INFLUENCE OF CORROSION OF REINFORCING BARS ON THE BOND BETWEEN STEEL AND CONCRETE AT ELEVATED TEMPERATURE

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Abstract
This paper presents an experimental investigation that reveals bond force slip relationships for corroded reinforcing bars under elevated Temperature conditions. The test program consisted of fabrication and testing of 6 pull-out specimens. The specimens were heated up to two levels of temperature (250C^o and 500C^o) in addition to roomtemperature. The obtained experimental results indicated that for specimens with corroded bars have bond strength higher than specimens with corroded bars at room temperature and that the bond strength reduce with high temperature for specimens with corroded and under corroded bars.

KEY WORDS :bond, bond-slip, high temperature

الخلاصة
هذه الدراسة تقدم بحثا عملي الاختيار تاثر قوة الربط بين الكونكريت وحديد التسليح المتصدأ ومدى تأثرها عند رفع درجات الحرارة وذلك بتسخين النماذج بواسطة الافران ثم اعادة تبريدها وفق قيم درجات الحرارة المعتمدة في هذه الدراسة وكما هو مبين في برنامج الاختبار. ستة نماذج تم فحصها وتسخينها لعدة درجات حرارية (٢٥٠و٥٠٠) درجة مئوية بالاضافة لدرجة حرارة الغرفة.من خلال النتائج التي تم الحصول عليها تبين بان النماذج مع قضبات التسليح الغير متصدأ لها قوة ربط اعلى من النماذج التي تحوي قضبان متصدئة في درجة الحرارة الاعتيادية وان قوة الربط هذه تقل مع ارتفاع درجات الحرارة للنماذج الحاوية على حديد تسليح متصدأ وغير متصدأ.

1-Introduction
Corrosion of the reinforcing steel causes a decrease in the bar diameter which affects adversely the mechanical properties of the steel bar in terms of its ultimate strength, yield strength, etc. Furthermore, when reinforcing bars corrode, the corrosion products occupy a much larger volume than the original steel, and eventually exerts a large force on the concrete surrounding it to cause cracks which grow slowly as the reinforcement continues to corrode followed by spalling of the concrete cover. Also, corrosion of the reinforcing steel causes changes in the surface conditions of the reinforcement steel, and layer of the corrosion products causes loss of cohesion and adhesion at the steel-concrete interface. As corrosion continues. it finally leads to changes in the profile of the bar rib. Eventually, all of the concrete around the steel bar is forced off by the growing corrosion products, and the reinforcement looses not only any remaining protection against corrosion, but also looses a significant part of the bond resistance to transfer the force from the reinforcing steel to the surrounding concrete, and vice versa(1). Studies conducted by Auyeung confirmed that the loss of bond strength for an unconfined corroded reinforcing steel bar is much more critical than the cross section loss, since a 2%diameter loss could lead to 80% bond reduction(2). Many researchers have conducted studies on the mechanism of bond failure. For example, Cairns and Jones proposed an analysis of the bond strength of ribbed reinforcing bars in which bond failure was considered as bearing failure of the ribs on the concrete. Cairns and Jones's

analysis suggested that bond strength was only partially dependent on the splitting resistance of the beam section[3,4].

2-Test program

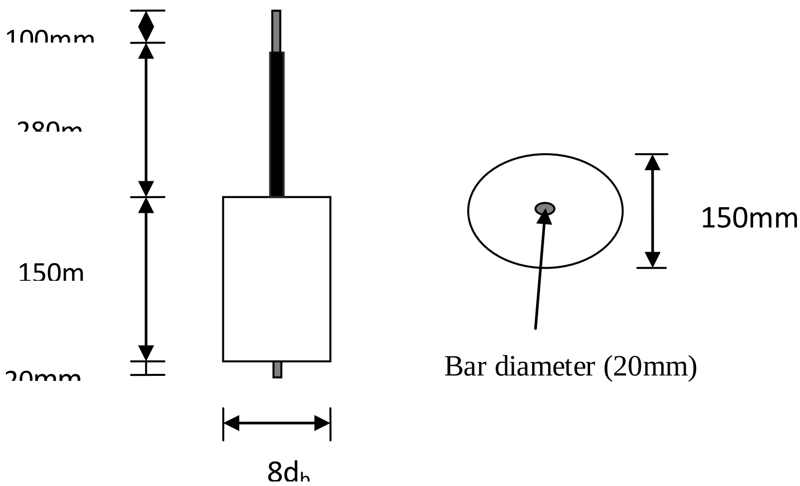
The test program consisted of fabrication and testing of 6 pull-out specimens. A single concrete mix proportion (cement: fine aggregate: course aggregate) of (1:1.5:3) by weight with water/cement ratio 0.45 was used. The specimens were heated to two stages of temperature ($250C^{o}$ and $500\ C^{o}$) in addition to room temperature.

The variables investigated using pull-out specimens were corrosion bars (as show in plate 1) and non-corrosion bars addition to the temperature stages. The embedment length was $3d_b$.

Plate(1) the corrosion bars

3- Fabrication and Details of Specimens

In this study, cylinder pull-out specimens were chosen. The cylinder was defined as a function of the bar diameter. The cylinder diameter was about eight times the bar diameter($D=8d_b$), as described in figure(1). The cylinders dimensions were (150x300mm) and for the 20 mm bar diameter. The specimens are reinforced by single central reinforcing bar, with a bonded length $3d_b$. The unbounded zone are performed by covering the reinforcing bar at these zone with a plastic tube. The steel bars were screwed from the two ends. The bottom end of the bar was screwed to be smaller in diameter than the original bar diameter, so it could fit the mold base hole and pass through it. Then the bar was fixed to the outside face of this base by a bolt, so that the bar could stand vertical at the center of the cylinder. Plate (2) shows the reinforcing bar details.



Figure(1) test specimens details

Plate (2) steel bar details

4- Materials

4-1 Cement

Ordinary Portland cement (type I) was used in this study. The cement is manufactured in kubaisa factory according to the Iraqi standard specification IQS 5:1984[(5)] requirement. The chemical and physical properties are shown in table (1).

Table (1-A) chemical composite of cement#

NO.	Chemical composite	Project cement percent	IQS:NO./1984
1	CaO	61.54	
2	SiO_2	21.7	
3	Al_2O_3	5.3	
4	Fe_2O_3	3.18	
5	MgO	2.71	5*
6	SO_3	2.46	2.8*
7	L.O.I	2.2	4.0*
8	Insoluble Residue	0.5	1.5*
9	L.S.F	0.68	0.66 – 1.02
10	C_3A	8.66	
11	C_3S	38.38	
12	C_2S	31.59	
13	C4AF	8.87	

Table (1-B) physical properties of the cement#

Physical properties	Test result	IQS:No.5l1984
Fine using Blain air Permeability apparatus (cm^2/gm)	4000	2300**
Sound using Autoclave method	0.17	0.8*%
Setting time using vicat's Instruments Initial (min) Final(min)	 150 225	 45** 600*
Compressive strength for Cement past cube (70.7 mm) at 3 days(MPa) 7 days(MPa) 28 days(MPa) 56 days(MPa)	 22.1 32.3 41.2 59.8	 15** 23** …. ….

All testing were made in Al- Anbar University Laboratories.
*Maximum Limit.
**Minimum Limit.

4-2 Fine Aggregate

Fine aggregate obtained from Rahhalia (Anbar) region was used. The grading of the fine aggregate is shown in table (2), and conformed to the requirements I.Q.S:45/1985(6).

Table (2)Grading of fine aggregate#

No.	Sieve (mm)	%Passing	
		Fine aggregate	IQS 45:1984
1	5.0	97	90 – 100
2	2.36	78	75 – 100
3	1.18	60	55 – 90
4	0.60	43.7	35 – 59
5	0.30	17.5	8 – 30
6	0.15	0	0 - 10

#All tests were made in Al- Anbar University Laboratories

4-3 Coarse aggregate

The coarse aggregate is crushed river gravel from Samara region with a maximum size 19mm. The coarse aggregate is washed. The aggregate was used in saturated surface dry condition. Gradation of coarse aggregate conforms to requirements of I.Q.S:45/1985(6) , as shown in Table (3).

Table (3) Grading of Coarse Aggregate#

No.	Sieve (mm)	%Passing	
		Coarse Aggregate%	IQS 45:1984
1	20	97	
2	14		
3	10	39	
4	5	9	
5	2.36	3	

#All tests were made in Al- Anbar University Laboratories

4-4 Reinforcing Steel

Deformed steel bars of (20mm) were used, with yield strength of (556), respectively. Table(4) describes the steel bars properties of reinforcement bar.

Table (4) Properties of Reinforcement Steel#

Approximate Diameter (mm)	Measured Diameter (mm)	Area (mm^2)	Modulus Elasticity (GPa)	*fy* MPa	*fu* MPa
20	19.62	314	200	556	705

#All tests were made in Al-Anbar University Laboratories

5- Molding, Casting and Curing

Steel moulds were used to cast all the pull-out specimens. The moulds were coated with oil before putting the reinforcing bar, and casting the concrete. Then the concrete was mixed for about three minutes by a horizontal rotary mixer of 0.19 m^3 capacity. The specimens were then casted into three layers; each of which was compacted by a table vibrator.

All specimens were demolded 24 h after the casting and placed in a water tank. After 14 days of water curing, the samples were transferred to an environmental chamber. The specimens were kept in the chamber for 14 days until they were dried.

6- Heating and Cooling

The specimens were heated by an electric furnace, see plate (3). The furnace internal dimensions were (500*600*750 mm). The specimens were heated slowly at a constant heating rate of 2 Co/min to avoid steep thermal gradient[7].

Once the required temperature level was attained, the specimens were thermally saturated for one hour at that level. Then the furnace was switched off and the air-cooling was opened. The specimens were left inside the furnace for about 3 hours and then they were stripped out from the furnace. Then after, the specimens were stored in the laboratory environment to be cooled in air for about 20 hours.

Plate (3) The Furnace Used

7- Test Procedure

The pull-out specimens was tested by applying a tensile force to the steel bar while the concrete cylinder bore against the platen of the testing machine. The slip of the bar at the free end was measured with a linear variable differential transformer. The specimens was tested until the maximum load was reached.

8- Test Results

It is noticed that the splitting failure is the common type of failure served in this study, as shown in plate 4 .

Figs. 2–4 depict the relationship between bars non-crrosion bars or corrosion bars and free end slip, under elevated temperature from room temperature to 500C^{o}. from this curve we shows, There is a difference in the slip increasing with temperatures and this appears in all levels of temperature. As the load increases the slip increases in a faster rate until bond break down and failure occurs.

For specimens with non-corrosion bars have bond strength higher than specimens with corrosion bars at room temperature as figure 2. Figure 5 and 6 shown that bond strength reduce with high temperature for specimens with corrosion and non-corrosion bars. Residual bond strength, The results summarized in graphically presented in Figs. (5 and 6) show that the residual bond strength was reduced as the exposure temperature was increased. Figure7show comparison between percentage residual bond strength of specimen have corrosion bars and non-corrosion bars at high temperature. From result, we shows that specimens with non-corrosion bars at high temperature ,the residual bond strength is higher than specimens with corrosion bars, the residual bond strength of specimens with non-corrosion bars were 88% and 56% at 250C^{o} and 500C^{o}, respectively, while the residual bond strength of specimens with corrosion bars were 81% and 50% at the same temperature.

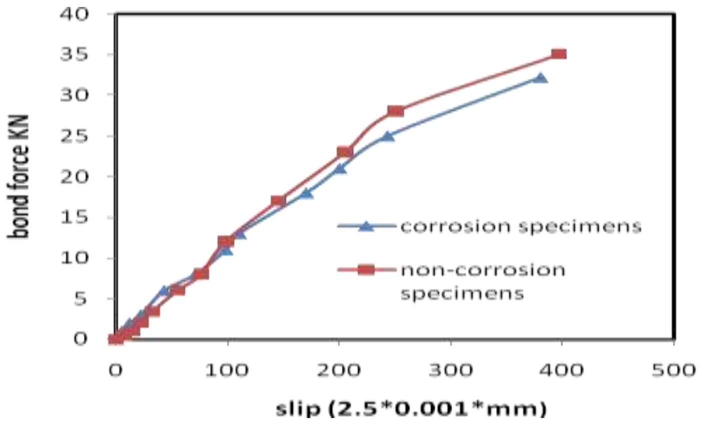


Fig. 2 bond force slip for specimen non-corrosion bars and and specimen with corrosion bars at room temperature.

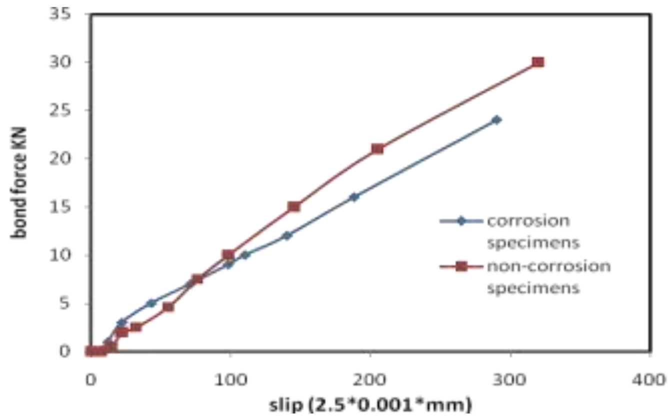


Fig. 3 bond force slip for specimen non-corrosion bars and and specimen with corrosion bars at 250 C^{o}.

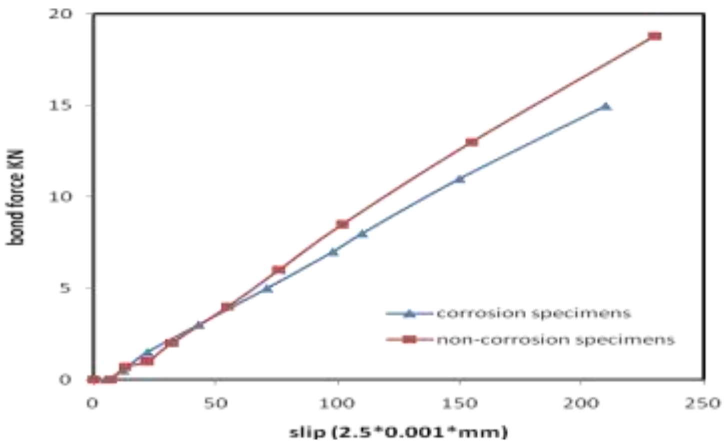


Fig. 4 bond force slip for specimen non-corrosion bars and and specimen with corrosion bars at 500C^{o}.

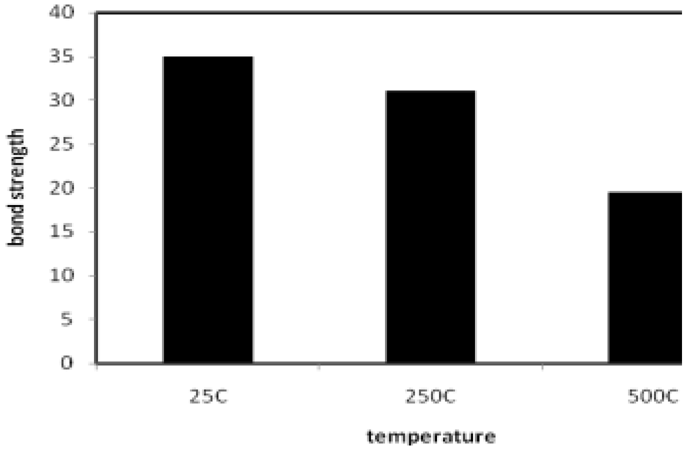


Fig 5.bond strength with temperature for specimens with non-corrosion bars

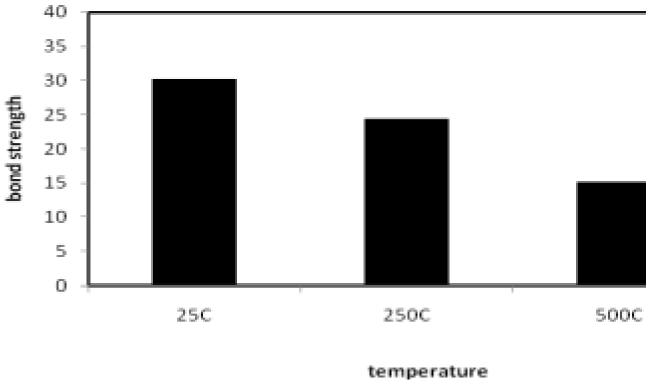


Fig 6.bond strength with temperature for specimens with corrosion bars

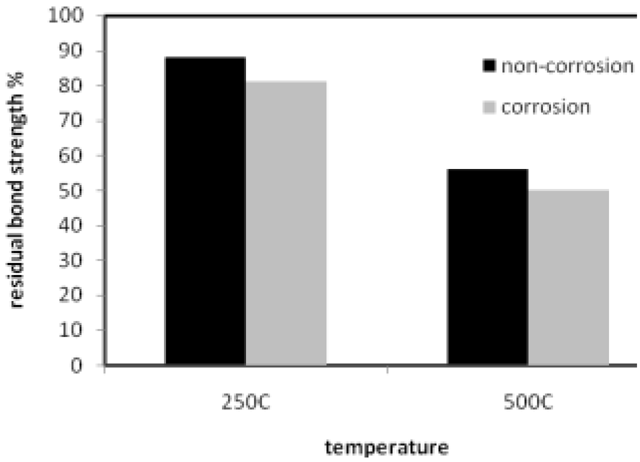


Fig 7.comparsion between residual bond strength of specimens have corrosion bars and non-corrosion bars

Plate (4) Splitting failure

9-Conclusions

From the results shown un this study, the following conclusions may bedrawn:

1)For specimens with uncorroded bars the bond strength is higher than specimens with corroded bars at room temperature

2) The residual bond strength was reduced as the exposure temperature was increased

3)The residual bond strength of specimens with uncorroded bars were larger than that of specimens with corroded bars at the same temperature.

4) At high temperature, the residual bond strength in specimens with uncorroded bars is higher than specimens with corroded bars by about 7% and 6% for 250C^o and 500 C^o ,respectively .

5) There is a difference in the slip increase with temperature that Appeared consistently at all temperatures. As the load increases the slip Increases in a faster rate (upon temperature increase) until the bond breaks down and failure occurs.

6) Bond strength is affected when exposed to high temperature, depending on level of temperature.

10-Refrences

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