire.

Ter	Comp	Control	Before fire	During fire	After fire	Ratio [%]
(F-S)	Load [kN]	77.37	25.79	Concrete = 300 °C	65.41	84.5
	Def-mid [mm]	20.7015	6.3		16.8	81.15
	Def-left [mm]	15.94	4.85	Steel bar = 140 °C	12.97	81.36
	Def-right [mm]	15.3	4.65		12.5	81.69
(F-B)	Load [kN]	110.63	36.87	Concrete = 300 °C	98.24	88.8
	Def-mid [mm]	48.03	14.4		39.92	83.1
	Def-left [mm]	41.12	12.39	BFRP = 133 °C	34.02	82.73
	Def-right [mm]	40.29	12.14		33.61	83.42
(F-C)	Load [kN]	133.57	44.5	Concrete = 300 °C	116.29	87.05
	Def-mid [mm]	30.12	9.68		24.82	82.4
	Def-left [mm]	26.47	8.47	CFRP = 136 °C	21.93	82.85
	Def-right [mm]	25.76	8.12		21.39	83.066
(F-G)	Load [kN]	103.71	34.57	Concrete = 300 °C	85.47	82.41
	Def-mid [mm]	41.71	13.16		34.13	81.83
	Def-left [mm]	35.19	11.2	GFRP = 134 °C	28.68	81.5
	Def-right [mm]	34.43	10.92		28.26	82.08

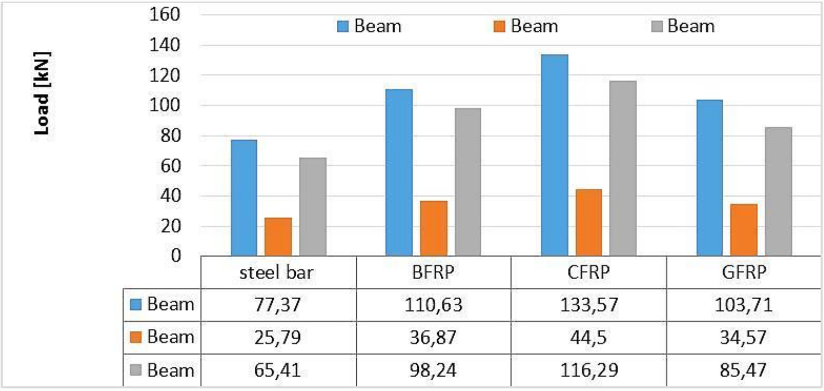


Fig. 13: Load values for the three cases (beam control & beam before fire & beam after fire).

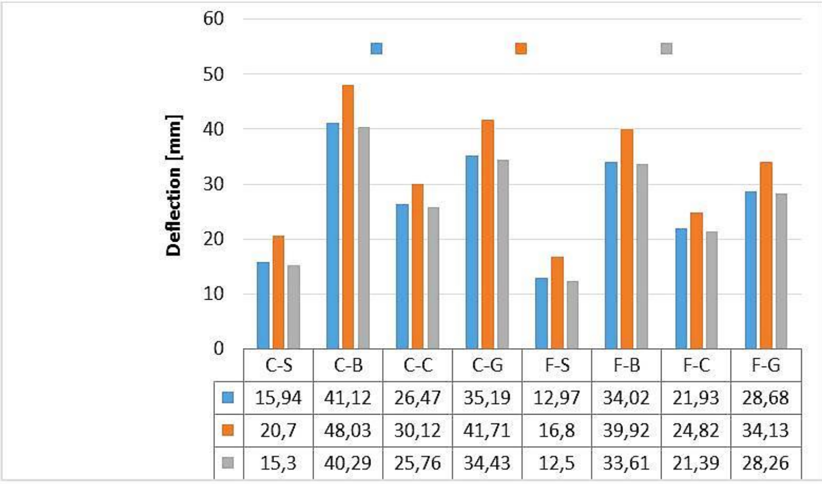


Fig. 14: Deflection values for the three cases (beam control & beam before fire & beam after fire).

Fig. 15: During 1/3 loaded – before fire for the beam (F-S).

Fig. 16: During the fire for the beam (F-S).

Fig. 17: After the fire and loading at failure load for the beam (F-S).

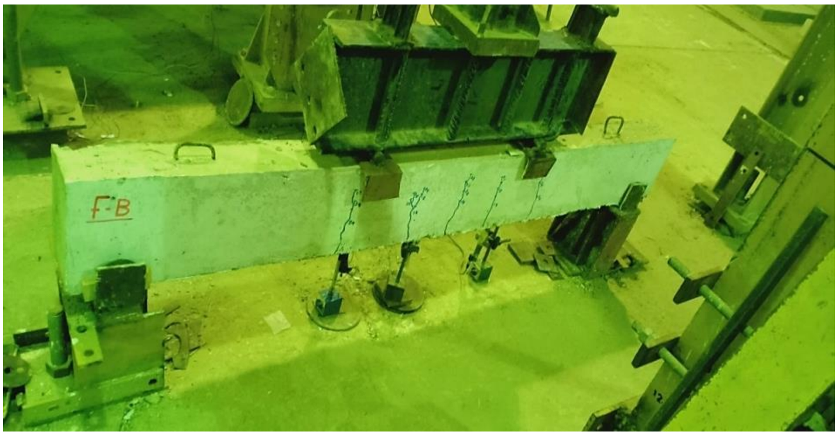


Fig. 18: During 1/3 loaded – before fire for the beam (F-B).


Fig. 19: During the fire for the beam (F-B).

Fig. 20: After the fire and loading at failure load for the beam (F-B).

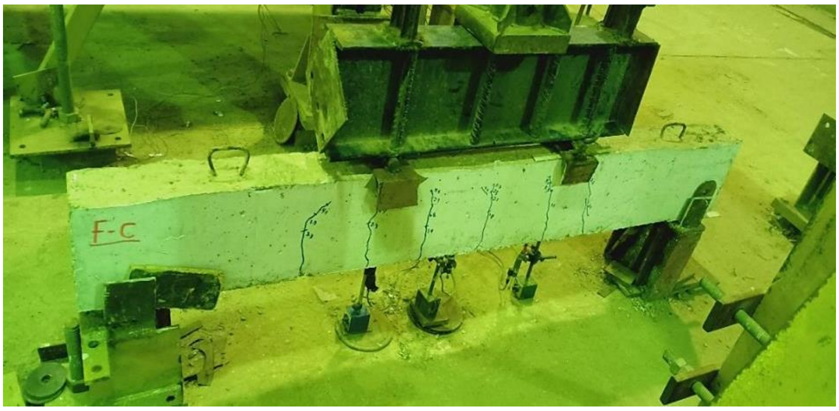


Fig. 21: During 1/3 loaded – before fire for the beam (F-C).

Fig. 22: During the fire for the beam (F-C).

Fig. 23: After the fire and loading at failure load for the beam (F-C).


Fig. 24: During 1/3 loaded – before fire for the beam (F-G).

Fig. 25: During the fire for the beam (F-G).

Fig. 26: After the fire and loading at failure load for the beam (F-G).

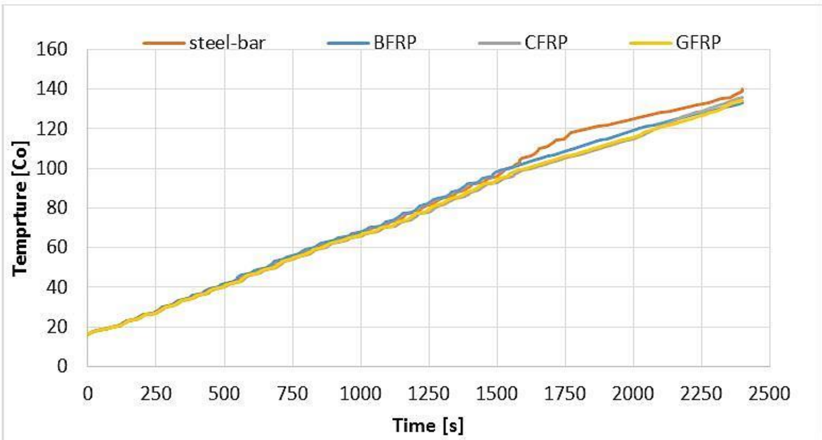


Fig. 27: Rate absorbing RFT (heat & time) at the specimen's group (2).

3.3 Discussion of fire test results

The decrease of flexural capacity of beams after fire ranged in reasonable values due to several effects. The relatively high compressive strength and indirect exposure added to the realistic time of fire used were the most important effects. And also, as a result a concrete cover of at least 20 mm at limited temperature and concrete compressive strength of 35 MPa should be used. It is also noted that the resin used in the production of fiber bars (FRP) improves its fire resistance. And according to research [12], it was found that the effect of the concrete cover of at least 30 mm but this is under effect of the fire of a high-temperature. And also, the grade of the concrete was among the main factors in raising the efficiency of fiber bars (FRP) in resisting fire.

4 Conclusions

The conclusion based on the results obtained is as follows:

1) It is noticeable that the use of FRP bars significantly increased the ultimate load of the specimens. Where the percentage of increase ranges between 34 - 73 % of the ultimate load of the specimen C-S under static load. And the greatest ultimate load was the beam that was reinforced with carbon bars (CFRP) and increase rate of 72 %. Then the beam with reinforcement with basalt bar (BFRP) and increase rate of 42 %. Then the beam with reinforcement with glass bar (GFRP) and increase rate of 34 %.

2) The deflection values obtained in the beams reinforced with carbon bars (CFRP) are less than the deflection vales obtained with basalt or glass bars (BFRP & GFRP). And it is the closest value to the deflection values produced in the beams reinforced with conventional steel. It is noticeable that the use of FRP rods significantly increases the deflection of the beams. The percentage increase is between 45 - 170 % of the final deflection of the C-S specimen under static load. This is one of the problems of using fiber bars (FRP), as it results in a very large deflection compared to using steel conventional.

3) Crack width was considerably bigger in beams reinforced with FRP.

4) It was noted that the effect of the fire on the beams reinforced with fiber bars (FRP), where the efficiency of bearing capacity of beams after fire decreases by 11 to 18 % of the actual efficiency of bearing capacity of beams control. As for the beam reinforced with conventional steel bars, its efficiency was reduced by 15 % from the actual capacity.

5) The reduction of flexural capacity of beams reinforced with FRP bars was found to be close to beams reinforced with steel bars, provided good concrete quality and realistic time of fire.

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