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STRENGTHENING OF LOADED R.C. FRAMES AFTER FIRE EXPOSURE USING F.R.P

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One of the most common defects encountered in reinforced concrete structures is the fire exposure. Therefore, strengthening investigations that attempt to increase the ultimate load capacity of the defected structural elements have become an important topic in the field of reinforced concrete studies, specially, for reinforced concrete frames as a whole structure.
Recently, composite material such as fiber-reinforced polymer (FRP) started to become a good replacement for strengthening of reinforced concrete elements to compensate the losses in ultimate capacity and energy dissipation due to fire exposure. In the last decade, many researchers and construction applications in industry showed great interest in this field and intensive researches were performed to begin the practical use of these materials in strengthening reinforced concrete structures.
In this paper nine reinforced concrete frames have characteristic strength 22.5 MPa of one sixth scale were tested and examined. These frames are divided into three groups, group (A) control frames, group (B) exposed to 600 ^{0}C and cooled with air, while the last three frames, group (C) exposed to 600 ^{0}C and cooled using water. Each group consists of three frames with different beam to column inertia. Group (A) control frames loaded till to failure to determine the ultimate capacity of sections, while groups (B) and group (C) are loaded to about 0.3 its ultimate load, the load kept constant at this value, then each frame exposed to fire of 600 ^{0}C, for at least two hours , then cooled such that with air or using water. After totally cooling each frame strengthened using glass fiber reinforced polymers laminates (GFRP). After strengthening, the load increased gradually up to failure. The ultimate loads, crack pattern, strain progress, mode of failure and energy absorption were here recorded and analyzed.

Keywords: *R.C. frames, strengthening, fire exposure, loading, glass fiber.*

INTRODUCTION

The urgent need to strengthen concrete structures is on the rise. Various motivations lead to the increased demand for strengthening. Deterioration and aging of concrete structures are not the only reasons for strengthening concrete elements. Other reasons include upgrading design standards, committing mistakes in design or construction, exposure to unpredicted loads such as truck hits or powerful earthquakes, and changing the usage of the structure. Moreover, the ever-increasing truck loads are sometimes beyond the design loads of most bridges in North America that were built after World War II. Since then, the average service loads were increased by 40 percent. The strengthening should ideally minimize the amount of material added to the structure to avoid increasing the dead load or decreasing the clearance demands. Along with that, strengthening should minimize disruption to the structure and its usage. Cited from ACI 440.2R-02 [1], in Europe FRP systems were developed as alternates to steel plate bonding. Bonding steel plates to the tension zones of concrete members with epoxy resins were shown to be viable techniques for increasing their flexural strengths. This technique has been used to strengthen many bridges and building around the world. Because steel plates can corrode leading to a deterioration of the bond between the steel and concrete, and that are difficult to install, requiring the use of heavy equipment, researchers have looked to FRP materials as an alternative to steel. Experimental work using FRP materials for retrofitting concrete structures was reported as early as 1978 in Germany.

Fire exposure is an important reason, which makes the concrete elements are needed to be strengthen using fiber reinforced polymer (FRP) for strengthening different concrete elements as, (slabs, beams, columns…) The concrete loses a part of its strength when the temperature degree reaches (200°C - 250°C), but cracks occur when the temperature reaches 300°C or more. Also at 300°C the compressive concrete strength decreases to (40-50) % of its original strength, more decreasing of concrete strength with temperature rise. When the temperature degree reaches (500°C - 600°C), the reinforcement tensile strength is reduced by about 50% and the concrete strength is decreased by about 70 % of its original strength.

Research and significance include determining and investigating the following:

1- The efficiency of GFRP as a strengthening material for reinforced concrete frames had exposed to fire.
2- The most efficient way of cooling reinforced concrete structure exposed to fire.
3- The most efficient pattern of strengthening.
4- The comparison between different beam to column inertia of frames and its effect on ultimate capacity of sections.

EXPERIMENTAL PROGRAM

Nine reinforced concrete frame models of one sixth scale are tested in this program. The nine frames have different inertia ratio I_b/I_c. All tested frames had constant column cross section of 15 cm x 24 cm while, for each group, there are three different girder cross section 15 cm x 24 cm, 15 cm x 30 cm and 15 cm x 36 cm (see Table.1). The span of the frame is 2.74 meter from centerline of columns.

MATERIAL CHARACTERISTICS

The concrete mix used in the tested frames is consisted of cement, sand, gravel, and water with ratios of 1: 1.83: 2.97: 0.5 by weight respectively. All used materials are match with ECP 203 limits [5]. The concrete strength of each tested frame is presented in Table 1. The main longitudinal reinforcement has yield stress of 400 MPa, and the yield stress of the stirrups is 240 MPa. The average characteristic concrete strength of tested cubes was 25 MPa.

TEST SETUP

The specimens are fixed at the base with the ground. They are loaded by four points load system to represent uniform load case. Test setup is shown in Fig.1. One hydraulic jacks of 500 kN capacity supported in the testing frame were used to apply the required load on the frame. The vertical deflections and lateral drift at the end of the column are measured using two dial gauges, Fig.2. The middle deflection measured using dial gauge set at the top of the girder to protect it during fire exposure. Four electrical strain gauges for each frame are used for measuring the strains in steel bars and concrete.

Table 1: Parametric Study.

Groups	Notation	Temp. Exposure	Dimensions (cm)				Steel Reinforcement		Inertia (m^4 * 10^{-4})			Strengthening
			Columns		Beams		Columns	Beams	Columns	Beams	I_b / I_c	
			b (cm)	h (cm)	b (cm)	h (cm)	A_s	A_s	I_b	I_c		
Group(A) Control	F1	0	15	24	15	24	4Φ12	2Φ12	1.38	1.38	1.00	-
	F2	0	15	24	15	30	4Φ12	3Φ10+1Φ8	2.70	1.38	1.96	-
	F3	0	15	24	15	36	4Φ12	3Φ10+1Φ10	4.66	1.38	3.38	-
Group(B) Air Cooled	F4	600	15	24	15	24	4Φ12	2Φ12	1.38	1.38	1.00	I
	F5	600	15	24	15	30	4Φ12	3 Φ10+1Φ 8	2.70	1.38	1.96	II
	F6	600	15	24	15	36	4Φ12	3Φ10+1Φ10	4.66	1.38	3.38	III
Group(C) Water Cooled	F7	600	15	24	15	24	4Φ12	2Φ12	1.38	1.38	1.00	I
	F8	600	15	24	15	30	4Φ12	3 Φ10+1Φ8	2.70	1.38	1.96	II
	F9	600	15	24	15	36	4Φ12	3Φ10+1Φ10	4.66	1.38	3.38	III

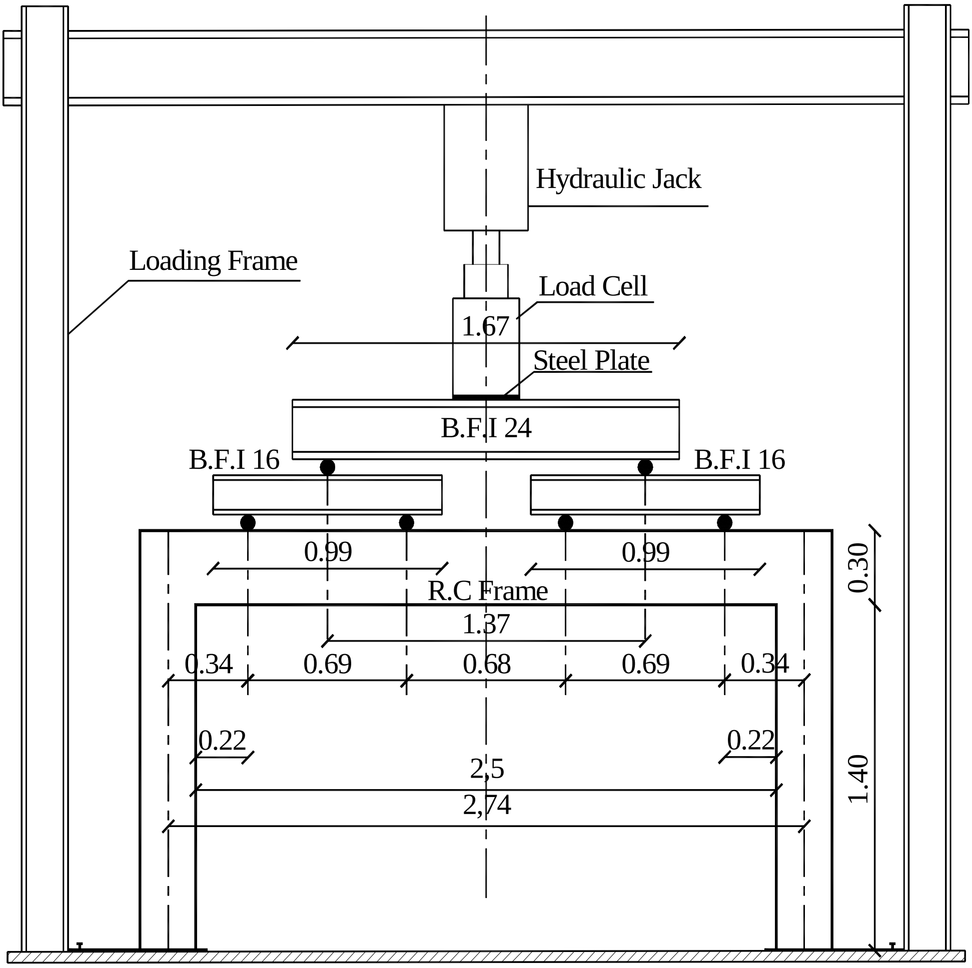

Fig.1: Test setup and frame dimensions.

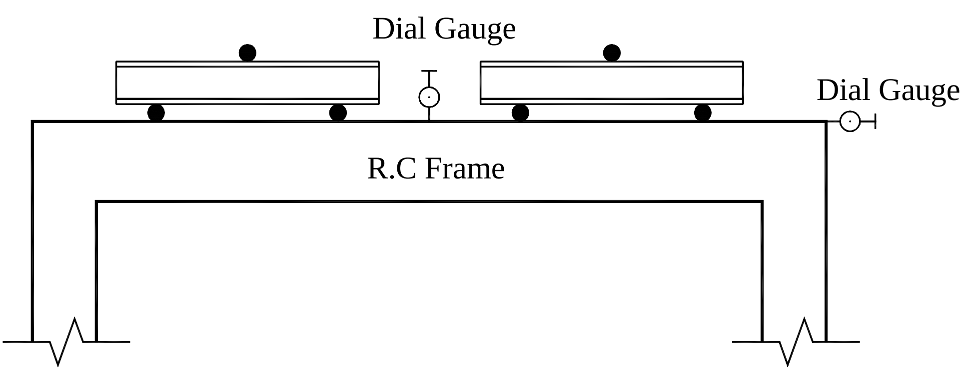

Fig.2: Dial gauges locations.

MEASUREMENTS

The central deflection and lateral drift are measured using the dial gauges while tensile steel strains of girder and upper part of the columns are measured using strain gauges at each interval of loading before fire exposure and after strengthening process till failure.

A thermal insulation system made specially to protect the instruments (Dial gauges and wire of steel gauges) from effecting by fire.

FIRE EXPOSURE PROCESS

To represent the reinforced concrete element fire exposure, a special furnace designed to take this effect at the bottom of girder as shown in Fig.3 and towards the inside part of girder to column connection. The time period of fire exposure was at least two hours after the temperature reached 600^{o} C.

Fig. 3: Fire exposure.

STRENGTHENING SCHEME

Glass fiber reinforced plastic sheets GFRP were used as a strengthening material at tension side for both girder and column. Scheme (I) strengthening of frames F4 and F7 at the lower tension side of the girder only, while Scheme (II) of strengthening frames F5 and F8 at the upper tension side beside the column and the outer side of the column, and finally Scheme (III) of strengthening frames F6 and F9 as the combinations of Scheme (I) and (II). Figure (4) indicates the three types of strengthening schemes.

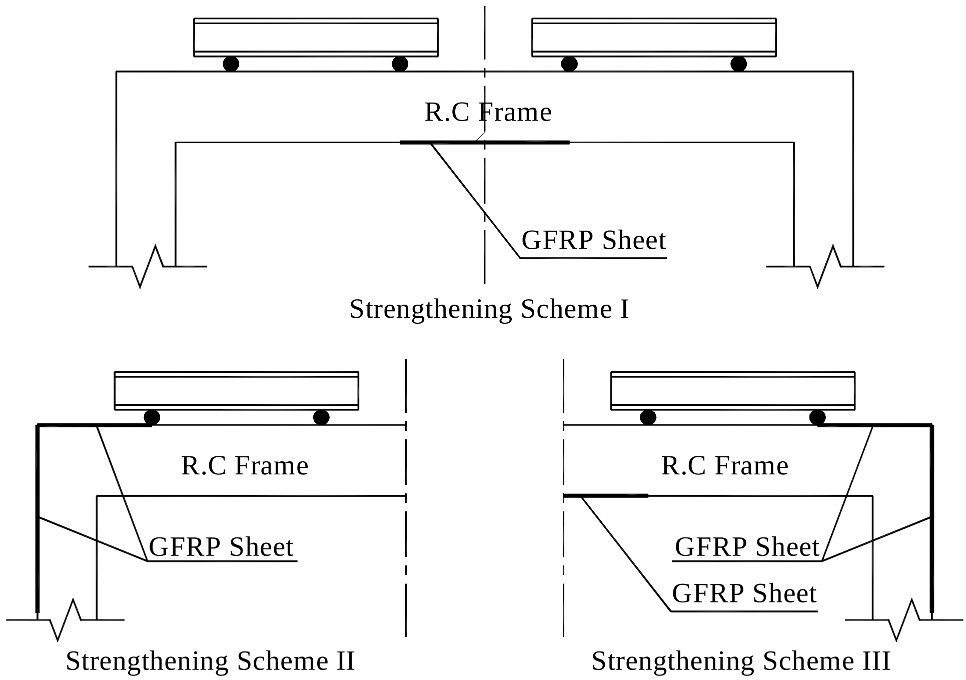

Fig.4: Strengthening schemes.

TEST RESULTS

The specimens are loaded and several measures are assessed. The cracking pattern is drawn on the specimen surface. The load at ultimate and the failure mode for all frames specimens is measured and presented in Table.2. In addition the relation of the load and vertical deflection is constructed for all specimens.

Gained Strength: In this study, the acquired of strength of using fiber strengthened frame specimens after fire exposure was (47.00% to 82.00%) % of the control frame specimens.

Type of Cooling: In this study, the specimens were cooled by slow air after fire exposure were gained strength (47.0% – 50.0%), while the specimens were cooled using rapid water after fire exposure were gained strength (55.0% – 82.0%) %, this means that, the rapid water cooling has a much greater effect on the acquired strength than the slow air cooling especially for the specimens which had great beam - column stiffness ratio (I_b / I_c).

Beam - Column Stiffness Ratio: The acquired strength of glass fiber strengthening frame specimens after fire exposure which were rapid water cooled has an inverse proportional with beam - column stiffness ratio (I_b / I_c).

Strengthening Scheme: In this study it has an inverse proportional between the gained strength and the type of strengthening [type I, type II and type III Fig.4 for frame specimens which were cooled using rapid water cooling after fire exposure, but it has not a significant effect for frame specimens which were slow air cooled after fire exposure.

Gained Energy Absorption: In this study, at the (mid-span frame girder sec), the acquired energy of the strengthening frame sections after fire exposure were ranging between 43% and 117% of the control specimens, this means that; the acquired energy due to using fiber reinforced polymer in strengthening frame specimens after fire exposure especially for the (beam-column connection strengthening section).

Table 2: Test results of specimens.

Group No.	Frame No.	Cracking Load (t)	Failure Load (t)	Deflection (mm)		Ductility μ_d $\Delta_{final}/\Delta_{yield}$	Energy Absorption (t.mm)
				Δ_{yield}	Δ_{final}		
(A) Control	F1	2.25	13.0	21	30	1.420	251.562
	F2	0.75	23.0	26.5	33	1.245	508.21
	F3	0.85	27.0	17.6	24.3	1.380	351.58
(B) Air Cooled	F4	1.6	12.0	19.3	26	1.350	251.48
	F5	1.5	22.0	7.05	21.5	3.049	218.89
	F6	1.75	26.0	9.1	20	2.197	208.154
(C) Water Cooled	F7	1.85	16.5	6.4	30	4.687	295.656
	F8	1.36	24.0	7.1	32	4.507	198.98
	F9	1.60	27.0	7.7	25	3.246	357.15

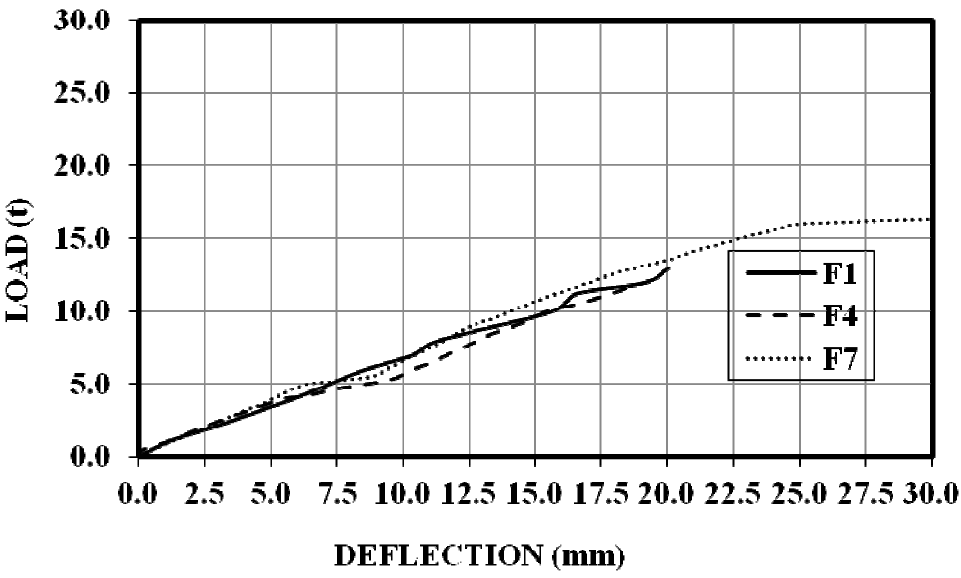

Fig. 5: Load – Deflection relationship of frames F1, F4 and F7.

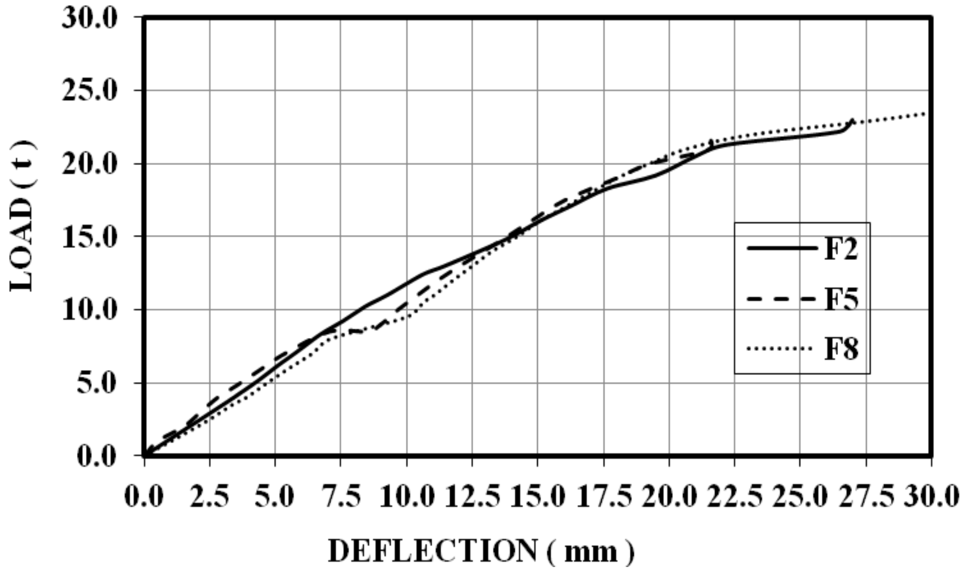

Fig. 6: Load – Deflection relationship of frames F2, F5 and F8.

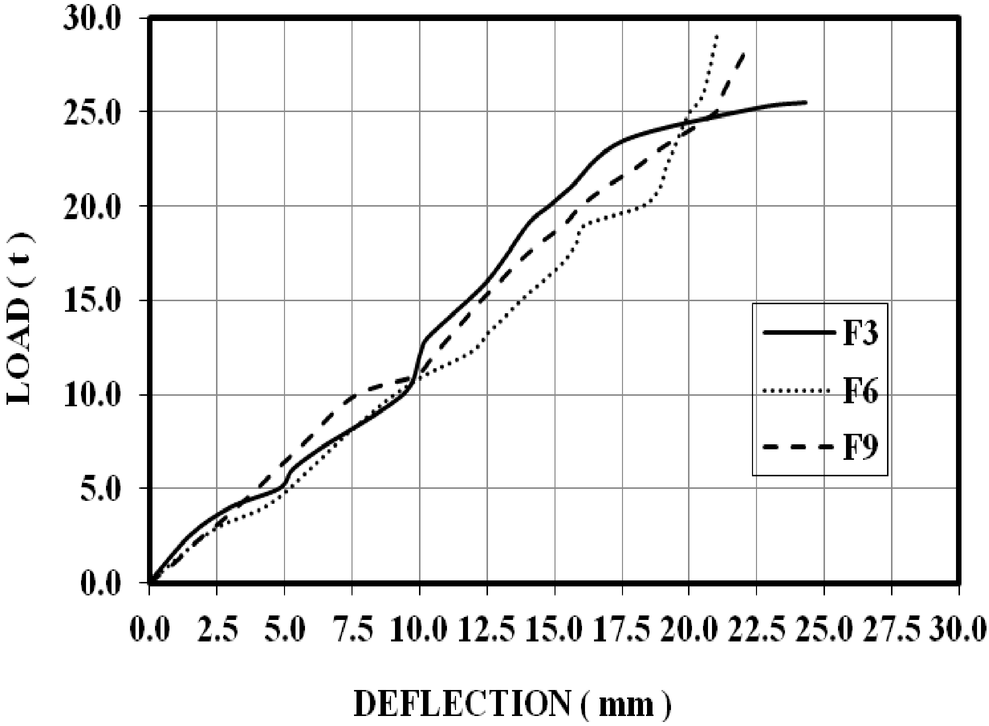

Fig. 7: Load – Deflection relationship of frames F3, F6 and F9.

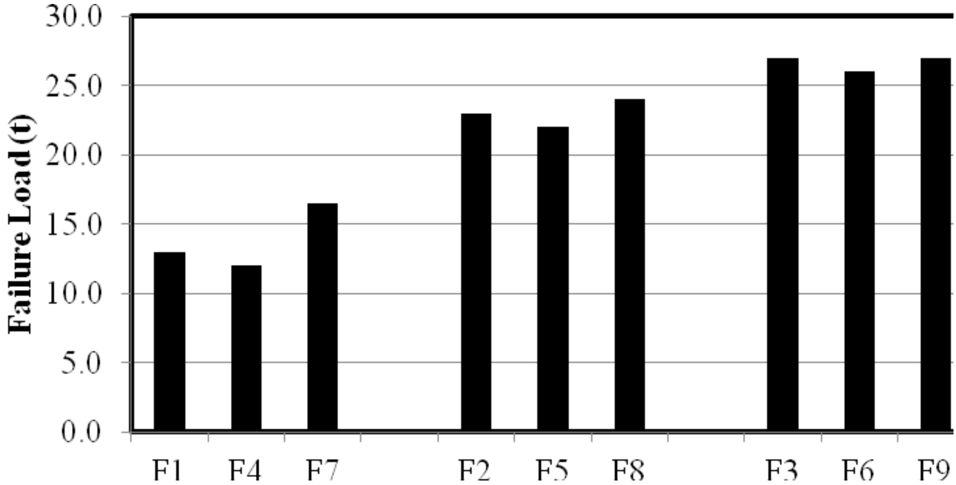

Fig. 8: Failure load of all frames specimens.

CONCLUSIONS

1- The acquired strength caused by using glass fiber reinforced polymer to strengthening frame specimens after fire exposure is nearly equal to 65 % more than the strength of control frame specimens .

2- The gained initial stiffness at the strengthening frame sections (mid-span frame girder sec) after fire exposure were (6.5% to 43%) of the initial stiffness of control specimen, and were (10% to 70%) at the (beam-column connection sec).

3- The gained ductility index μ_d of the strengthening frame sections (mid-span frame girder sec) after fire exposure were (95% to 362%) of the control specimens, and were (55% to 259%) of the control specimens at the (beam-column connection section).

4- The gained energy absorption of the strengthening frame sections (mid-span frame girder sec) after fire exposure were (39% to 118%) of the control specimens, and were (63% to 155%) of the control specimens at the (beam-column connection section).

5- The rapid water cooling has a greater effect than the slow air cooling on the gained strength, gained ductility, and gained energy absorption for the two sections of frame, but it's had no significant effect on the gained stiffness.

6- The gained strength of glass fiber strengthened frame specimens after fire exposure which were cooled using rapid water cooling has an inverse proportional with beam - column stiffness ratio $(\mathbf{I_b / I_c})$, but in case of cooling using slow air cooling, it hasn't any significant effect for the proportional beam - column stiffness ratio $(\mathbf{I_b / I_c})$.

7- Strengthening Scheme type III indicated more acquired energy absorption than strengthening scheme type I and type II for frame specimens were cooled using rapid water cooling after fire exposure, while in case of cooling using slow air, there are not any significant effect on energy absorption for any strengthening scheme.

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تقوية الإطارات الحرسانية المسلحة المحملة بعد التعرض للحريق باستخدام البوليمرات المقواة بالألياف

إن تقوية الإطارات الخرسانية المسلحة أثناء تحميلها محض اهتمام كبير من جانب الباحثين والعاملين في مجال الهندسة الإنشائية نظرا لأهميتها وخطورتها عند الإنهيار. ومن أساليب تقوية هذه الإطارات هي لصق شرائح من الألياف الزجاجية أو الألياف الكربونية لسهولة عملها وسرعة تنفيذها. أغلب الأبحاث السابقة تم إجراؤها علي عناصر إنشائية منفصلة مثل أعمدة ، كمرات وبلاطات محملة سابقا أو تم تحميلها وإزالة الحمل ثم عمل التقوية ، لذا رأينا في هذا البحث أن تكون التقوية أثناء تحميل منشأ عبارة عن إطار مكون من كمرة وعمودين بعد تعرضه للحريق ، وقد تمت الدراسة في ظل المتغيرات الآتية:

1- طريقة التبريد بعد التعرض للحريق: تم تبريد مجموعة من الإطارات باستخدام المياه ومجموعة أخرى تم تركها فى الهواء لتبرد تماما

2- مكان التقوية بالألياف : تم تقوية مجموعة من الإطارات أسفل الكمرة ، المجموعة الثانية تم تقويتها بإضافة شرائح الألياف الزجاجية بالجانب الخارجي من العمود وأعلى الكمرة من الطرف ، أما المجموعة الثالثة فتم تقويتها باستخدام شرائح الألياف الزجاجية كما فى المجموعة الأولى والثانية معا.

*3- التحميل السابق أثناء التقوية: لجميع الإطارات المقواة ، تمت التقوية عند حمل سابق يعادل **30%** من حمل الإنهيار لعينة التحكم ، .*

*ولدراسة المتغيرات السابقة تم في هذا البحث ، تم إختبار ودراسة عدد **9** إطارات من الخرسانة المسلحة بأبعاد تمثل ثلث أبعاد الإطارات الحقيقية في الطبيعة ، حيث تم إختيار جميع الأعمدة ذات قطاعات ثابتة مستطيلة الشكل بعرض **15** سم وطول **24** سم وارتفاع صافي **140** سم ، أما كمرات الإطار فقسمت إلى ثلاث ، المجموعة الأولى بعرض **15** سم وطول **24** سم ، والثانية بعرض **15** سم وطول **30** سم ، أما المجموعة الثالثة بعرض **15** سم وطول **36** سم ، وذلك للأخذ فى الاعتبار نسب القصور الذاتى لقطاعات الكمرة والأعمدة ، أما طول الكمرات فكان جميعها **250** سم . وكانت نسبة التسليح ثابتة في جميع الكمرات ، وتسليح متساوي في جميع الأعمدة ، وقد قسمت الإطارات التسعة إلي ثلاث مجموعات ، المجموعة الأولي هي مجموعة التحكم ثلاث عينات بدون تقوية وقد حملت بحمل حتي الإنهيار لتحديد حمل إنهيار الإطار والذي علي أساسه تم تقوية بقية الإطارات في باقي المجموعات تحت حمل يعادل قيمة **30%** من حمل الإنهيار لعينة التحكم ، بعد تعرضها للحريق بدرجة **600** درجة مئوية ولمدة لا تقل عن ساعتين ، ثم تبريد نصف المجموعات بالماء (المجموعة الثانية – ثلاث عينات) والنصف الأخر (المجموعة الثالثة – ثلاث عينات) بردت بالهواء بعد ذلك تم تكملة تحميل الإطارات بعد تقويتها باستخدام الألياف الزجاجية في ثلاث أماكن ، حتي الوصول إلي درجة الإنهيار . تم*

تحليل النتائج ودراسة تأثير تقوية الإطارات علي كل من قيم حمل الإنهيار، الإزاحة الطولية ، مقدار الطاقة الممتصة من الإطار، والترخيم . وقد أدت الدراسة إلي النتائج الآتية:

1- المقاومة المكتسبة باستعمال الألياف الزجاجية لتقوية الإطارات بعد تعرضها للحريق تقريبا **65** % زيادة عن مقاومة عينات التحكم.

2- تقدر قيمة الكزازة الإبتدائية لقطاعات منتصف كمرة الإطارات المقواة بعد التعرض للحريق من **6.5** % إلى **43**% من قيمة عينة التحكم بينما تقدر قيمة الكزازة الإبتدائية لقطاع عند إتصال العمود بالكمرة للإطارات المقواة بعد التعرض للحريق من **10** % إلى **70** % من قيمة عينة التحكم المثيلة لها.

3- يقدر معامل الممطولية المكتسب لقطاعات منتصف كمرة الإطارات المقواة بعد التعرض للحريق من **95** % إلى **362** % من قيمة عينة التحكم بينما تقدر نفس القيمة لقطاع عند إتصال العمود بالكمرة للإطارات المقواة بعد التعرض للحريق من **55** % إلى **259** % من قيمة عينة التحكم المثيلة لها.

4- الطاقة الممتصة المكتسبة لقطاعات منتصف كمرة الإطارات المقواة بعد التعرض للحريق من **39** % إلى **118** % من قيمة عينة التحكم بينما تقدر قيمة الطاقة الممتصة المكتسبة لقطاع عند إتصال العمود بالكمرة للإطارات المقواة بعد التعرض للحريق من **36** % إلى **155** % من قيمة الطاقة الممتصة لنفس القطاع بعينة التحكم المثيلة لها.

5- تبريد الإطارات المعرضة للحريق بطريقة أسرع باستخدام المياه أكثر تأثيرا على قيم كل من المقاومة المكتسبة ، الممطولية المكتسبة والطاقة الممتصة المكتسبة لكلا القطاعين منتصف كمرة الإطار وقطاع إتصال العمود بالكمرة ، بينما التبريد باستعمال الهواء ليس له تأثير يذكر على القيم السابقة.

6- تتناسب المقاومة المكتسبة للإطارات المقواة بعد تعرضها للحريق تناسبا عكسيا مع قيمة نسبة عزم القصور لقطاع الكمرة إلى عزم القصور لقطاع العمود ، بينما لا يوجد تأثير يذكر فى حالة التبريد البطئ باستخدام الهواء.

7- شكل التقوية رقم **(3)** عن طريق تقوية كمرة الإطار من أسفل وكذلك تقوية ركن الكمرة والعمود من أعلى ةمن الخارج على التوالى أكثر إكتسابا للطاقة الممتصة عن شكل التقوية رقم **(1)** ، **(2)** والتى تقوى فيها كل من قطاع الكمرة من أسفل وقطاعى الكمرة والعمود من أعلى ومن الخارج كل على حدى ، وذلك للإطارات التى بردت بالمياه بعد التعرض للحريق بينما التبريد باستعمال الهواء ليس له تأثير يذكر على القيم السابقة.