Retrofitting Reinforced Concrete One–Way Damaged Slabs Exposed to High Temperature

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ABSTRACT:

Exposure of reinforced concrete buildings to an accidental fire may result in cracking and loss in the bearing capacity of their major components, columns, beams, and slabs. It is a challenge for structural engineers to develop efficient retrofitting techniques that enable RC slabs to restore their structural integrity, after being exposed to intense fires for a long period of time. Experimental investigation was carried out on twenty one slab specimens made of self compacting concrete, eighteen of them are retrofitted with CFRP sheets after burning and loading till failure while three of them (which represent control specimens) are retrofitted with CFRP sheet after loading till failure without burning. All slabs had been tested in a simply supported span and subjected to two-point loading. The main variables were the effect of different temperature levels (300ºC, 500ºC and 700ºC), different concrete compressive strength (20MPa, 30MPa and 40MPa) and cooling rate (gradually and sudden cooling conditions) on the behavior of retrofitted one way slabs .The structural response of each slab specimen was investigated in terms of load-deflection behavior, ultimate load carrying capacity and mode of failure. The experimental results, generally, indicate that slabs retrofitted using CFRP sheets restored flexural strength values nearly equal to or lower than those of the reference slabs, the retrofitted slabs exhibited larger deflection than the control slabs at ultimate loads. Retrofitted control slabs after loading regained about 93.95% to 97.92% of their original load capacity (before retrofitting) while the other slabs regained from 42.% to 84% of the load capacity of the original control specimens. Most of the tested slabs failed by concrete crushing at mid span and partial debonding of certain retrofitting systems was also observed for a few cases.

KEY WORDS: Retrofitting , Reinforced concrete one–way slabs ,CFRP, High temperature

اعادة تاهيل البلاطات باتجاه واحد الخرسانية المسلحة المتضررة المعرضة الى درجات حرارية عالية

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الخلاصة:

إن تعرض البنايات الخرسانية المسلحة لدرجات حرارة عالية (الحريق) يؤدي إلى تشققات ونقصان في قابلية التحمل لأجزائها الرئيسية كالأعمدة ، العتبات والبلاطات .إن تطوير تقنية لإعادة تأهيل البلاطات الخرسانية ليستعيد المنشأ نسبة من سلامته وتكامله بعد تعرضه للحريق لفترة طويلة تعتبر احد التحديات الكبيرة التي تواجه المهندس الإنشائي. في هذه الدراسة تم إجراء فحوصات مختبريه على نماذج من البلاطات الخرسانية المسلحة لبيان تأثير تأهيل البلاطات باستخدام ألياف الكاربون البوليمرية المسلحة على استرجاع قابلية التحمل بعد تعرضها لدرجات حرارة مختلفة (300 ، 500 ، و 700 درجة مئوية) وتحميلها لحد الفشل. لقد اجريت الفحوصات المختبرية على واحد وعشرين (21) نموذجا ذات خرسانة مرصوصة ذاتيا ، ثمانية عشر (18) نموذجا منها قد أعيد تأهيلها بعد حرقها وتحميلها لحد الفشل بينما أعيد تأهيل ثلاث (3) منها بعد تحميلها لحد الفشل دون حرقها وهي النماذج المرجعية. لقد تم فحص البلاطات تحت تأثير نقطتي تحميل وبفضاء بسيط الإسناد وكانت المتغيرات هي : درجات حرارة مختلفة ، مقاومة انضغاط مختلفة و طريقة تبريد مختلفة (تبريد مفاجئ وتدريجي) وقد ركزت الدراسة على تأثير هذه المتغيرات على علاقة الحمل- الانحناء ، وقابلية التحمل القصوى ونوع الفشل ومقارنة النتائج مع نتائج النماذج المرجعية (وهي النماذج التي لم

تتعرض للحريق) قبل إعادة تأهيلها. لقد تبين من النتائج أن البلاطات التي أعيد تأهيلها قد استعادت نسبة من المقاومة مساوية تقريبا أو أقل من المقاومة الأصلية كما تبين أن الانحراف للبلاطات التي أعيد تأهيلها تحت تأثير الحمل الأقصى اكبر من الانحراف للنماذج المرجعية. لقد استعادت النماذج المرجعية بعد إعادة تأهيلها من 93.95% إلى 97.92% من سعة الحمل الأقصى الأصلي بينما استعادت باقي النماذج من 42% إلى 84% من سعة الحمل الأقصى الأصلي للنماذج المرجعية. معظم النماذج المفحوصة فشلت بتهشم الخرسانة في وسط الفضاء كما لوحظ أن بعضها قد فشل بانعدام التماسك بين طبقة الألياف والخرسانة.

1. INTRODUCTION:

Repair and strengthening of existing RC structures is of great interest not only for extending their service life, but also – and rather often – for their retrofitting after being damaged during exceptional events such as earthquake and fire . . etc. Retrofitting of reinforced concrete slabs with (FRP) composite is becoming an attractive alternative in the construction industry. These laminates offer the advantages of composite materials, such as immunity to corrosion, and allowing a high strength to weight ratio **[Klaiber et al, 2003]**. Due to the usually high cost of new construction there is an increasing need for repair, strengthening, or retrofit of RC structures. The concrete repair manufacturing industry is responding by producing new and more advanced materials for concrete repair and retrofit. A new structure composite technology that uses FRP has recently emerged as a very practical tool for strengthening and/or retrofitting of concrete structures, because of FRP's excellent strength to weight ratios. Reduced FRP material costs, relatively unlimited material length, comparably simpler construction and immunity to corrosion are some advantages of FRP. There are many types of FRP such as Carbon Fiber Reinforced Polymer, Glass Fiber Reinforced Polymer and Aramid Fiber Reinforced Polymer. The use of externally bonded fibre reinforced polymer (FRP) for strengthening bridges and other reinforced concrete (RC) structures has received considerable attention in recent years **[Meir, 1987]**. Experimental investigations conducted by **[Kim *et al.*, 2010; Smith et al., 2009; Mosallam and Mosalam , 2003 and Teng et. al, 2002]** demonstrate the advantages of retrofitting or strengthening of existing RC slabs using rectangular FRP sheets or thin plates bonded to the tensile face. On the other hand, a brittle and sudden failure due to delamination of FRP sheets or thin plates has also been observed. **[Haddad et. al ,2011]** investigated the behavior of reinforced concrete slabs repaired with advance composite materials and study the effect of repairing on increasing the flexural capacity of burn-damaged slabs . The results showed that most of the repaired slabs could approach their original stiffness and strength of unburnt slabs. In previous research **[Hammadi et al, 2012]** which was carried out to study the effect of fire flame on the behavior and strength of one way self compacted RC slabs specimens by burning eighteen of them in fire flame at different temperatures then loaded them until failure, while three specimens are loaded till failure without burning, they represent the reference specimens as indicated in **Table 1** . In this study the same damaged specimens are retrofitted by CFRP and loaded till failure to investigate the efficiency of retrofitting system to restore the load capacity of burned - damaged slabs.

2. EXPERIMENTAL PROGRAM

2.1 Material properties:

Type I Portland cement, fine aggregate with (4.75mm) maximum size, coarse aggregate with (10mm) maximum size, water , superplasticizer , silica fume and reinforcing bars are used in casting slabs. Smooth reinforcing steel bars were of diameter 3mm (2.93mm). The reinforcing ratio was constant, details of reinforcement as shown in **Fig 1 and 2**. The results of yield stress test of steel bars show that the yield stress value of bars was (800 MPa) with modulus of elasticity (195.9 GPa). The unidirectional SikaWrap Hex-230C is an externally applied retrofitting system for RC slabs. Carbon fiber fabric SikaWrap Hex- 230C and epoxy based impregnating resin Sikadur-330 properties are shown in **Tables 2** and **3** as reported by the manufacturer.

2.2 Concrete mix proportions:

In this research, three groups of compressive strength of self-compacting concrete has been used. The ratios of mixing are resulted by casting trial mix cubes and testing in (7 days) age. Every trial mix has six cubes of (100 × 100 × 100mm). three cubes are tested to find out the compression strength of the concrete before burning and the other three are tested after burning. **Table 4**, shows the details of mixes, while **Table 5** shows the compression strength before and after exposure to fire flame.

2.3 Experimental procedure

Twenty one reinforced concrete slabs were tested. All of specimens have the same dimensions, length is 500mm, width is 250mm and their thickness was 40mm. The reinforcement for all specimens are $(6-\phi 3mm)$ in long direction and $(8-\phi 3mm)$ in short direction. The dimensions and reinforcement of the slabs are shown in **Figs. 1 and 2.** The slabs in this research are divided in to three groups; R, G and S. Group R contain three specimens which are not exposed to temperature representing the reference specimens; each specimen has a different strength (20, 30 and 40 MPa). Each of groups G and S has nine specimens; the difference between them is in the method of cooling after exposing to high temperature. Group G is gradually cooled while group S is suddenly cooled by water. Each groups G and S is divided into three subgroups; each of them has a different strength (20, 30 and 40 MPa). The three specimens of each subgroup are exposed to a different temperature (300, 500 and 700 C^0). All slabs were tested under two point loads until failure and then were retrofitted with two layer of CFRP sheets and renamed (FR, FG and FS) for (group R, groups G and groups S) respectively. The detailed classification of groups is shown in **Table 6.**

2.4 Retrofitting process

After burning slab at high temperature and loading until failure, the slab was overturned (upside down) so that retrofitting should be done on its bottom surface. In order to ensure correct application of the external strengthening materials and to remove the deformation (curved shape) due to the loading at the first stage (after burning the specimens and before retrofitting them), it was considered necessary to improve the concrete surface characteristics on the contact areas to be bonded . It included removing the cement paste, The spalled areas at corner of slabs were patched conventional concrete repair methodologies, grinding the surface by using an electrical hand grinder, and removing the dust generated by surface grinding using an air blower. After that the primer was applied to repair surfaces with non-shedding brush. The adhesive was applied to the tension face of the slab Sikadur®-330 (two-part epoxy impregnation resin) was used in this work for the bonding of CFRP sheet. The two-part epoxy was mixed according to the manufacturer’s specification: 4 parts resin to 1 part hardener by weight. The epoxy system was thoroughly hand mixed for at least 3 minutes at room temperature. The CFRP sheets placed in the bottom of slab after applying thin layer of epoxy. The time gap between the CFRP sheets bonding and the slab test was at least 7days. The procedure of applying of CFRP is shown in **Figs. 3 to 6.**

2.5 Test setup

All specimens were loaded by two point loads until failure using hydraulic testing machine in the Structural Laboratory at the College of Engineering of Baghdad University as shown in **Fig. 7**. The distance between the specimen supports was 400mm and the distance between each point load was100mm. Deflection of the slab specimens was measured at mid-span using a dial gauge with travel distance of 50 mm and accuracy of 0.01 mm.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Results of ultimate load, maximum deflection and percentages of residual ultimate load of specimens exposed to high temperature and retrofitted specimens are summarized in **Table 7.** The behavior of the retrofitted slabs was investigated in terms of load-deflection , ultimate load carrying capacity and mode of failure to make comparisons with the performance of the original unburned slabs (reference specimens). The role of different parameters affecting the strength and deflection of retrofitted specimens is discussed in the following paragraphs in some detail.

3.1 Load-mid span deflection relationship

The retrofitted slabs exhibited larger deflection than the damaged reference slabs at ultimate load. This observation deviates from test results reported by **[Chan and Niall,2001]**, who showed that the deflections were higher in the specimens with preload prior to applying FRP laminates and the load-deflection behavior becomes brittle.

All retrofitted slabs behaved similarly, it can be observed that the load versus mid-span deflection response can be divided into two stages of behavior. The first limited stage was characterized by an approximately linear relationship between the load and the mid-span deflection. During this stage of behavior, the section was uncracked (no new cracks were observed) and both the concrete and steel, in addition to the CFRP sheet, behave essentially elastic. The second stage represents the behavior post initial cracking of the composite section (exhibit inelastic behavior) where the stiffness of the slab was decreased as indicated by the reduced slope of the load versus mid-span deflection curve.

The stiffness of specimens R and specimens FR were nearly identical as shown in **Fig. 8**. Similar remarks have been made by **[Obaidat et al, 2010].** It should be noted that repair of reference slabs after loaded allowed recovering the original stiffness.

Slab specimens FG and FS for all compressive strength at all exposure temperature showed decreases in stiffness when compared with the of reference slab specimen R. The stiffness of specimens (FG and FS) is higher than (G and S) respectively at the earlier loading stage. After initiating new cracks or growing the old cracks due to loading, the stiffness of (FG and FS) is decreases than (G and S) respectively as shown in **Figs. 9 to 11** . It should be noted that repair groups (S) and (G) could not restore the stiffness to the level of the reference slabs.

3.2 Ultimate load

From **Table 7** the percentage of residual ultimate load carrying capacity with respect to reference slabs was 97.92%, 93.95% and 97.17% for specimens FR20, FR30 and FR40 respectively indicating that repair of specimens loaded until failure allowed approximately restoring original load carrying capacity . There was no significant difference in the load carrying capacity for slabs R (without burning and without retrofitting) and FR (without burning but retrofitting after loading until failure). No codes and standards have consistently taken the influence of preload and overload level into account and there are not enough experimental data for investigating the influence of the preload level on ultimate strength. **[Tan and Mathivoli 1997 , Arduini and Nanni 1997 and Shbeeba, 2012]** noted that there was a drop in ultimate capacity due to preload, other researchers such as **[Chan and Nail ,2001; Rahimi and Hutchinson 2001]** reported that the level of preload (i.e., the presence of existing cracks) did not have any effect on the ultimate capacity of the strengthened slabs .

The average percentage of residual ultimate load carrying capacity for specimens (FG) is 78.74, 74.16 and 55.37 at 300, 500 and 700 °C respectively and the average percentage of residual ultimate load carrying capacity for specimens (FS) is 75.48, 65.82 and 45.42 at 300, 500 and 700 °C respectively . So, the average percentages of residual ultimate load carrying capacity for gradual cooling was larger than for sudden cooling by 3.26%, 8.34% and 9.95% for 300, 500 and 700 °C respectively. Clearly, the retrofitting system adopted here could not return the slabs (FG and FS) to their original strength prior to burning, this because, the retrofitting process including two zones: First, retrofit the tension cord (the damaged steel reinforcement bars due to burning and preloading) by using laminate CFRP sheets. Second, the compression cord, which is the default part of retrofitting, because there is no epoxy with low viscosity be ensure that inter and close all cracks .However , repairing with CFRP provided reasonable enhancement in restoring the original load carrying capacity. These results were due to the serious damages in slabs associated with exposure to high temperature and loading until failure .It is seen that the failure mode of debonding of FRP for slabs subjected to (700) ^{0}C temperature, reduces the effectiveness of FRP by not utilizing the strength of FRP. Debonding phenomenon is a major effect for the reduction on the flexural strength **[Mohammad et al. 2007, Kaur et al. 2007, Zhang et al. 2006, Sergio and Beth 2004]**.

3.3 Mode of failure

In general, most of the tested slabs failed by concrete crushing at mid span and partial debonding of certain retrofitting systems was also observed for a few cases. For all slabs subjected to 300 ^{0}C temperature and slabs FR group, few flexural cracks started first at the constant moment region, also few diagonal cracks near the supports were observed, with increasing applied load, one of these cracks developed diagonally to the nearest loading point. The slabs failed by crushing of the concrete in high moment region on the top surface and debonding was not observed with high elongate as shown in **Fig. 12-A** similar failure pattern was observed by **[Ramanathan,2008]** who noted that failure was characterized by compression failure of the concrete in the constant moment region on the top surface of slabs which should be expected for a section having a short effective depth.

For all slabs subjected to (500) ^{0}C temperature ,cracking started in concrete layer between the CFRP and the embedded longitudinal steel reinforcement. The slab failed by crushing of the concrete on the top surface and CFRP debonding was not observed as shown in **Fig. 12-B** for slab FG20-500.

For slabs FG20-700 , FG40-700 and FS40-700, the failure was by critical diagonal crack with debonding of CFRP sheet starting at the critical diagonal crack under point load and proceeded toward the support. The failure was extremely brittle and occurred at one end of the slab emanating from the support as shown in **Fig. 12-C** for slab FS40-700 and FG40-700. This type of collapse has also been reported as a failure mechanism for the externally bonded FRP on RC one-way slab systems **[Ramanathan,2008]**. For slabs FS20-700 , FG30-700 and FS30-700, diagonal crack originated under an external load point in the region of combined highest moment and shear and propagated toward the support .This crack generated high stresses in the CFRP sheet. Since the concrete could not maintain the interface shear and normal stresses, the CFRP separation was initiated at the location where the diagonal crack contacted the CFRP and propagated in the direction of decreasing moment (toward the support). Failure of the test specimen was by CFRP debonding at the end span with sudden failure by complete separation of the concrete as shown in **Fig. 12-C** for slab FS20-70. This type of collapse has also been reported as a failure mechanism for the externally bonded FRP on RC one-way slab systems **[Karbhari etal. ,1999; Tann, 2003 ;Ramanathan,2008; Shadhan,2011]**.

3.4 The effect of different parameters (compressive strength, high temperature exposure and type of cooling method) on the strength and deflection of retrofitted slabs.

The ultimate load of retrofitted slabs increased with an increase in the compressive strength of concrete and decrease with increase in exposure temperatures . The percentage of the residual ultimate load capacity is found to be increased proportionally with compressive strength of concrete .Similar remarks have been made by **[An et al ,1991 and Khomwan et al ,2005]** who documented that an increase in the compressive strength of concrete increased the ultimate load of the section, in contrast **[Mckenna ,1993]** concluded that the compressive and tensile strength of the concrete used do not appear to affect the maximum load at which the carbon fibre sheet fails significantly.

Considering the diagrams in **Fig. 13** it can be concluded that the specimens with high compressive strength show more stiff behavior than slabs with low compressive strength at all exposure temperature . The effect of exposure temperature was very clear on both slabs FG and FS, **Fig. 14** show the comparison between specimens with different exposure temperature at the same compressive strength, the stiffness increased when the temperature decreased. When comparison are made between (FG) and (FS) for all compressive strength at all exposure temperature, it was shown that the stiffness of specimens cooled suddenly are lower than that specimens cooled gradually. This is because of the formation and propagating of the cracks due to the burning process, which had a great effect on the rigidity of the slab specimens, causing a high mid-span deflection. Also, the rate of cooling affects this propagation of cracks, where it increased as the rate of cooling increased, resulting in decrease in the rigidity and increase in deflection. In addition to the more cracks which allowed to higher debonding between the concrete and the steel bars. The ultimate loads of the specimens cooled suddenly were less than the specimens cooled gradually for the same compressive strength concrete because of the more minor cracks in the specimens cooled suddenly by water resulted in reducing in the bonding between the steel bars and concrete

3.5 Conclusions

Based on the experimental results and test observations the following conclusions can be drawn:

- The test results indicated that a significant gain in flexural strength can be achieved by bonding CFRP laminates to the tension face of RC slabs which were burned and loaded till failure.
- Slabs FR repair with CFRP regained 97.92%, 93.95% and 97.17% of the original load capacity for the specimens FR20, FR30, FR40 respectively while for group FG and FS ,the average percentage of residual ultimate load carrying capacity

for specimens (FG) is 78.74, 74.16 and 55.37 at 300, 500 and 700 °C respectively and the average percentage of residual ultimate load carrying capacity for specimens (FS) is 75.48, 65.82 and 45.42 at 300, 500 and 700 °C respectively .So, the average percentage of residual ultimate load carrying capacity for gradual cooling was larger than for sudden cooling by 3.26%, 8.34% and 9.95% at (300, 500 and 700 °C) respectively.

- The ultimate load of the retrofitted slabs (FG and FS) increased with an increase in the compressive strength of concrete and decrease due to exposure temperatures prior to applying FRP sheets.
- The retrofitted slabs exhibited larger deflection than the reference slabs at ultimate loads**.**
- Slabs with high compressive strength show more stiff behavior than slabs with low compressive strength at all exposure temperatures . The effect of exposure temperature was very clear on both slabs FG and FS, the stiffness increased when the temperature decreased.
- Most of the tested slabs failed by concrete crushing at mid span and partial debonding of certain retrofitting systems was also observed for a few cases.

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Table 1: Details of slabs before Retrofitting [Hammadi,2012].

Group	*No.*	*Concrete Strength*												*Type of cooling*
		20				*30*				*40*				
		Temp. C ^{o}				*Temp. . C ^{o}*				*Temp. . C ^{o}*				
		NE	*300*	*500*	*700*	*NE*	*300*	*500*	*700*	*NE*	*300*	*500*	*700*	
R	**3**	**1**	**-**	**-**	**-**	**1**	**-**	**-**	**-**	***1***	**-**	**-**	**-**	**-**
G	**9**	-	***1***	***1***	***1***	-	***1***	***1***	***1***	-	***1***	***1***	***1***	***Gradual.***
S	**9**	-	***1***	***1***	***1***	-	***1***	***1***	***1***	-	***1***	***1***	***1***	***Sudden.***

NE = No exposure to high temperature
R: Refference or control specimen

Table 2: Technical properties of CFRP sheets [from manufacturer].

Properties	**SikaWarp® Hex-230C**
Tensile strength (MPa)	4100
E-modulus (GPa)	230
Elongation at break (%)	1.7
Width (mm)	300/600
Thickness (mm)	0.12

Table 3: Technical properties of impregnation resin [from manufacturer].

Properties	**Sikadur®-330**
Tensile strength , MPa	30
Density	1.30kg/l$_{\pm.1}$ kg/l
E-modulus , GPa	4.5
Open time , min.	30 (at +35^{o}C)
Full cure , days	7(at +35^{o}C)
Mixing ratio	1:4
Elongation at Break	0.9%

Table 4: Concrete mix details of SCC mixes [Hammadi,2012].

No.	Mix properties / Concrete strength (MPa)	Cement Kg/m^3	Fine agg. Kg/m^3	Coarse agg Kg/m^3.	SP (Glenium51) Lit/m^3	S.F Kg/m^3	Water Lit/m^3
1	20	400	600	640	12	8	228
2	30	400	600	640	12	8	200
3	40	500	600	640	15	10	200

S.F. : Sillica fume

Table 5: Results of compression test for burned and reference cubes

Groups of Method Compressive f 'c	Compressive Strength of Cubes				Method of Cooling
	*Reference Cube (MPa)	Burned Cubes (MPa)			
		Temperature of Burning			
		300°C	500°C	700°C	
Grade 20 MPa	19.6	18.03	15.09	9.21	Gradually
		16.85	13.72	7.84	Suddenly
Grade 30 MPa	28.8	25.63	20.45	12.96	Gradually
		24.48	19.29	10.94	Suddenly
Grade 30 MPa	37.8	32.51	25.70	15.87	Gradually
		30.99	23.81	12.47	Suddenly

* Control Specimens without burning.

Table 6: Details of slabs after Retrofitting.

Group	No.	Strength												Type of cooling
		20				30				40				
		Temp.				Temp.				Temp.				
		NE	300	500	700	NE	300	500	700	NE	300	500	700	
FR	3	1	-	-	-	1	-	-	-	1	-	-	-	-
FG	9	-	1	1	1	-	1	1	1	-	1	1	1	Gradual.
FS	9	-	1	1	1	-	1	1	1	-	1	1	1	Sudden.

NE = No exposure to high temperature but loaded until failure

Table 7 : Load and Deflection Characteristics at Ultimate Loads

Results before retrofitting				Results after retrofitting			
Specimen No.	Ultimate load (N)	Maximum deflection (mm)	Percentages of residual ultimate load %	Specimen No.	Ultimate load (N)	Maximum deflection (mm)	Percentages of residual ultimate load %
R20	12000	7.43	100	FR20	11750	7.9	97.92
G20-300	9780	7.81	81.5	FG20-300	9100	8.5	75.83
S20-300	9350	9.33	77.9	FS20-300	8500	10	70.83
G20-500	9000	9.89	75	FG20-500	8110	11.12	67.58
S20-500	8200	11.32	68.3	FS20-500	7210	12.92	60.08
G20-700	7480	15.27	62.3	FG20-700	6120	17.3	51
S20-700	7000	16.2	58.3	FS20-700	5500	18.1	45.31
R30	12932	7.2	100	FR30	12150	7.85	93.95
G30-300	11085	7.74	85.7	FG30-300	9981	8.2	77.18
S30-300	11000	9.2	85	FS30-300	9825	10.1	75.97
G30-500	10800	9.74	83.5	FG30-500	9920	11.1	76.70
S30-500	10000	10.87	77.3	FS30-500	8850	12.4	68.43
G30-700	9350	11.23	72.3	FG30-700	7950	13.95	61.48
S30-700	7811	13.48	60.4	FS30-700	6248	16.55	48.31
R40	14000	6.64	100	FR40	13605	7.4	97.17
G40-300	12932	7.46	92.3	FG40-300	11652	8.15	83.22
S40-300	12600	8.33	90	FS40-300	11150	9.1	79.64
G40-500	12000	9.53	85.7	FG40-500	10950	10.67	78.21
S40-500	11085	10.21	79.1	FS40-500	9655	11.95	68.96
G40-700	10836	10.3	77.4	FG40-700	7509	11.4	53.64
S40-700	9000	12.52	64.2	FS40-700	5900	13	42.14

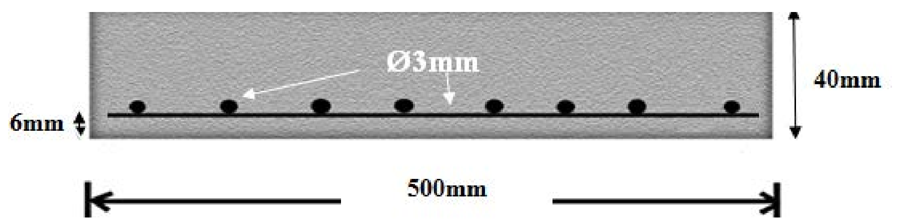


Figure 1 :side cross of slab

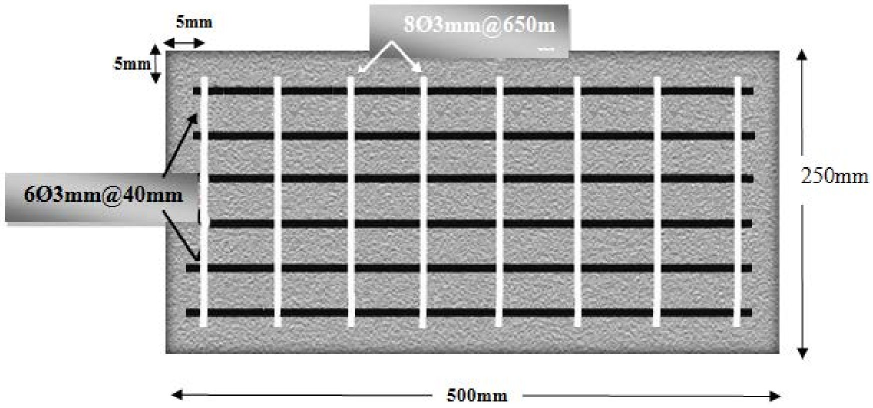


Figure 2 :Top view of slab with reinforcement details

Figure 3: Repair of damaged and spalled areas of concrete with mortar (1 cement + 1 sand) at top and bottom surfaces.

Figure 4: Concrete surface preparation by grinding

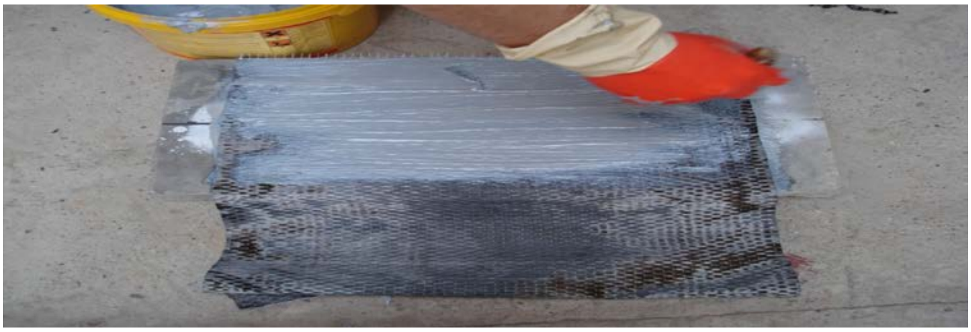


Figure 5: A thin layers of epoxy is applied between concrete surface and CFRP then CFRP first layer and second layer

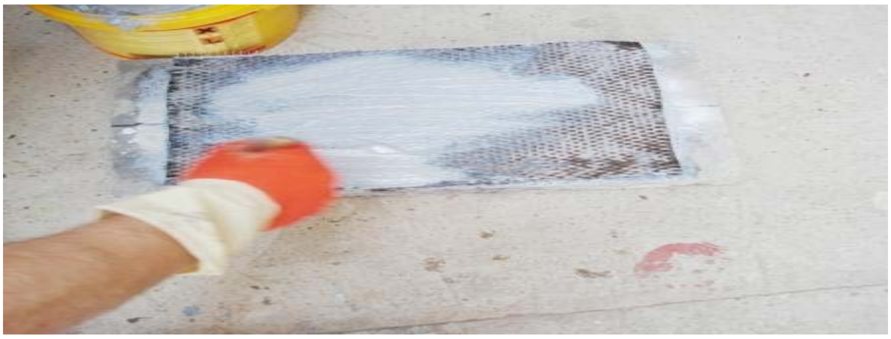


Figure 6 : Coating of the second layer of CFRP with a layer of epoxy.

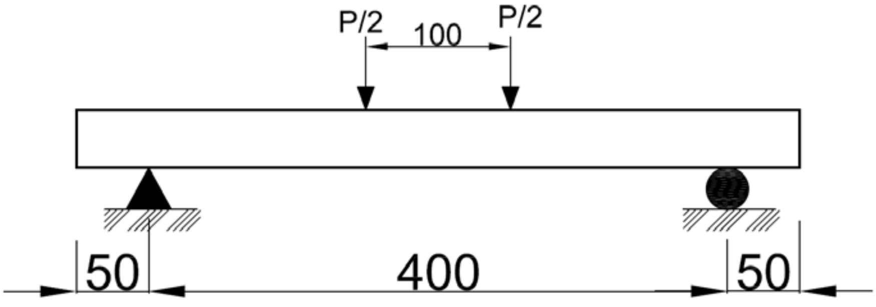


Figure 7 : Testing of specimens under two point loads

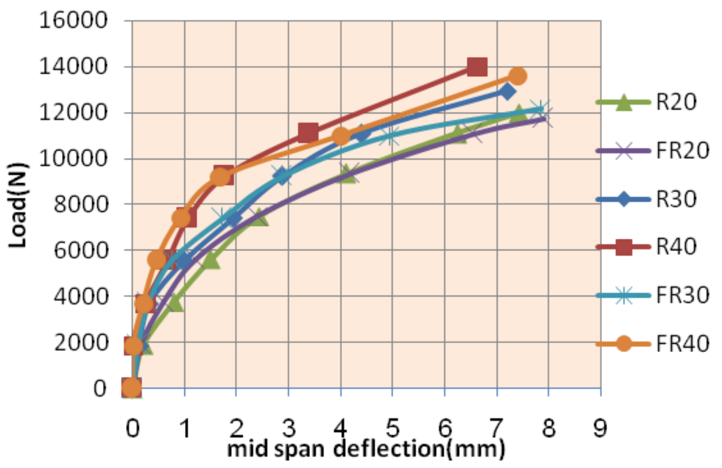


Figure 8 :load-mid span deflection relation of reference slab before and after retrofitting(R&FR)of different concrete strength

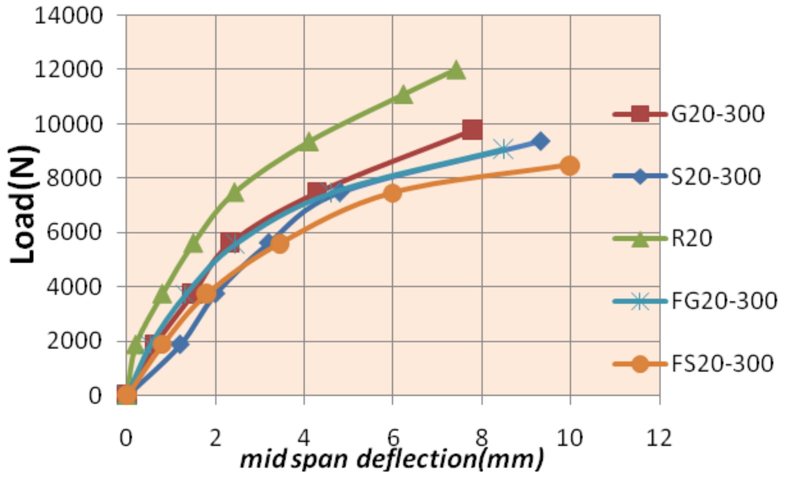


Figure 9 : Load-mid span deflection relation of slabs before and after retrofitting of f'_c=20MPa subjected to300^{0}C temperature with both cooling methods

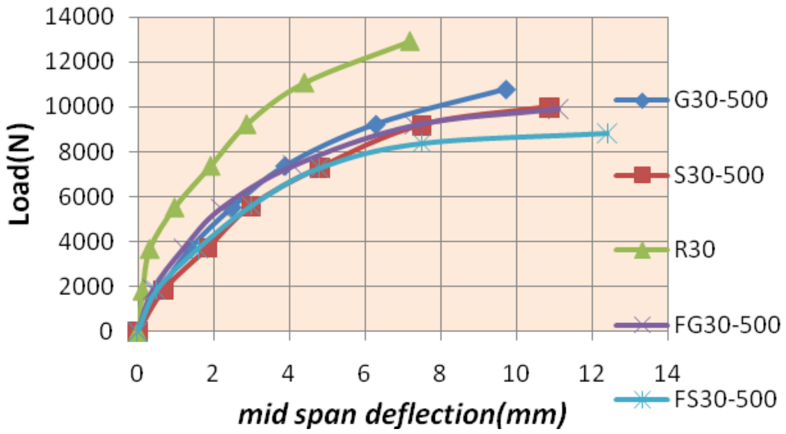


Figure 10 : Load-mid span deflection relation of slabs before and after retrofitting of f'_c=30MPa subjected to500^{0}C temperature with both cooling methods.

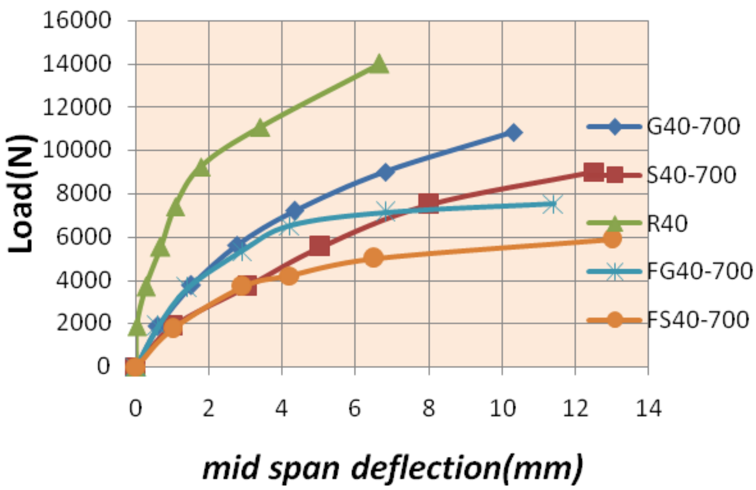


Figure 11 : Load-mid span deflection relation of slabs before and after retrofitting of f'_c= 40MPa subjected to 700^{0}C temperature with both cooling methods .

Failure of specimenFR30-300. **Failure of specimen FS20-300.**

A) Crushing of concrete at compression zone

Failure of specimenFG20-500

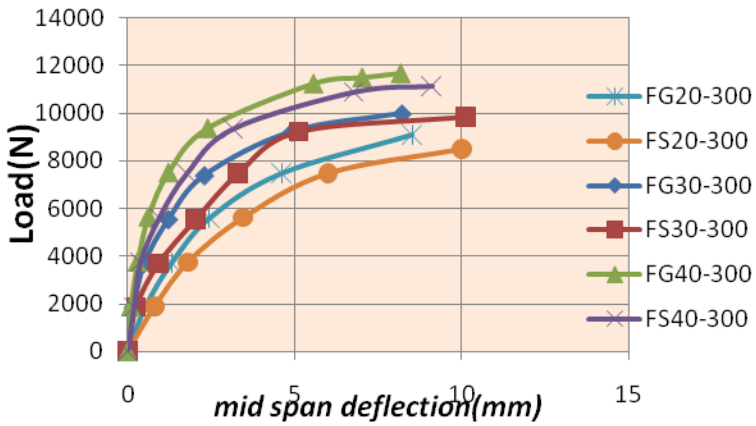
B) cracking started in concrete layer between the CFRP and the embedded longitudinal steel reinforcement

. **Failure of specimen FG40-700** **Failure of specimen FS40-700**

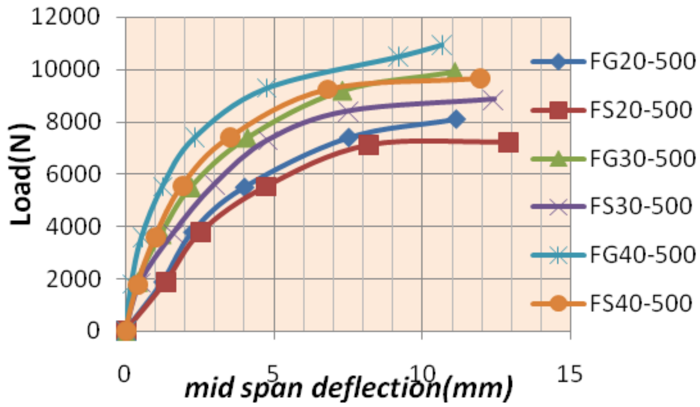
Mid span debonding of Specimen FS20-700

C) Critical diagonal crack with debonding of CFRP sheet starting brittle failure

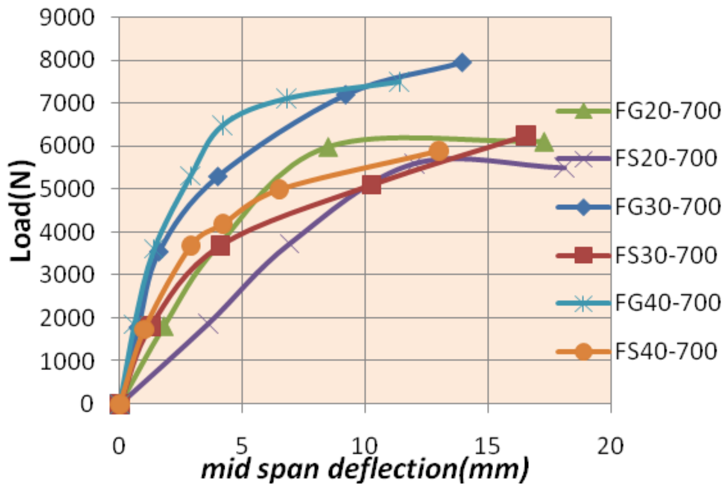
Figure 12 : Mode of Failure



(A)

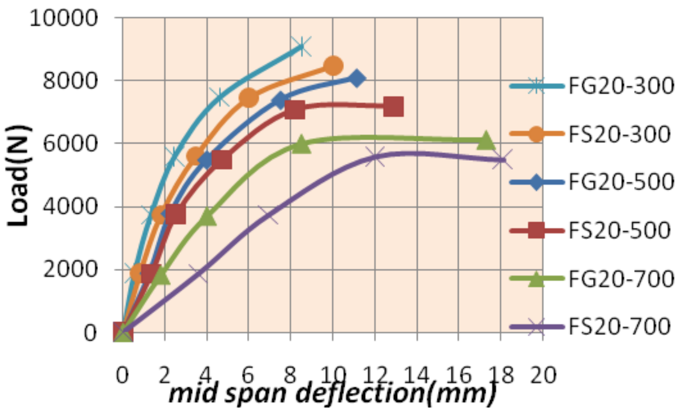


(B)

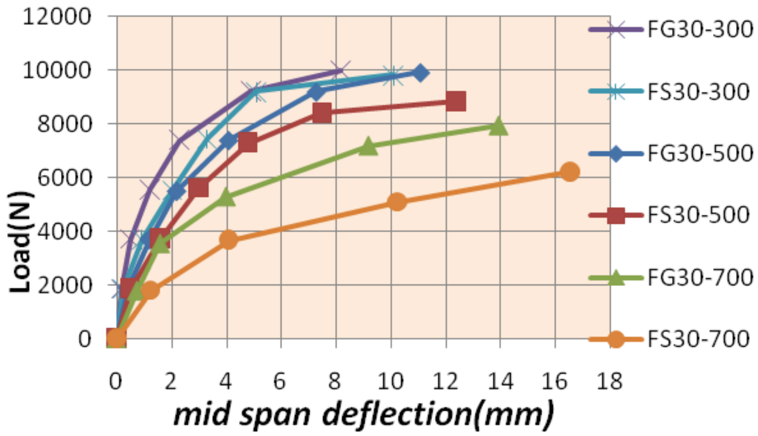


(C)

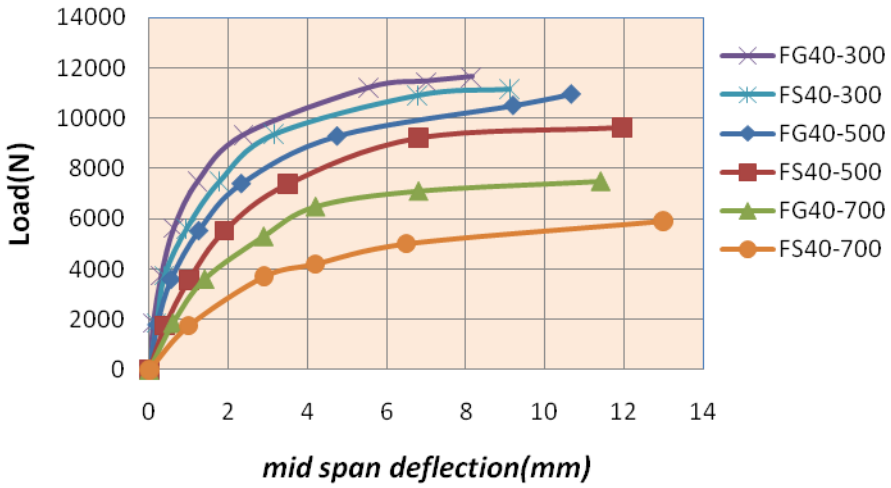
Figure 13 : Load-mid span deflection relation of retrofitted slabs(FG&Fs) with different compressive strength concrete (20MPa ,30MPa and 40MPa) at :
(A) exposure temperature 300^{0}C
(B) exposure temperature 500^{0}C
(C) exposure temperature 700^{0}C



(A)



(B)



(C)

Figure 14 : Load-mid span deflection relation of retrofitted slabs FG & FS with different exposure temperatures (300 , 500 and 700)C^0 for:
(A)compressive strength concrete(20MPa)
(B) compressive strength concrete(30MPa)
(C)compressive strength concrete(40MPa)