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Effect of Fire Exposure at Different Techniques of Strengthening RRC Columns

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Abstract:
It has been known that fire dramatically reduces the characteristic strength of the reinforced concrete columns. A significant effort has been devoted to study the effect of fire on the reinforced concrete columns. Most of them were focused on evaluating column's fire resistance and provided some recommendations of structural fire resistance. Little attention was paid to the behavior of (GFRP), and Ferrocement jacketing under fire conditions. This paper aims to two main purposes, first the effect of applying (GFRP) laminate, Ferrocement jacketing, and the combined technique between (GFRP), Ferrocement on RC columns, and the performance of using the outer coating on the behavior of the (GFRP) laminates specimens, secondly the effect of the elevated temperature on the same techniques. For that purposetwenty two specimens were involved in the experimental test program, eleven of them were tested directly under axial compression load, and the rest eleven specimens were firstly subjected to fire up to 650°c, with period 1 hour. The studyprogram includes1, 2, and 3 layers of(GFRP) laminate with and without using outer coating,1,2 , and 3 wire meshes for Ferrocement jacketing, and finally 1 layer of laminated (GFRP) and wire mesh were applied to the combined technique. Experimental work was conducted to the specimens to get the maximum load capacity (MCL) of each specimen, vertical displacement, and energy absorption wasdetermined. The results showed the maximum load capacity of each specimen, and the reduction of it under fire exposure, and the combined technique recorded great results for resistance, high temperature, beside the great effect of the outer coating for (GFRP)specimens compared with the specimens without coating.
Keywords: *FRP,GFRP,laminate, Ferrocement jacketing, Cement, Axial compression, , Fire exposure, coating*

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I. Introduction

Concrete structures when subjected to fire presented in general good behavior. The low thermal conductivity of the concrete associated with its great capacity of thermal insulations of the steel bars is the responsible for this good behavior. The fire protection of concrete structures is mainly based on the maintenance of correct distance from the axis of the steel bars on the outside surface of the element. However a phenomenon such as the concrete spalling may compromise the fire behavior of the elements.

To avoid the phenomenon of spalling, several studies were paid out worldwide for the development of concrete compositions of enhanced fire behavior, little of them focused at the behavior of the strengthened reinforced concrete columns under high degree of temperatures. So in this research we focused at the performance of the strengthened reinforced concrete columns that were overwhelminglyexposed to high temperature.

II. Background

Over the last two decades, many researchers study the response of RC columns under firefor different cases of columns, shapes, slender ratio and temperature degrees [1,2,3],on the other hand researchers initiated studies to determine the effect of different techniques in strengthening concrete columns,some of them focused at using Ferrocement, CFRP, and GFRP as a technique of strengthening for RC columns,and under fire condition, little researchers studied the effect of adding an outer cover to the GFRP technique under high temperatures as a protection material. and no one spotted using GFRP laminate and Ferrocement jacketing together in the same specimen as a technique of strengthening before, and after exposed to high temperatures.

Researches of GFRP technique.[4,5,6,7,8] studied the behavior of strengthening RC columns with different parameters; (shear, shear connectors, load capacity, stiffness, and ductility).
In the same way, Researches of Ferrocement technique. [9,10,11,12] focused at the performance of the strengthened RC columns under different conditions. Little of researches.[13,14,15,16] focused at the material protection for GFRP laminate.

III. Experimental work

i. Materials

Different materials were used in this research, such as concrete with its different components in addition to the strengthening materials from Ferrocement jacketing to GFRP laminate.

Reinforced concrete materials

The reinforced concrete for columns specimens consisted of fine, and coarse aggregate, cement, water, and steel. The used fine and coarse aggregate in this research were natural sand from 6 October quarries and basalt from Sinai quarries. They were tested according to Egyptian standard specifications. In the same way, the cement that was used in this research was Ordinary Portland Cement (OPC) ,and it was tested according to Egyptian standard specification.

There are two types of the steel reinforcement were used in this research. The first type was high tensile steel with yield strength Fy = 360 N/mm2 for the longitudinal bars with diameter 10mm. The second type was mild steel with yield strength Fy = 280 N/mm2 for the stirrups, with diameter 6mm.The mechanical tests were performed on the two types of steel. Finally, the water that was used in this research was ordinary tap portable water.

Concrete Mix Design

The achieved compressive strength of the concrete was 25MPa. Table (1) showed the concrete mix for one cubic meter.

Table 1. Concrete mix content by weight for one cubic meter of concrete.

Mix. No.	Cement(Kg)	Water (lit).	Fine Agg.(Kg.)	Coarse Agg.(Kg.)
1	350	175	650	1300

A standard cubes with dimensions 150×150×150 mm were casted and curing, mixing was performed in a horizontal pan mixer. The fine and coarse aggregates were blended in the mixer, and then the mixer was rotated to provide a uniform distribution of aggregates. Cement was then added followed by water. The contents were then thoroughly mixed mechanically for a period of three minutes.

GFRP laminates

i. Sika-wrap Hex 430G

The GFRP laminated(Sika-wrap Hex) was about fibers with thickness 0.173 mm, and width 500mm. the density of the material was 2.54gm/cm^3. Tensile strength was 22760 kg/cm^2.Fig. 1showed the used laminated material.

ii. Epoxy resin (Sikadur-330)

This material was divided into two components (A, and B) with ratio (4:1). The weight of the two component 4 kg, 3.2 for component A, and 0.80 kg for component B. density of the composite material is 1.31 kg/lt. Tensile strength is 300 kg/cm2 for the epoxy resin.

Ferrocement jacket

i. Steel Anchors

Steel anchors of nominal diameter 8 mm and length 70 mm were used for fixing the steel wire mesh to the concrete specimens before mortar.

ii. Steel wire meshes

One type of steel wire mesh was used in this paper. The type was expanded wire mesh with closely hexagonal openings showed in fig. 2.

Table 2. Mechanical properties of the materials

Materials	Parameter	Properties	values
Sikadur-330		Tensile strength(kg/cm^2) =	300
		Elongation (%) =	0.90
Sikawrap-Hex430 G		Tensile strength (kg/cm^2) =	22760

		Elongation (%) =	4.0
Silica fume		Bulk Density(kg/m^3) =	660
Addicrete (BVF)		Density(kg/m^3) =	1.18
Addibond(kg/m^3)		Density(kg/m^3) =	1.02
Cement		Strength after 3 days(kg/cm^2)	210
		Strength after7 days(kg/cm^2)	290
Steel	10mm	(Tensile strength kg/cm^2)	4998
	6mm	(Tensile strength kg/cm^2)	5410

Ferrocement and GFRP Cement Plaster

The mix proportion of the cement-polymer plaster is 1:2 by weight of cement and sand, respectively. The water to cement ratio is 0.46. The ratio of the Silica fume (SF) was 10% from the weight of the cement. Super-plasticizer (Addicrete BVF) was 1.50% from the weight of the cement. The Addibond (65) ratio was about 1:3 from the weight of water. The compressive strength of mortar was achieved 42.5 Mpa at 28 days of curing. **Table. 3**showed the mix proportions for six cubes of cement plaster.

Table 3. The mix proportions for the six cubes of cement plaster

Mix.No	Cement (kg)	Sand (kg)	Water (lit)	Silica-fume kg)	Addicrete BVF(lit)	Addibond (lit)	W/C	Fcu (kg/cm^2) 28 days
Mix.1	1.5	3	0.60	0.150	0.015	-------	0.40	310
Mix.2	1.5	3	0.60	0.150	0.015	0.200	0.40	425
Mix.3	1.5	3	0.60	0.150	-------	0.200	0.40	360
Mix.4	1.5	3	0.60	0.150	------	--------	0.40	275

From the results ofTable3., the mix (2) with polymer had the highest compressive strength comapred with the other mixes. These results referred to the role of adding polymer material (Addibond65) to the cement plaster, as we reached cement mortar with high strength up to 42.5 MPa after 28 days from casting and curing.

Fig.1 GFRP Laminate (Sikawrap)

Fig. 2 Hexagonal steel wire mesh

IV. Preparations of test specimens

A total number of 22reinforced concrete column specimens with height of 1000 mm, and initial cross-section (100×120) mm were constructed, half of them were tested directly under axial compression, and the other specimens were subjected to high elevated temperature up to 650°c, with 1 hour period. Each model had two specimens with two symbols **"r, and f "**. Symbol **"r"** represented the specimen that was directly tested under axial compression load, and symbol **"f"** referred to the specimen that firstly subjected to 650°c with 1 hour period, before tested under axial compression load.

i. Classification of the specimens

The test specimens were divided into fiveseries (i.e. CC, CG, CGW, CF, and CFG) based on their technique of strengthening. Series C consisted of 2 columns with cross-section (100×120) mm, without any strengthening technique as shown in fig. 3. Four deformed steel bars with 10-mm diameter were used as internal reinforcement providing a longitudinal steel ratio "μ=2.50 %".

Fig. 3 Cross section of the control columns

Series CG included 6 columns with rectangular cross-section (100×120) mm. The internal steel bars as the same of CC series. The (GFRP)was applied to the 6 specimens with 1, 2, and 3 layers respectively without coating.

Series CGW was the same as series CG, beside of adding a coating material from a cement plaster with 15mm for all sides of the specimen's cross-section. The final cross section of the series CGW reached to (130×150) mm.

Series CF included 6 column specimens with initial cross-section (100×120) mm. The Ferrocement jacketing was applied to the 6 specimens with 1, 2, and 3 layers of hexagonal wire mesh with thickness 1mm. Cement-polymer plaster was applied to the specimens with thickness 15 mm from all sides of the cross-section, so the final cross-section was to (130×150) mm.

Series CFG included 2 specimens, strengthed with 1 layer of (GFRP), and 1 layer of hexagonal wire mesh, then, cement plaster was applied with thickness 15mm from all sides of the cross-section, so that, the final cross-section was (130×150) mm.Table 4 showed the details of all specimens .

Table 4. Details of the research specimens.

Series	Specimen	Final-Cross-section(Cm)	Length (Cm)	Slenderness ratio	RFT	Parametric study
CC	C_r	10×12	100	10	4Φ10	Control-specimen
	C_f	10×12	100	10	4Φ10	Control-specimen
CG	CrG1	10×12	100	10	4Φ10	One layer GFRP
	C_fG1	10×12	100	10	4Φ10	One layer GFRP
	C_rG2	10×12	100	10	4Φ10	Two layers GFRP
	C_fG2	10×12	100	10	4Φ10	Two layers GFRP
	C_rG3	10×12	100	10	4Φ10	Three layers GFRP
	C_fG3	10×12	100	10	4Φ10	Three layers GFRP
CGW	C_rGW1	13×15	100	7.7	4Φ10	One layer GFRP with coating
	C_fGW1	13×15	100	7.7	4Φ10	One layer GFRP with coating
	C_rGW2	13×15	100	7.7	4Φ10	Two layers GFRP with coating
	C_fGW2	13×15	100	7.7	4Φ10	Two layers GFRP with coating
	C_rGW3	13×15	100	7.7	4Φ10	Three layers GFRP with coating
	C_fGW3	13×15	100	7.7	4Φ10	Three layers GFRP with coating
CF	C_rF1	13×15	100	7.7	4Φ10	One layer wire mesh
	C_fF1	13×15	100	7.7	4Φ10	One layer wire mesh
	C_rF2	13×15	100	7.7	4Φ10	Two layers wire mesh
	C_fF2	13×15	100	7.7	4Φ10	Two layers wire mesh
	C_rF3	13×15	100	7.7	4Φ10	Three layers wire mesh

	C_fF3	13×15	100	7.7	4Φ10	Three layers wire mesh
CFG	C_rF1G1	13×15	100	7.7	4Φ10	One layer GFRP +one layer wire mesh
	C_fF1G1	13×15	100	7.7	4Φ10	One layer GFRP +one layer wire mesh

ii. Instrumentation and testing

Tests were executed using hydraulic loading machine of 1000 KN capacity. The machine was calibrated before testing to ensure the accuracy of results. All series specimens with 1000 mm height, was placed on the rigid two RC blocks that was resting on the rigid steel floor of the machine. Rigid steel plates were fitted under and above the ends of the column specimens. Vertically of column specimen was carefully examined and adjusted to ensure perfect centric loading on the column. Steel jackets were clamped and bolted together with high strength bolts to provide enough confinement at loading and supporting ends. One vertical displacement transducers was used at top of the column specimen in vertical direction to measure the axial deflection. The load and displacement were monitored and logged using an automatic data acquisition system.

The other part of the specimens, were subjected to elevated high temperature up to 650°c, with 1 hour period using furnace. The furnace was made from two layers of steel plates welded together with steel angles at edges. The furnace was insulated between the two steel plate's layers with a 7 cm thickness glass wool. A rigid steel plate was put at the bottom of furnace as a base to rest the specimens on it.

A main part of furnace was 8 electrical heaters with capacity up to 1200 °C, which are connected with an insulation automatic control box as electric source. One thermocouple was connected with an automatic control box to print the actual temperature on digital screen; either digital screen was used to setup the test temperature between 0:1200 °C. The clear space inside the furnace was 45 cm x 45 cm x 120 cm, and then the specimens were tested under axial compression load after exposed to fire, using the same machine.

V. Experimental results and discussion

All specimens were tested to failure. The load and displacement data were collected using the data logger connected to the compression machine. The test results of all series are presented in table 5.Fig. 4 and fig. 5 showed the ultimate loads and maximum displacements respectively, of the test specimens.The energy absorption was estimated by calculating the area under load-axial deflection curve for each column specimen in each series as shown in fig. 5, fig 6, fig. 7, fig.8 and fig.9 forseries CG, CGW, CF & CFG respectively. The test results of all series are presented in Table 5.

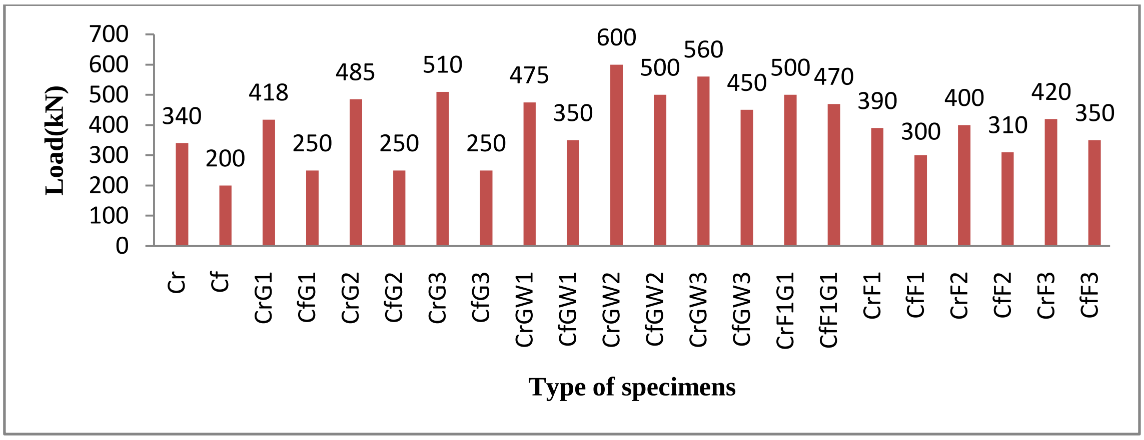


Fig.4: Ultimate load for all specimens.

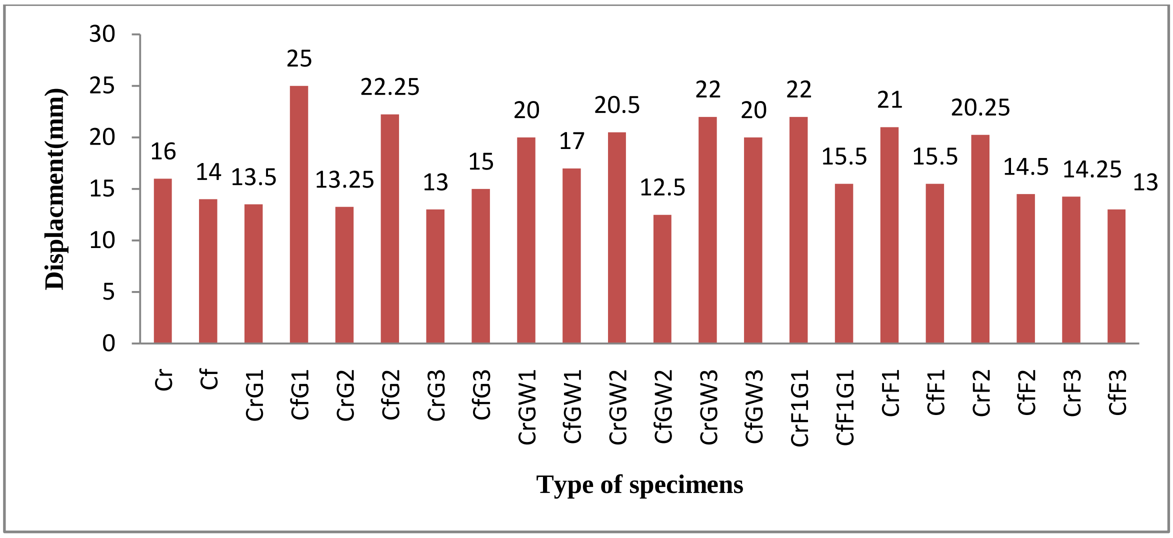


Fig. 5 Displacement for all specimens.

Table 5. Test results for all test series

Series	Specimens	P_{ult} (kN)	(P_r/P_{rc}) & (P_f/P_{fc}) %	% (P_f/P_r)	Fire. Effect % $(1-P_f/P_c)$	V.Disp (mm)	Energy absorption (Ep)@ P_{ult}(KN.mm)	$(E_p/E_c)_r$ & $(E_p/E_c)_f$ %	Max.fire temperature(°c) Point (1) furnance .Temp	Point (2)	Point (3)
CC	C_r	340	100%	58.80%	41.20 %	16	E_{cr}=2156	100%			
	C_f	200	100%			12	E_{cf}=975	100%	650	600	400
CG	C_rG1	418	123 %	59.80%	40.20 %	13.5	2695	125%			
	C_fG1	250	125%			25	1075	110%	650	550	375
	C_rG2	485	143%	51.50%	48.50 %	13.25	2875	133%			
	C_fG2	250	125%			22.50	1122	115%	650	525	350
	C_rG3	510	150%	49%	51%	13.00	3225	149%			
	C_fG3	250	125%			15	1200	123%	650	500	325
CG W	C_rGW1	475	140%	73.68%	26.32 %	20	3415	158%			
	C_fGW1	350	175%			17	1755	180%	650	475	245
	C_rGW2	560	165%	89.28%	10.72 %	20.50	4778	221%			
	C_fGW2	500	250%			12.50	1925	197%	650	450	240
	C_rGW3	600	176%	91.60%	8.4%	22	5400	250%			
	C_fGW3	550	275%			20	2205	226%	650	425	235
CF	C_rF1	390	115%	70.50%	29.50 %	22	3780	175%			
	C_fF1	275	137%			15.50	1232	126%	650	480	255
	C_rF2	400	118%	75%	25%	21	4120	191%			
	C_fF2	300	150%			15.50	1310	134%	650	460	240
	C_rF3	420	124%	77.30%	22.70 %	20.25	4536	210%			
	C_fF3	325	162%			14.50	1390	142%	650	440	230
CFG	C_rF1G1	500	147%	94%	6%	14.25	4720	219%			
	C_fF1G1	470	235%			13	2388	245%	650	450	250

Where:

P_{ult} **:** The maximum failure load for all specimens

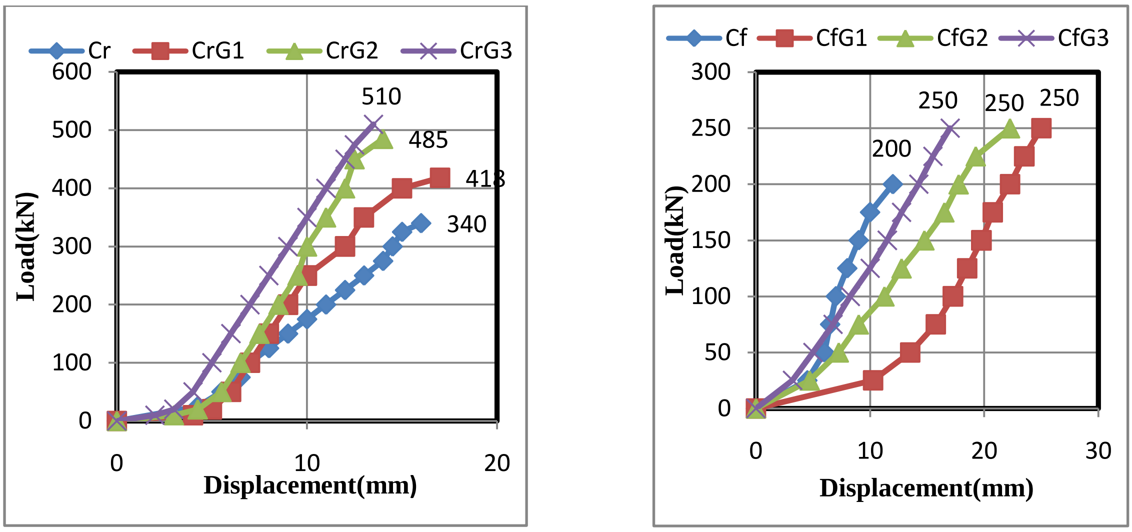
P_r, P_f**:** The maximum failure load for all specimens before and after fire effect

P_{rC}, P_{fC}**:** The maximum failure load for control specimen before and after fire effect

E_p: Energy absorption for all specimens at the maximum failure load.

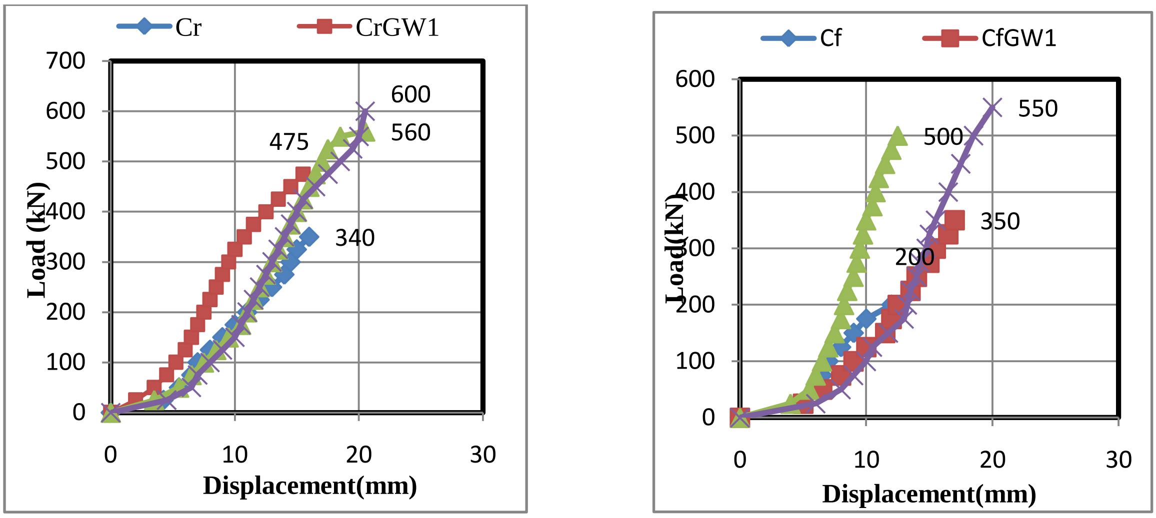
E_{cr}, E_{cf}: Energy absorption for the control specimen before and after the fire effect.

Point 1,2,3 : measuring thermal points as shown in fig. 10.



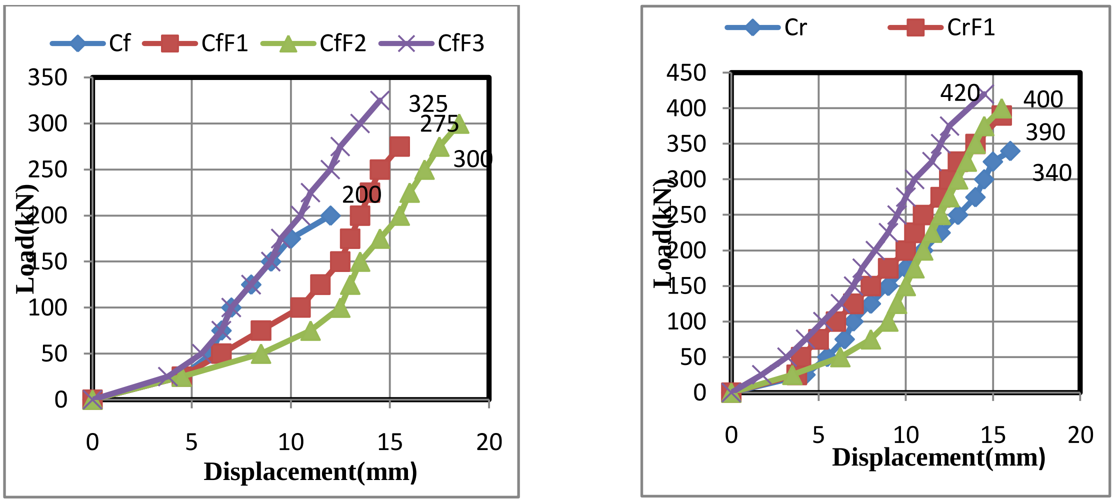
a): Before fire exposure **b): After fire exposure**

Fig.6 load displacement relationship for Series (CG)



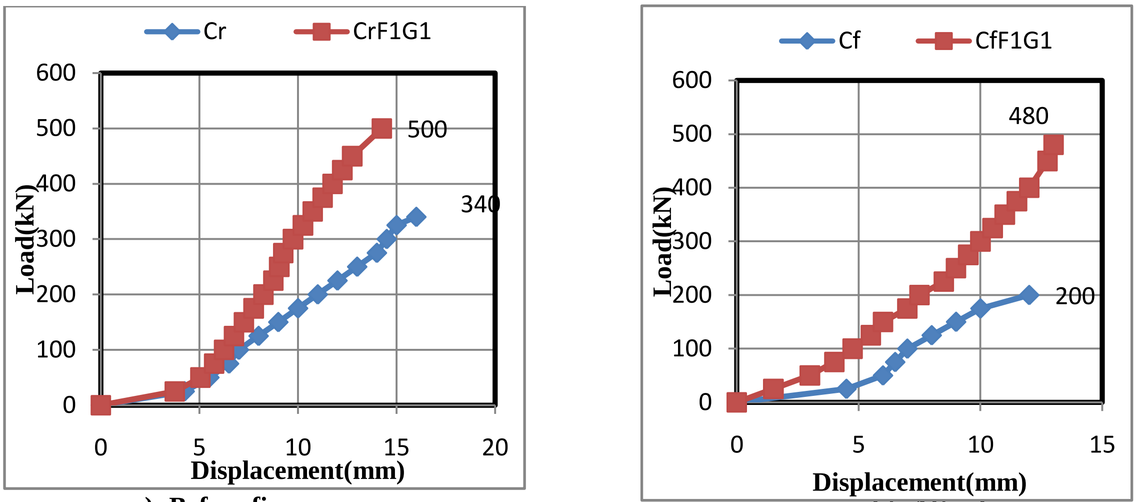
a): Before fire exposure **b): After fire exposure**

Fig.7 load displacement relationship for Series (CGW)



a): Before fire exposure **b): After fire exposure**

Fig.8 load displacement relationship for Series (CF)



a): Before fire exposure **b): After fire exposure**

Fig.9 load displacement relationship for Series (CFG)

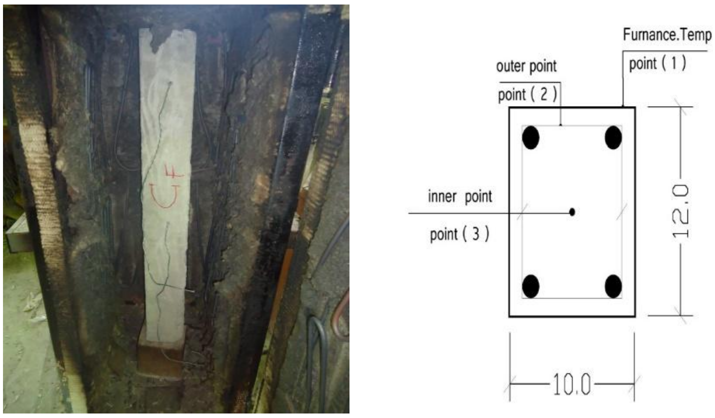


Fig.10: The furnace with column model and thermal measuring points

i. Series (CC) Control specimens.

From table 5, the results showed that the maximum load capacity, and the vertical displacement at the ultimate load for $C_r$were 340 KN, 16mm respectively.

Specimen C_f had the same parameter as $C_{r,}$ with applying fire exposure before it was tested under axial compression load. The maximum load capacity and the vertical displacement for the specimen were 200 KN, and 12mm respectively. The residual load from the two specimens was (C_f /C_r)%=58.8%, so the losses were about 41.20%of its original capacity due to the fire exposure.

ii. Series (CG)

From table 5 and fig. 6, and before the fire effect, the results showed that the ultimate failure load for the specimensincreased with the increasing number of layers with percentage 123%, 143%, and 150%, respectively,compared with the control specimen, on the same way, the energy absorption increased by 125%, 133%, and 149% respectively for 1, 2, and 3 layers.

After fire exposure, the ultimate failure load of the specimens was 125% for the three specimens compared with the control specimen.

The energy absorption was increased by increasing of GFRP lamination layers with percentage 110%, 115%, and 123% respectively for 1, 2, and 3 layers, but it was decreased compared with the case before exposed to fire.

iii. Series (CGW)

From table 5 and fig. 7, and before the fire effect, the results showed that the ultimate failure load for the specimens increased with the increasing in number of layers with 140%, 165%, and 176%, respectively, compared with the control specimens, in the same way, the energy absorption increased by 158%, 221%, and 250% respectively for 1, 2, and 3 layers.

After fire exposure, the ultimate failure load of the specimens was 175%, 250%, and 275% respectively compared with the control specimen C_f.These results showed that the resistance of specimens to the high degrees of temperature, and it's referred to the importance of adding the coating as a protective material for the GFRP lamination.

On the same way, the energy absorption, increased by 180%, 197%, and227% respectively for 1, 2, and 3 layers compared with control specimens, but it was decreased compared with the case before exposed to fire.

iv. Series (CF)

From table 5 and fig 8, and before the fire effect, the results showed that the ultimate failure load for the specimens increased with the increasing in number of wire mesh layers with 115%, 118%, and 124% respectively compared with the control specimens, on the same way, the energy absorption increased by 175%, 191%, and 210% respectively for 1, 2, and 3 layers of wire mesh.

After fire exposure, the ultimate failure load of the specimens was 137.50%, 150%, and 162% respectively compared with the control specimen. On the same way, the energy absorption, increased by 126%, 134%, and142% respectively for 1, 2, and 3 layers compared with control specimens.

v. Series (CFG)

This series contains two specimens (C_rF1G1), and (C_fF1G1).GFRP technique was applied together with Ferrocement jacketing, one layer of GFRP material, with one layer wire mesh, covered with cement plaster. (C_rF1G1)specimen was tested under axial compression until failure mode; the result's values were 500KN, and 14.25 mm. The results showed an increasing at the maximum load capacity by 147% compared with the control specimen.(C_fF1G1) specimens were tested firstly under high temperature reached to 650°c,with 1hour period, then it was tested under axial compression load. The results showed that the loss of the ultimate load capacity were about 6 % fromtable 5.

vi. Failure modes

Figures.11to 15showed the failure modes of all specimens for each series. It was observed that the mode crushed in most specimens at mid-height, in some specimens at top of specimens, and the others were at the bottom of the specimens. Increasing the Ferrocement layers makes the failure in concrete before ferrocement cracks and the ferrocement crack length longer than other GFRP crack.

From the crack patterns of specimens, it was showed, that Ferrocement jacketing specimens were more ductile than GFRP techniques; on the other hand, GFRP laminate specimens are more brittle, it is result to the effect of epoxy resin in GFRP.

Using a polymerized cement mortar as a coating or in Ferrocement mortar helped to make a failure mode more ductile.

C_r **C_f**

Fig. 11 failure mode for control specimens series (CC) before and after fire exposure

C_rG1 **C_fG1** **C_rG2** **C_fG2** **C_rG3** **C_fG3**

(CG1) (CG2) (CG3)

Fig. 12 failure mode for series (CG) before and after fire exposure

C_rGW1 C_fGW1 C_rGW2 C_fGW2 C_rGW3 C_fGW3

(CGW1) (CGW2) (CGW3)

Fig. 13 failure mode for series (CGW) before and after fire exposure

C_rF1 C_fF1 C_rF2 C_fF2 C_rF3 C_fF3

(CF1) (CF2)(CF3)

Fig. 14 failure mode for series (CF) before and after fire exposure

C_rF1G1 C_fF1G1

Fig. 15 failure mode for series (CFG) before and after fire exposure

VI. Conclusion

The major conclusions derived from this study can be summarized as follows:

1- Columns which exposure to fire their capacity reduced about 6% for CFG series and about 51% for CG with three layers. On the other hand,according to the type of strengthening column, the reduction of column capacity varies from 8.4% to 29.5 %, for series CGW and CF respectively.

2- These results showed that the behavior of all specimens after the elevated temperature up to 650°c, with 1hour period, was the approximately the same as the control specimen Cf , as the epoxy resin was deteriorated rapidly under high temperature. With sequence, column specimen lost its confinement to the GFRP system, and the specimens considered without strengthening material.

3- The difference between the two series CG, and CGW was the coating, and compared with the results, it was shown that the ultimate failure load approximately increased about 15% compared with specimens with the same layers.

4- The results of series CF showed that, Ferrocement jacketing increased the ultimate load failure with increasing the number of wire meshes, but not the same as the (GFRP) lamination for both series CG, and CGW. After fire exposure Ferrocement jacketing was more effective than (GFRP) without coating, and was less than GFRP with coating.

5- The results indicated that the composite technique had a greater resistance to high temperature compared with other test specimens, although it wasn't the biggest load capacity compared with CGW1, CGW2, CG3, but increasing the number of wire mesh or GFRP layers, lead to increase the maximum load capacity.

6- Increasing the Ferrocement layers makes the failure in concrete before ferrocement cracks and the ferrocement crack length longer than other GFRP crack.

7- From the crack patterns of specimens, it was showed, that Ferrocement jacketing specimens were more ductile than GFRP techniques; on the other hand, GFRP laminate specimens are more brittle, it is the resultof the effect of epoxy resin in GFRP.

8- Using a polymerized cement mortar as a coating or in Ferrocement mortar helped to make a failure mode more ductile.

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