Effect of Elevated Temperatures on Bond Strength of Steel Reinforcement and Concrete Enhanced with Discrete Carbon Fibers

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Abstract

In the case of exposing a reinforced concrete structure to accidental fire, if this structure remain standing, an assessment of its residual capacity is needed, which requires accurate information regarding the residual capacity of concrete, steel and bond between them. In the peasant work, the effect of exposing carbon- fibered reinforced concrete to elevated temperatures on its bond strength with reinforcing steel bars was investigated. An experimental program consisted of fabricating and testing of 54 pull-out cubic specimens was prepared to serve this purpose. The specimens were divided into three groups to study the effect of addition of various amounts of discrete carbon fiber on its residual bond strength and the bond strength- slip response after exposure to temperature levels of 150°C, 250°C, 350°C,450°C and 550°C in addition to the room temperature. The carbon fiber content considered was 0.0%, 0.75% and 1.0% by weight of cement. In addition to the pull-out specimens, 9 cubes having the same pull-out specimens size (3 from each concrete group mix) were tested in compression. It was concluded that the percentage residual bond strength after exposure to temperature level of 550 °C for the concrete reinforced with 0.75% carbon fiber by weight of cement (28%) is lower than that for plain concrete and the concrete reinforced with 1.0% carbon fibers which are the same (32%). There is no clear conclusion that can be obtained concerning the effect of changing temperature levels on bond- slip response of plain concrete and that reinforced with 0.75% and 1.0% carbon fibers.

Key Words: Bond strength, carbon fiber, pull-out test, elevated temperatures.

الخلاصة

تحتاج المنشأءات الخرسانية المسلحة عند بقاءها قائمة بعد تعرضها الى الحرارة المفاجئة العالية الى تقييم قدراتها المتبقية وهذا يحتاج بدوره الى معلومات دقيقة عن القدرة المتبقية للخرسانة والحديد ومقاومة الربط المتبقية بينهما. حقق البحث الحالي في تأثير تعرض الخرسانة المسلحة بالياف كاربونية قصيرة الى مستويات من درجات الحرارة على مقاومة الربط مع قضبان حديد التسليح. تم اعداد برنامج عملي يتكون من تصنيع و فحص 54 نموذج سحب مكعب

الشكل لخدمة هذا الغرض. قسمت النماذج الى ثلاث مجاميع لدراسة تأثير اضافة كميات مختلفة من الالياف الكاربونية القصيرة على مقاومة الربط المتبقية والعلاقة بين مقاومة الربط -الانزلاق بعد تعريضها لمستويات من درجات هي 150درجة سيليزية و 250 درجة سيليزية و350 درجة سيليزية و450 درجة سيليزية و 550 درجة سيليزية بالاضافة الى درجة حرارة الغرفة. استخدمت الالياف الكاربونية بنسب 0.0% و 0.75% و 1.0% من وزن السمنت. أجري فحص الانضغاط لتسعة مكعبات بنفس حجم مكعبات السحب (ثلاث من خلطة كل مجموعة) بالاضافة الى نماذج السحب. استنتج بان النسبة المئوية لمقاومة الربط المتبقية بعد تعرض الخرسانة المسلحة ب 0.75% الياف كاربونية كنسبة وزنية من السمنت (28%) اقل من تلك المتبقية في النماذج المسلحة بالياف كاربونية بنسبة 1.0% والاعتيادية (32%). لم يتم الحصول على استنتاج واضح بخصوص تأثير مستويات درجات الحرارة على منحني المقاومة- الانزلاق للخرسانة غير المعززة والمسلحةب 0.75% و 1.0% الياف الكاربونية.

1. Introduction

1.1 Exposer of Reinforced Concrete to Elevated Temperatures

One of the major dangers confronting buildings is the exposure to elevated temperatures. There are many ways of exposing concrete structural members to elevated temperatures. One of the most common types of exposure is by accidental fire in buildings. Another way of heat exposure may be found in some industrial installations where concrete is used in places exposed to sustained elevated temperatures such as furnaces walls, industrial chimneys , floors below boilers and kiln and nuclear-reactor pressure vessels [1].

It has been known that concrete is weak in tension and has a brittle character. So, concrete is usually reinforced with continuous reinforcement to increase strength and ductility. The introduction of fibers in discrete form in plain or reinforced concrete also increases the strength and ductility. Since it makes the concrete to be more homogeneous and isotropic so, when concrete cracks, the randomly oriented fibers start functioning, arrest crack formation and propagation. There are many types of fibers such as steel fibers, glass fibers, polypropylene fiber, carbon fibers…etc [2, 3].

When a reinforced concrete structure has been involved in a fire, it is often possible to remain standing because of the good fire resisting properties of concrete. This means that in dealing with such situations, a choice can be made between reconstruction and reinstatement. Reinstatement can be often quicker and cheaper alternative. However, before a decision can be made, it is necessary to establish whether or not the damaged structure is suitable for such treatment. To do this, its residual capacity for structural performance must be assessed, which requires knowledge of the properties of steel and concrete and of the bond between them at temperature experienced in fires [4].

During the past years, extensive researches on concrete subjected to temperature were carried out. Although bond strength is one of the major characteristics with reinforced concrete structures, the amount of information concerning the residual bond strength after exposure to high temperature is limited.

1.2 Bond Strength

Bond stress between steel reinforcement and concrete is defined as the unit shearing stress acting parallel to steel bars axis [3], thus permitting the transfer of force from the concrete to the reinforcing bar and vice versa. This shear stress (bond stress) modifies steel stress in the bar, either increasing or decreasing it. It has been customary to define bond stress as shear force per unit area of bar surface, using the nominal surface of the deformed bar (which ignores the extra surface created by the lugs and ribs) [5]. Bond stress could also be measured by the rate of change of steel stress in the bar. Whether one chooses to think in this term or not, there can be no bond stress unless the bar stress changes, or there can be no change in bar stress without bond stress [4]. Another definition of the Bond strength is that, it is the resistance to slipping of the steel bar, or separation (splitting) of concrete around the bar which is embedded in concrete. This property is of a great significance in structural design of concrete members [3]. Moreover, the transfer of stress between concrete and steel has a great influence in limiting the space and the width of cracks [4, 6]. Effective bond strength creates the composite action of steel with concrete. Better performance of reinforced concrete members requires an adequate interaction between the steel bar and the surrounding concrete. This performance occurs only if an adequate bond is provided between the two materials. Resistance against slipping or Pull- out of the reinforcing bar depends upon the shape of its surface and is provided by the three components,

1- Chemical adhesion between the steel and surrounding concrete

2- Friction resistance.

3- Bearing of lugs against the concrete (mechanical interlock).

The main methods of testing bond between steel and concrete are the pull-out test and beam test. The advantages of pull-out test are the easy setup and specimens simplicity, and the additional confinement provided by the compression induced into the specimen around the anchorage area [7].

2. Experimental Program

The experimental program of the present research work consists of casting and testing of 54 pullout cubic specimens having size of 150 mm *x*150 mm *x*150 mm and 9 cubic control specimens having the same size of pullout ones to obtain the compressive strength of fibrous and non fibrous concrete. The specimens were tested according to ASTM C900 -06. The variables investigated using the pull-out specimens were: level of temperature (0 ^{o}C, 150 ^{o}C, 250 ^{o}C, 350 ^{o}C, 450 ^{o}C and 550 ^{o}C) and fiber/ cement ratio by weight (f/c).

An embedment or bonded length L_b of three times the bar diameter d_b (L_b=3d_b) was bounded by two unbounded zones (L_u), where L_u= ((L-L_b)/2) as shown in **Figure (1).** The embedment length or bonded length of three times the bar diameter is assumed to be short enough to produce approximately uniform bond stress distribution along the length, but long enough as compared with the maximum size of aggregate particles [8]. The unbounded zones were performed by covering the reinforcing bar at these regions with a plastic tube and layer of an adhesive tape. All specimens are fabricated without using lateral reinforcing bar. The steel bars were screwed from the loaded end. At a distance 100mm from the bottom end of the bar, the bar was covered in this zone with adequate number of layers of an adhesive tape, so that the bar could stand vertical at the center of the cube. The upper screwed part of the bar is fabricated to fit the testing requirements. **Plate (1)** shows the reinforcing bar details

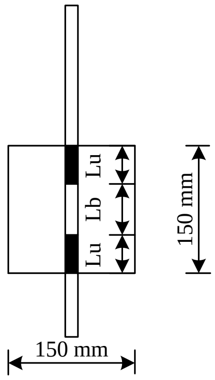


Figure (1) Testing specimen details.

Plate (1) Reinforcing bar details.

The pull- out specimens were divided into three groups. Each group consists of 18 different specimens. **Table (1)** gives pull- out details of these specimens.

The notation used are as follows: C means that the concrete is plain (without fibers), CF means that the concrete is reinforced with carbon fibers, first number in the designation represents the percentage of carbon fibers and the second number in the designation represents the heating temperature level. For example, the specimen CF-1-350 means that the specimen is reinforced with 1.0% carbon fibers and heated to 350°C.

2.1 Materials

The properties and quantities of materials used are as follows:

2.1.1 Cement, Corse Aggregate and Fine Aggregate

Ordinary Portland cement type I was used. The coarse aggregate was a 14mm maximum size crushed gravel and the fine aggregate was natural river sand (AL-Ukhaider),zone 2 according to IQS:45 1984 with a 2.71 fineness modulus.

2.1.2 Reinforcing Steel

Deformed steel bars of 20 mm nominal diameter were used; **Table (2)** shows the full properties of these reinforcing bars.

Table (1) Pull- out test specimens details.

Group	Sample Designation	No. of Specimens	Bar Diameter (mm)	Bonded Length $L_b=3d_b$ (mm)	(Fiber/cement) %
A	C-0-0	3	20	60	0.0
	C-0-150	3	20	60	0.0
	C-0-250	3	20	60	0.0
	C-0-350	3	20	60	0.0
	C-0-450	3	20	60	0.0
	C-0-550	3	20	60	0.0
B	CF-0.75-0	3	20	60	0.75
	CF-0.75-150	3	20	60	0.75
	CF-0.75-250	3	20	60	0.75
	CF-0.75-350	3	20	60	0.75
	CF-0.75-450	3	20	60	0.75
	CF-0.75-550	3	20	60	0.75
C	CF-1-0	3	20	60	1.0
	CF-1-150	3	20	60	1.0
	CF-1-250	3	20	60	1.0
	CF-1-350	3	20	60	1.0
	CF-1-450	3	20	60	1.0
	CF-1-550	3	20	60	1.0

Table (2) Properties of reinforcing bars.

Nominal Diameter	Measured Diameter (mm)	Area (mm^2)	Yeild Stress (MPa)	Ultimate Stress (MPa)	Elongation (%)
20	19.77	306.975	395.2	556.2	16

2.1.3 Discrete Fibers

The discrete carbon fibers used are shown **Plate (2)** and their properties are shown in **Table (3)**.

2.1.4 Super plasticizer

Chloride free liquid admixture commercially named Top Bond was used. Its properties and description are shown in **Table (4).**

Table (3) Properties of carbon fibers.

Type	Length mm	Carbon Content	Tensile Strength (MPa)	Young´s Modulus (MPa)	Linear Density (g/m)	Density (g/cm^3)
SY-DQCF-25	25	95%	≥ 3000	210 000	0.8	1.76

Plate (2) Discrete carbon fibers used in the present study.

Table (4) Properties and description of superplasticizer.

Appearance	Specific Gravity	Chloride Content	Flash Point
Dark Brown/Black	1.21@25 ± 2ºC	Nil.	N/A

3. Mix Proportion

Materials contents used in each mix were: 385 kg/m^3 as cement content, 578 kg/m^3 as sand content and 1156 kg/m^3 as gravel content. The water and superplasticizer contents were 223 le/ m^3 and 5.0 le/ m3. These contents lead the mix proportion to be 1:1.5:3 by weight and w/c = 0.58.

4. Molding, Casting and Curing

Steel molds with wood base were used to cast all the pull-out specimens. The molds were coated with oil before fixing the reinforcing bars in position. Then the concrete was mixed for about three minutes by using a horizontal rotary mixer of 0.19 m^3 capacity. The mix of fiber reinforced concrete should have a uniform dispersion of fibers in order to prevent segregation or balling of the fibers during mixing. External vibration is preferable to prevent fiber segregation. The specimens were then cast into three layers; each of which was compacted by a table vibrator. The pull-out specimens were cast in groups, each group was consisted of 9 cubes with three cubes of dimensions 150 mm *x*150 mm *x* 150 mm to investigate the compressive strength of concrete as shown in **Plate (3).** After casting, the specimens were covered with a nylon cover to prevent evaporation of water for a period of 24 hours. After 24 hours, the molds were stripped from the specimens and placed in water containers in the laboratory for 28 days to be cured as shown in Plate **(4).** After curing the specimens were removed from water.

Plate (3) Casting of pull- out specimens.

Plate (4) Curing of specimens.

5. Heating and Cooling

The specimens were heated by an electrical furnace (type Winger).The furnace internal dimensions are 500mmx 600mmx750mm.The specimens were heated with a slow heating rate. Once the required heating temperature level was attained, the specimens were thermally saturated for one hour at that level. Then, the furnace was switched off. The specimens were removed from the furnace and left in the air to be cooled for 20 hour before testing.

6. Tests Setup and Instrumentation

6.1 Pull- out Test

The pull-out specimens were tested by a specially fabricated testing frame as shown in **Figure (2)** according to ASTM c 900-06. The frame consisted of a fixed part made from steel sections, which consisted of two standing parts. The upper heads of the standing parts were fastened to a bearing plate by screws and welding. The bearing plate had a central hole which permits the prisms reinforcing bar to pass through. The two standing sections together with the bearing plate formed an inverted U shape, which was fastened to the steel base by means of screws and welding. Six (3 Ton) capacity hydraulic jacks were fastened to the steel base by screws. The upper heads of the hydraulic jacks were also fastened by screws to stiffen the moving section, which had a central hole located exactly on the bearing plate hole. The hydraulic jacks were controlled by a hydraulic machine as shown in **Plate (5)**, which enabled the jacks to supply the same loads. With this machine three types of jacks could be used, 1 Ton, 2 Ton and 3 Ton hydraulic jacks. For every type of jacks, there is a loaded gage, as shown in **Figure (2)**.

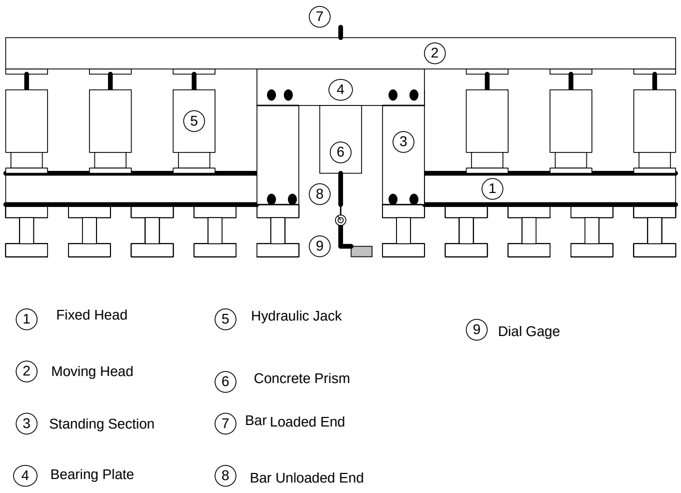


Figure (2) Testing frame details.

Plate (5) Testing frame machine.

The pull-out specimens were positioned hold inside the inverted U section. The loaded end (top end) of tested cube is pressed on the inside face of the bearing plate. The reinforcing bar passed through the two holes and is screwed at the upper face of the moving head. The slip was measured at the unloaded end by a dial gage with an accuracy of 0.002mm.

6.2 Compressive Strength Test for Control Concrete Specimens

A universal testing machine was used to test the three groups of control specimens cast. The 150 mm *x*150 mm *x*150 mm cubes were cast and tested in accordance with BS1881(part 116: 1983) standard to determine the compressive strength of the concrete mixes (f_{cu}) at age of testing 28 days. Three cubes cast from each concrete batch, were tested.

7. Results and Discussions

7.1 Compressive Strength of Concrete

Results of this test are shown in **Table (5)**. The test results show that the addition of carbon fibers in group B (f/c =75%) and C (f/c =1.0%) increases the compressive strength of concrete by about 9.5% and 10.8 %,respectively.

7.2 Bond Strength-temperature Curves

Test results for the pull- out specimens for different studied groups are summarized in **Table (6).** The residual bond strength- temperature curves are shown in **Figure (3).**

Table (5) Compressive strength of the investigated concrete pull- out Specimens.

Group	Fiber content (%)	f_{cu} (MPa)	Average f_{cu} (MPa)	% of Increase*
A	0.0	34.66	33.7	-
		33.33		
		33.11		
B	0.75	37.55	36.88	9.5
		37.77		
		35.33		
C	1.0	35.33	37.33	10.8
		36		
		40.66		

*The percentage of increase is measured with respect to group A.

Table (6) Test results of pull- out specimens.

Group	Sample Designation	Temperature Stage °C	Maximum Slip (mm)	Failure Load (kN)	Residual Bond Strength (Mpa)	Residual Bond Strength %	Failure Mode
A	C-0-0	Room Temp.	3.5	62.5	16.58	100	Pulling out
	C-0-150	150	2.99	55	14.6	88	Splitting
	C-0-250	250	4.04	52.5	13.92	84	Splitting
	C-0-350	350	4	45	11.94	72	Splitting
	C-0-450	450	2	42.5	11.27	68	Splitting
	C-0-550	550	6	20	5.3	32	Pulling out
B	CF-0.75-0	Room Temp.	5.87	62.5	16.58	100	Pulling out
	CF-0.75-150	150	3.61	52.5	13.92	84	Splitting
	CF-0.75-250	250	4.45	55	14.6	88	Pulling out
	CF-0.75-350	350	2.3	50	13.26	80	Pulling out
	CF-0.75-450	450	4	45	11.94	72	Pulling out
	CF-0.75-550	550	7	17.5	4.64	28	Pulling out
C	CF-1-0	Room Temp.	4.5	62.5	16.58	100	Splitting
	CF-1-150	150	5	55	14.6	88	Splitting
	CF-1-250	250	4.72	50	13.26	80	Splitting
	CF-1-350	350	4.1	40	10.6	64	Splitting
	CF-1-450	450	5	27.5	7.29	44	Splitting
	CF-1-550	550	7	20	5.3	32	Pulling out

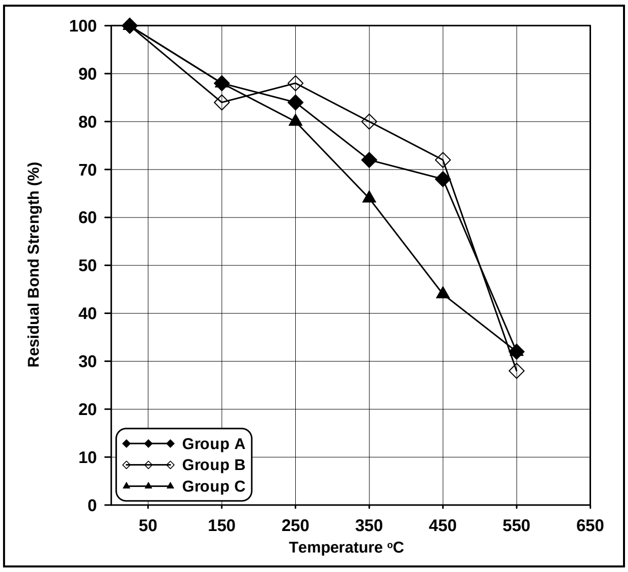


Figure (3) Relationship between residual bond strength versus temperature for groups A (f/c =0.0%), B (f/c =0.75%) and C (f/c =1.0%).

From **Table (6)** and **Figure (3)**, it can be observed that the bond strength deteriorates after exposure to high temperatures. The residual bond strength was noticed to be less than the unheated strength for all the studied levels of temperature. The percentage residual bond strength for group B specimens (f/c =0.75%) is 84% which is lower than the percentage residual bond strength for the two other groups which is 88% at temperature level 150 ºC. For temperature levels 250 ºC, 350 ºC and 450 ºC the percentage residual bond strengths for group B specimens (f/c =0.75%) are 88%,80% and 72%, respectively, which are the highest as compared with that for the two other groups followed by the percentage residual bond strength for group A specimens (f/c =0.0%) which are 84%,72% and 68% %, respectively, and finally group C specimens (f/c =1.0%) has the lowest percentage residual strength which are 80%, 64% and 44%, respectively. At temperature level 550 ºC, group B specimens residual bond strength is 28% which is lower than that in the two other groups which is 32%.

7.3 Failure Mode

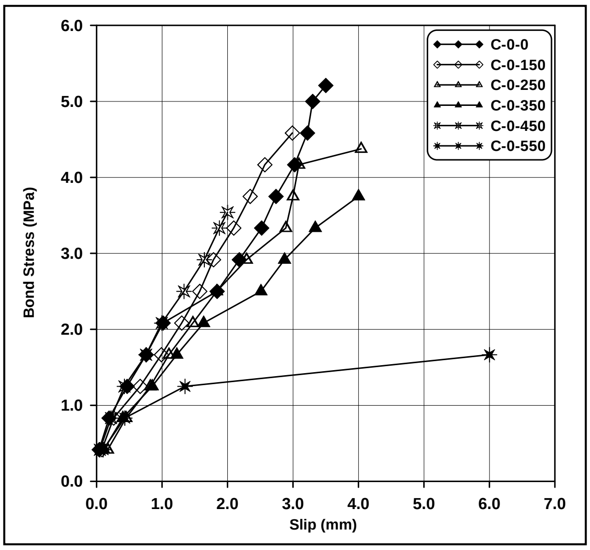
Results of failure modes are shown in **Table (6)**. From the observation of this table, it can be seen that at room temperature, group A and B specimens fail pulling- out the reinforcing steel bars while group C specimens fail by splitting of concrete. At temperature levels of 150 ºC, 250 ºC, 350 ºC and 450 ºC group A and C specimens fail by splitting of concrete while they fail by pulling out of the reinforcing steel bars at temperature level 550 ºC. Group B specimens fail by pulling out the reinforcing bars for all the tested temperature levels except at temperature level higher than 150 ºC since they fail by splitting of concrete.

7.4 Effects of the Investigated Parameters on Bond –slip Response

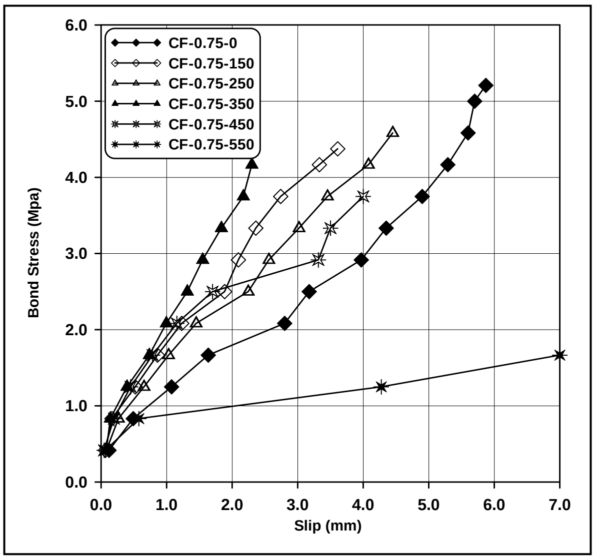
Effect of the considered temperature levels (room temperature, 150 °C, 250 °C, 350 °C, 450 °C, and 550 °C) and f/c ratio on bond- slip response were studied in this section.

7.4.1 Effect of Elevated Temperature Levels

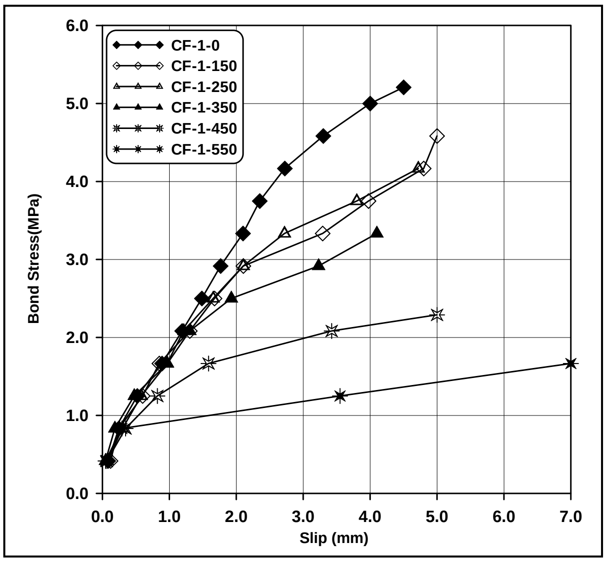
Figures (4), **(5)** and **(6)** show the effect of elevated temperatures on bond- slip response for the groups A, B and C, respectively.



Figure(4)Bond- slip response for group A spesemens (f/c =0.0%).



Figure(5)Bond- slip response for group B spesemens (f/c =0.75%).

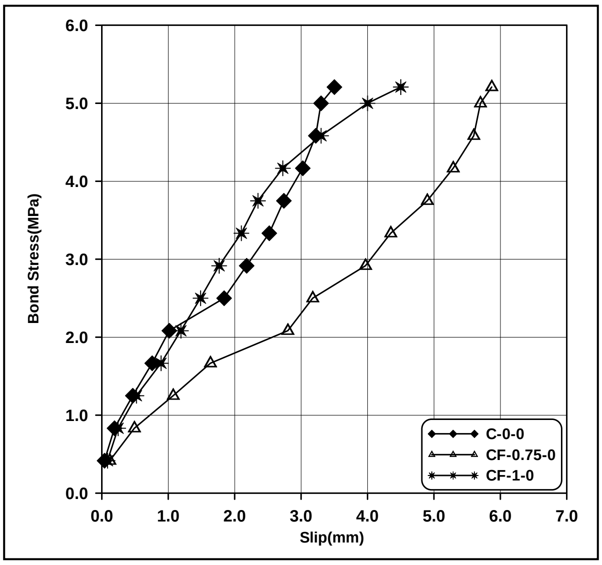


Figure(6)Bond- slip response for group C spesemens (f/c =1.0%).

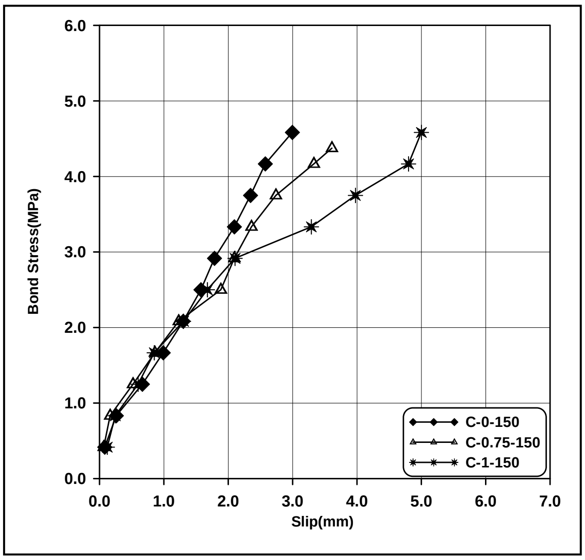
The figures reveal that there is no clear conclusion that can be obtained concerning the effect of changing temperature levels on bond- slip response.

7.4.2 Effect of Fiber/Cement Ratio

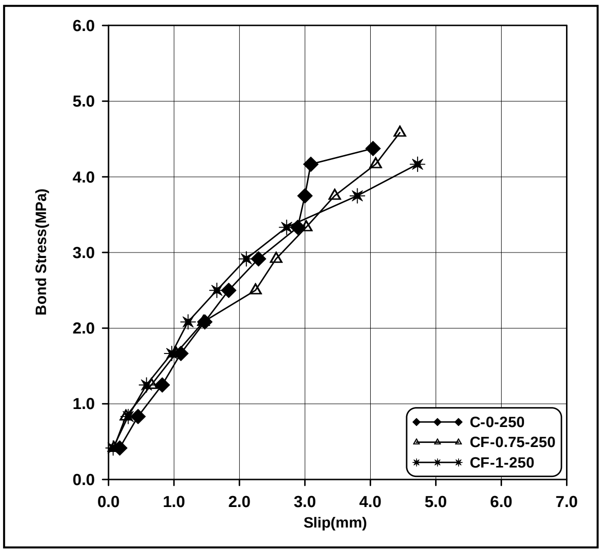
Figure (7) shows the bond- slip response for specimens of groups A, B and C at room temperature. In general, for a given stress level, group C specimens have the lowest slip values followed by group A specimens and then group B specimens. **Figures (8)** and **(9)** show the bond- slip response for specimens of groups A, B and C at temperature level of 150 ^oC and 250 ^oC. At early stress levels, the three groups A, B and C specimens have convergent slip values. At latter stress levels group A specimens have the lowest slip values followed by group B specimens and then group C specimens. **Figure (10)** shows the bond- slip response for groups A, B and C specimens at temperature level of 350 ^oC. In general, for a given stress level, group B specimens have the lowest slip values followed by group C specimens and then group A specimens. **Figure (11)** shows the bond- slip response for specimens of groups A, B and C at temperature level of 450 ^oC. In general, for a given stress level, group A specimens have the lowest slip values followed by group B specimens and then group C specimens. **Figure (12)** shows the bond- slip response for groups A, B and C specimens at temperature level 550 ^oC. In general, for a given stress level, group A specimens have the lowest slip values followed by group C and B specimens which have convergent values.



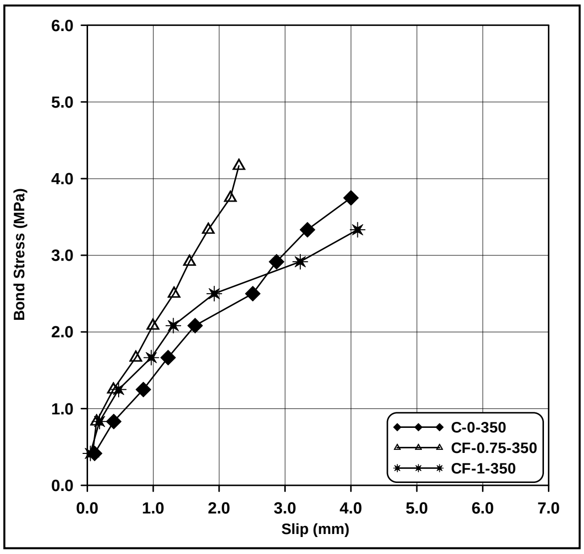
Figure(7)Bond- slip response for groups A,B, and C spesemens at room temperature.



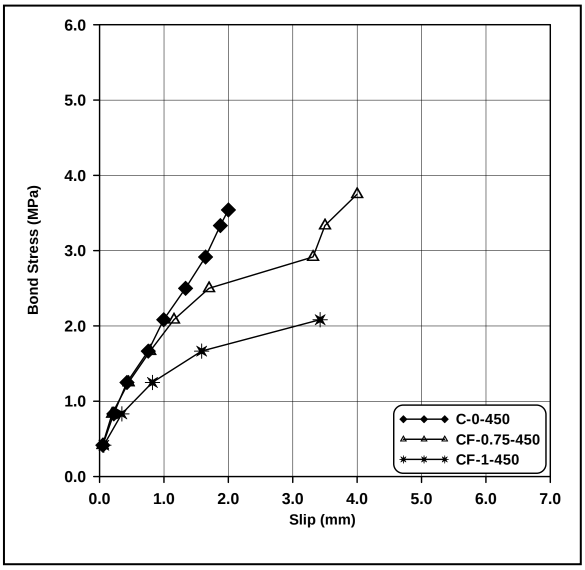
Figure(8)Bond- slip response for groups A,B, and C spesemens at temperature level of 150 ^oC.



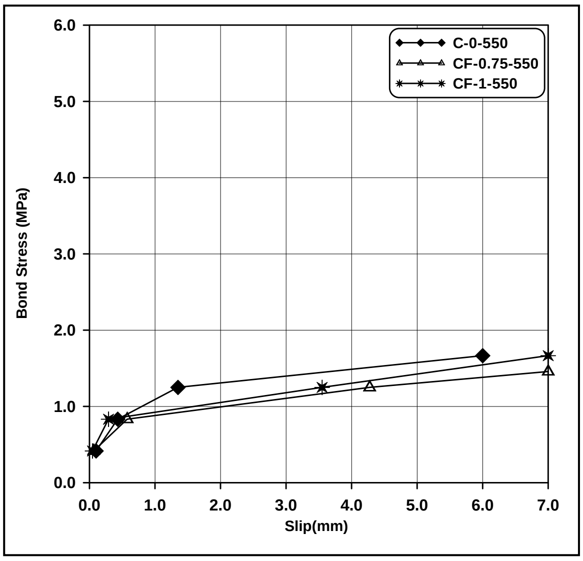
Figure(9)Bond- slip response for groups A,B, and C specimens at temperature level of 250 °C.



Figure(10)Bond- slip response for groups A,B, and C specimens at temperature level of 350 °C.



Figure(11)Bond- slip response for groups A,B, and C specimens at temperature level of 450 oC.



Figure(12)Bond- slip response for groups A,B, and C specimens at temperature level of 550 °C.

8. Comparison of Experimental and Different Analytical Predicted Percentage of Residual Bond Strength

The residual bond strength (RBS) obtained from the present research work has been compared with that predicted using empirical expressions obtained by linear regression analysis of pull- out tests of many investigators as given by Jaffar [9]. The purpose was to find out which one of these regression analysis gives results having the best correlation with the present experimental results. The expressions considered are linearly relate the RBS values to the corresponding temperature levels (t). The expressions considered are:

1. The linear expression **Equation (1)** depends on the work of Morely and Royles [10] which is applicable for temperature levels ranging from 100 °C to 700 °C:
   $$RBS = 111.46 - 0.12t \qquad (1)$$
2. The linear expression **Equation (2)** depends on the work of Al-Owaisy [11]which is applicable for temperature levels ranging from 100 °C to 500 °C :
   $$RBS = 99.63 - 0.074t \qquad (2)$$
3. The linear expression **Equation (3)** depends on the work of Jaffar [9] which is applicable for temperature levels rangeing from 100 °C to 700 °C:
   $$RBS = 92 - 0.04674t \qquad (3)$$

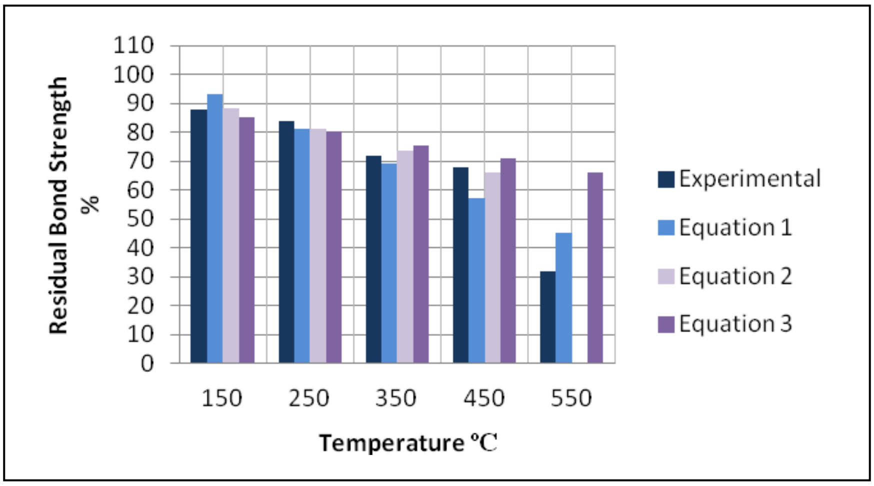
Table (7) Shows a comparison between the results obtained using these equations and the results of the current study

Table (7) Percentage of residual bond strength according to Equations (1), (2) and (3) compared with results of the current work.

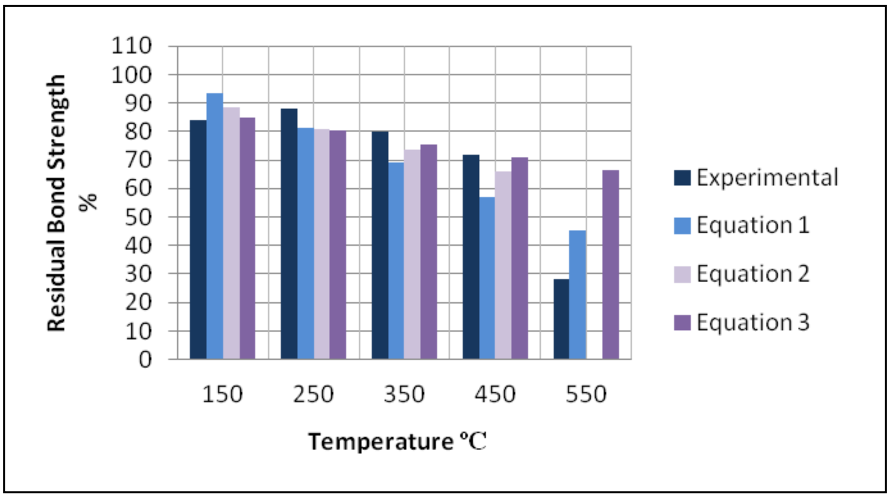
Group	Sample Designation	Temperature Stage °C	Percentage Residual Bond Strength (%)			
			Exp.	Eq(1)	Eq (2)	Eq (3)
A	C-0-150	150	88	93.4	88.5	85
	C-0-250	250	84	81.3	81	80.3
	C-0-350	350	72	69.2	73.6	75.6
	C-0-450	450	68	57.2	66.1	71
	C-0-550	550	32	45.1		66.3
B	CF-0.75-150	150	84	93.4	88.5	85
	CF-0.75-250	250	88	81.3	81	80.3
	CF-0.75-350	350	80	69.2	73.6	75.6
	CF-0.75-450	450	72	57.2	66.1	71
	CF-0.75-550	550	28	45.1		66.3
C	CF-1-150	150	88	93.4	88.5	85
	CF-1-250	250	80	81.3	81	80.3
	CF-1-350	350	64	69.2	73.6	75.6
	CF-1-450	450	44	57.2	66.1	71
	CF-1-550	550	32	45.1		66.3
X⁻(Experimental RBS/Analytical RBS)				1.09	1.01	1.28
S.D.(Experimental RBS/Analytical RBS)				0.24	0.16	0.5
C.O.V.(Experimental RBS/Analytical RBS)				0.18	0.1	0.4

The comparison given in **Table (7)** is based on the mean (X^-) ,the standard deviation (S.D.) and the coefficient of variation(C.O.V.) of the experimental RBS to analytical RBS. **Table (7)** reveals that **Equation (2)** gives RBS values which are in good agreement with the present experimental ones since it has the lowest C.O.V. for the experimental RBS to analytical RBS which is 0.1 while the C.O.V. for **Equation (1)** and (**3)** are 0.18 and 0.4, respectively**.**

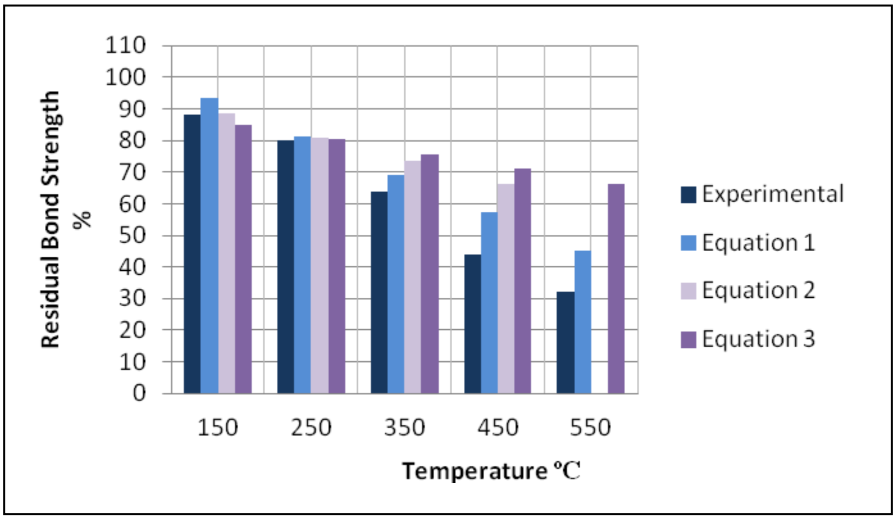
Figures (13), **(14)** and **(15)** show the comparison between the experimental RBS and that obtained using the three premensioned equations for specimens of groups A, B and C, respectively.



Figure(13)Comparision of expremental residual bond strength and that obtained using Equations (1),(2) and (3) for group A specimens.



Figure(14)Comparision of expremental residual bond strength and that obtained using Equations (1),(2) and (3) for group B specimens.



Figure(15)Comparision of expremental residual bond strength and that obtained using Equations (1),(2) and (3) for group C specimens.

9. Conclusions

1. The addition of 0.75% and 1.0% carbon fibers by weight of cement increases the compressive strength of concrete by about 9.5**%** and 10.8 %respectively.

2. The percentage residual bond strength after exposure to temperature level of 550 °C for the concrete reinforced by 0.75% carbon fibers by weight of cement is lower than that for non fibrous concrete and the concrete reinforced with 1.0% carbon fibers by weight of cement which are the same. The percentage residual bond strength after exposure to temperature level of 550 °C for non fibrous concrete and that reinforced by 0.75% and 1.0% carbon fibers by weight of cement are 32%,28%and 32%, respectively.

3. At temperature levels in the range between room temperature and 150 °C, the percentage residual bond strength for the concrete reinforced by 0.75% carbon fibers by weight of cement specimens is 84% which is lower than that obtained for concrete reinforced by 1.0% and non fibrous concrete which is 88%.

3. For temperature levels of 250 °C, 350 °C and 450 °C the percentage residual bond strengths for the concrete reinforced by 0.75% carbon fibers by weight of cement specimens are 88%, 80% and 72%, respectively, these values are the highest as compared with the non fibrous concrete and that reinforced with 1.0% carbon fibers followed non fibrous concrete specimens which are 84%,72% and 68% %, respectively. Finally the specimens reinforced with 1.0% carbon fibers have the lowest percentage residual strength which are 80%, 64% and 44%, respectively for the prementioned temperature levels.

4. There is no clear conclusion can be obtained concerning the effect of changing temperature levels on bond – slip response of non fibrous concrete and that reinforced with 0.75% and 1.0% carbone fibers by weight of cement.

5. The percentage residual bond strengths can be obtained using the expression which relates these percentages to the temperature levels obtained from the linear regression analysis of Al-Owaisy in 2001 since it has low C.O.V value of 0.1.

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