International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES),(UGC APPROVED)
Impact Factor: 5.22 (SJIF-2017),e-ISSN:2455-2585
National Conference on
Sustainable Practices & Advances in Civil Engineering (SPACE 2019)
Volume 5, Special Issue 06, June-2019.

EXPERIMENTAL INVESTIGATION OF CORROSION ON BOND SLIP RELATION OF ANTI RUST PAINTED (ARP) DEFORMED STEEL BARS IN ALKALINE SOLUTION

Shrivas Abhi Mukesh[1], V Sanjay Gokul[2]
[1]*PG Scholar, Department of Civil Engineering, KITS Warangal, India*
[2]*Assistant professor, Departmentof Civil Engineering, KITS Warangal, India*

Abstract: Corrosion has been recognized as a major deterioration phenomenon which leads to the structural concrete degradation due to environmental actions. Numerous researchers had turned their focus to this area and developed various techniques and analysis models over the time. Focusing on the same area, this paper discusses the effect of corrosion on ARP deformed steel bar, bond stress, bond stress vs slip relation based on 16 prism specimens(400 x 150 x100)mm tested in universal testing machine. Out of 16 specimens, 8 specimens were casted with ARP bars and 8 with conventional bars. 4 prism specimens were provided with two embedment length (100mm) and (300mm) in addition to two different bar diameter (12mm), and (16mm). Prior to testing 8 specimens were kept in alkaline solution of 5% Nacl for 5 days. Bond slip relation is obtained experimentally and compared with the theoretical models found in literature.

Keywords: Bond slip relationship, ARP deformed bars, corrosion

I. INTRODUCTION

Corrosion is defined as the destruction or dissolution of metals due to interaction with its environments. Concrete is high alkaline material (pH =12-13.5) which forms cover to the steel surface and prevents dissolution of iron. Furthermore, concrete made with low water/cement ratio has a low permeability that minimizes the penetration of ingredients that induced-corrosion, such as chloride, carbon dioxide and moisture to the steel surface. Various protection methods have been also carried out to protect the steel reinforcement and guarantee long service life by corrosion prevention. These include cathodic protection, the use of coated steel rebar, corrosion inhibitors, and additive minerals such as silica fume, fly ash, etc, to reduce permeability and provide better corrosion control. Various coating has been implemented to act as a barrier to prevent the transfer of electrochemical charge from the corrosive solution to the metal underneath. One of such protective coating is paint type coating which is a cost effective way of preventing corrosion. For coating film thickness, the coated bars developed bond strengths essentially equal to bond strength for the uncoated bars.

With the growth of bond researches, a reinforced concrete structure was known as a composite structure , whereby the slip occurs along the reinforcing bar under loading and the bond action is a function of the slip. To put it concretely, when the external force is progressively applied to a reinforced concrete member, interfacial stresses between the reinforcing bar and the concrete are created and the capacity of the interface to transmit stresses begins to weaken at certain load levels. These irreparable damages spread to the surrounding concrete. As a result of this process, the capacity of the interface to transmit stresses gradually deteriorates and a slip of both materials inevitably occurs.

As shown in Figure 1, the stress transfer mechanisms, which refer to the bond action, are usually expressed by the bond stress-slip relationship obtained from pull-out tests. The bond actions are comprised of an adhesive bond, a frictional bond, and a shear bond. In the case of deformed bars, the bond resistance capacity is mainly governed by the mechanical interlocking action.Conventional and Anti rust painted(ARP) deformed bars(Fe 500) of two different diameter 12mm and 16mm is employed to be investigated for corrosion impact on bond strength.

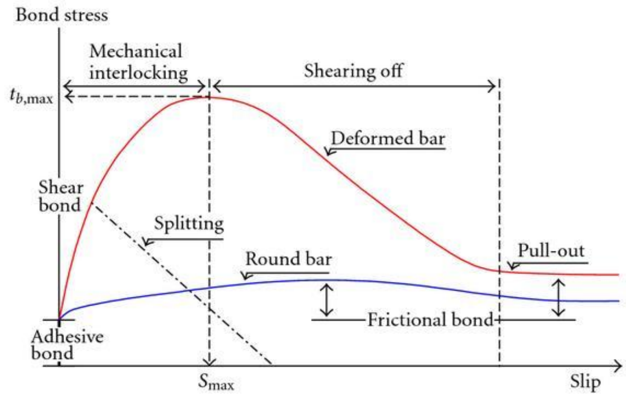

Fig1: Bond Slip relation.

II. LITERATURE REVIEW

` Corrosion of reinforcing steel causes damage to concrete structure and it is very costly problem in terms of its financial implications and also for its structures safety(scully 1975).

Concrete made with low water/cement ratio has a low permeability that minimizes the penetration of ingredients that induced-corrosion, such as chloride, carbon dioxide and moisture to the steel surface(Ahmed 2003).

For coating film thickness, the coated bars developed bond strengths essentially equal to bond strength for the uncoated bars. Experimental values of bond strength for these coated bars were higher than minimum acceptable values given in the building design code and highway bridge requirements. Bond strength of the bars with thick epoxy coating were unacceptable. Samples prepared were of prism size 10 x 10 x 12 in.(Robert g mathey)

.

As mentioned earlier steel reinforcement in concrete is normally immune from corrosion due to high alkanilty of concrete, however, steel corrodes wheattacked by aggressive agents. The mechanism of corrosion of steel in concrete is two-fold: either by chloride attack or by carbonation of concrete. These two mechanisms usually do not attack the integrity of concrete but they attack steel bars. However, other ions such as sulfates attack the integrity of concrete before attacking the steel (Broomfield 1997).

The presence of chloride in sufficient concentration at steel concrete interface causes damage to reinforcement by attacking the passive layer. The depassivation mechanism for chloride attack differs from carbonation. The chloride ions act as a catalyst for the broken passive film. In the absence of chloride, the passive film dissolves slowly as ferric ions. (Ramirez et al. 1990, Thangavel and Rengaswamy 1998).

III. EXPERIMENTAL INVESTIGATION

A. *Preparation of specimens*

16 Prism specimens(400 x 150 x100)mm tested in universal testing machine. Out of 16 specimens, 8 specimens were casted with ARP bars and 12 with conventional bars. Specimens were casted by placing the bars centrally along its longitudinal axis. Six prism specimens were provided with three embedment length (100mm)and (300mm) in addition to two different bar diameter (12mm), and (16mm). After curing for 28 days, 8 specimens were kept in alkaline solution for 5 days by applying artificial cracks.details of the specimens are listed below.

Table I

Specimen details

Specimens shape(size)mm	Compressive strength/design mix	Curing method	Bar diameter(mm)	Embedded length(mm)
Prism(400x150x100)	86N/mm^2/1:1.6:3.02	NNARP	12	100
			12	300
			16	100
			16	300
		ANARP	12	100
			12	300
			16	100
			16	300
		NARP	12	100
			12	300
			16	100
			16	300
		AARP	12	100
			12	300
			16	100
			16	300

B. Cement

In this present work Birla Gold cement of 53 grade ordinary Portland cement (OPC) is used for casting cubes and cylinders and beams for all concrete mixes. The various tests conducted on cement are specific gravity, initial and final setting time, standard consistency and fineness tests.

Table II

Properties of Cement

Tests	**Results**
Standard Consistency	31%
Fineness	7%
Specific Gravity	3.10
Initial Setting Time	140 minutes
Final Setting Time	230 Minutes

C. Fine Aggregate

The sand used for this project was locally procured and conformed to grading zone II as per IS 383-1970.

Table III

Properties of Fine Aggregate

Tests	**Results**
Specific Gravity	2.65
Bulk Density	1.6gr/cm^3
Grading Zone	II
Fineness modulus	2.89
% of Voids	39%
Void Ratio	0.57

D. *Coarse Aggregate*

Locally available coarse aggregate having the maximum size of 20mm is used in the present work.

Table IV

Properties of Coarse Aggregate

Tests	Results
Specific Gravity	2.89
Bulk Density	1.502gm/cm^3
Void Ratio	0.92
% of Voids	49.8%
Fineness Modulus	6.89

E. *Preparation of 5%NaCl solution*

5kg of NaCl and 665 grams of Na2Co3 was added to 100 litre water tank .Na2Co3was added to alter the PH value of the solution upto PH=11.

F. *Mix Design*

Grade of concrete is M30, water cement ratio is 0.45, The mix design is done as per IS: 456-2000 and IS: 10262-2009.

Table V

Mix Design of M30 Grade Concrete

Materials	Cement	Fine aggregate	Coarse aggregate	Water
Quantity/sample	2.81kg	4.496kg	8.48kg	1.26lt
Proportions	1	1.6	3.02	0.45

G. *Preparation ofspecimens for testing.*

After 28 days of curing, the beam specimens were taken out from the curing tank. The surfaces of specimens were made dry by placing it in the open atmosphere for the minimum duration of 4 hours. Once its surface became dry, surface of the specimens were smoothened through concrete cutter to obtain uniformity so that the bearing plate can transfer the load through that surface.

H. *Test setup and testing apparatus*

A universal testing machine with maximum capacity of 40ton was used for all tests. It was practical to read the slip values from the dial gauges as well as to read the loads directly from the testing machine .The pull out face of the prism was in contact with the bearing plate assembly. The supporting of the bearing plate was necessary to transfer the reaction to the movable part of the testing machine .the projected reinforcing bar passed through the bearing plate assembly and the support it was gripped for tension by the upper jaws of the testing machines.

Fig 2: Test setup in UTM

I. *Experimental Approach*

Till date there is no standard test available to determine bond strength between the concrete and reinforcing bar. In a reinforced concrete beam or slab, the concrete is surrounding the reinforcement bar is in tension whereas, in the concentric pull out test the concrete is in compression.Prepared specimen was fixed in UTM for Pull out test.Strains were measured for the corresponding loads with which bond stress and slip were obtained.

- Pulling force =Resisting force(bond stress x stressed area)
- Bond stress =pulling force /πdl

Table VI
Experimental maximum Bond an Slip value

Curing method	Bar diameter(mm)	Embedded length(mm)	Maximum Bond stress(N/mm2)	Maximum slip(mm)	First crack stress(N/mm2)
NNARP	12	100	9.78	0.8	8.32
	12	300	16.65	3.4	15.61
	16	100	10.408	0.7	9.36
	16	300	26.02	1.2	24.67
ANARP	12	100	7.28	0.9	7.28
	12	300	16.65	5	14.96
	16	100	7.28	0.9	7.28
	16	300	26.02	0.9	26.02
NARP	12	100	10.408	0.6	9.78
	12	300	17.9	1.3	16.36
	16	100	9.36	1.1	9.36
	16	300	17.69	0.9	17.69
AARP	12	100	8.32	0.8	8.32
	12	300	15.61	1.9	14.96
	16	100	9.36	1	9.36
	16	300	17.69	0.7	16.65

J. *Theoretical Approach*

In order to formulate a bond model which works successfully under axial boundary conditions,Sungnamhong and Sun kyu parkwith some modification of the Ikki et al.model,proposed the bond model as

$$\tau_b = k \times f_c'^{\,2/3} \times \left\{1 - \exp\left[-4500\left(\frac{S}{d_s}\right)^{1.45}\right]\right\}^{0.5} \times \exp\left[-5\left(\frac{S}{d_s}\right) + 5.5 f_R^{\,0.9}\right],$$

where k: coefficient that accounts for the effects of the proposed model on bond stress, f_R : relative rib area.

From the position of the reinforcing bar during casting, and depending on whether or not a stirrup is used, $k$can be classified as

$$k = 0.2 \times \exp\left\{[-4.5 + 55(3.06 f_R - 0.24)] \times \frac{100}{A_c}\right\}$$

(vertically cast bar),

$$k = 0.2 \times k_{sh} \times \exp\left\{[-4.5 + 55(3.06 f_R - 0.24)] \times \frac{100}{A_c}\right\}$$

(vertically cast bar with stirrups),

$$k = 0.2 \times \exp\left\{[-4.5 + 55 f_R] \times \frac{100}{A_c}\right\}$$

(horizontally cast bar),

$$k = 0.2 \times k_{sh} \times \exp\left\{[-4.5 + 55 f_R] \times \frac{100}{A_c}\right\}$$

(horizontally cast bar with stirrups),

where :A_c cross sectional area of the concrete,K_{sh} : coefficient which expresses the effect of the stirrups (1.0 for a vertically cast stirrup, 0.85 for a horizontally cast stirrup),f_R : relative rib area.

The relative rib area, so called bond index, is defined as

$$f_R = \frac{A_R}{\pi \times d_s \times l_d}$$

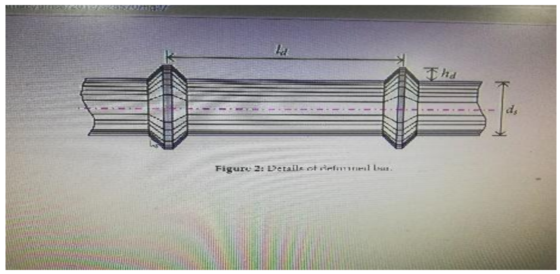

Fig3: Details of deformed bar

Table VII

Theoretical maximum Bond and Slip value

Curing method	Bar diameter(mm)	Embedded length(mm)	Maximum Bond stress(N/mm2)	Maximum slip(mm)
NNARP	12	100	27.60	0.8
	12	300	9.78	3.4
	16	100	23.8	0.7
	16	300	27.8	1.2
ANARP	12	100	26.519	0.9
	12	300	8.06	5
	16	100	26.519	0.9
	16	300	26.519	0.9
NARP	12	100	28.8	0.6
	12	300	22.46	1.3
	16	100	31.99	1.1
	16	300	26.519	0.9
AARP	12	100	27.60	0.8
	12	300	18.24	1.9
	16	100	30.6	1
	16	300	25.4	0.7

IV. RESULTS AND DISCUSSION

12/10-12mm diameter bars/10cm embedded length

12/30-12mm diameter bars/30cm embedded length

NNARP-Normally cured Non ARP specimen

NARP-Normally cured ARP specimen

16/10-16mm diameter bars/10cm embedded length

16/30-16mm diameter bars/30cm embedded length

ANARP-Alkaline cured Non ARP specimen

AARP-Alkaline cured ARP specimen

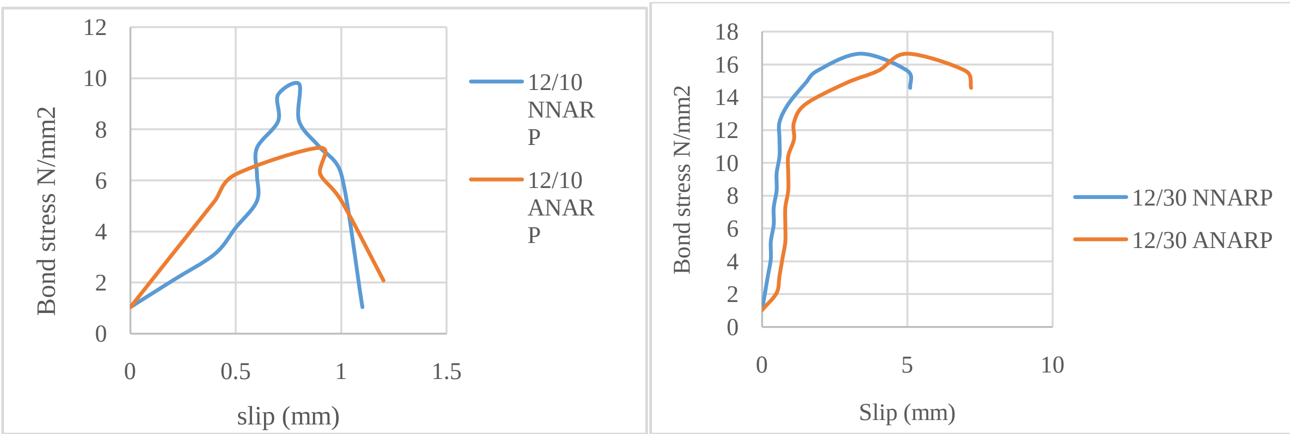

Fig 4: Bond-Slip relation for 12/10 and 12/30 NNARP and ANARP

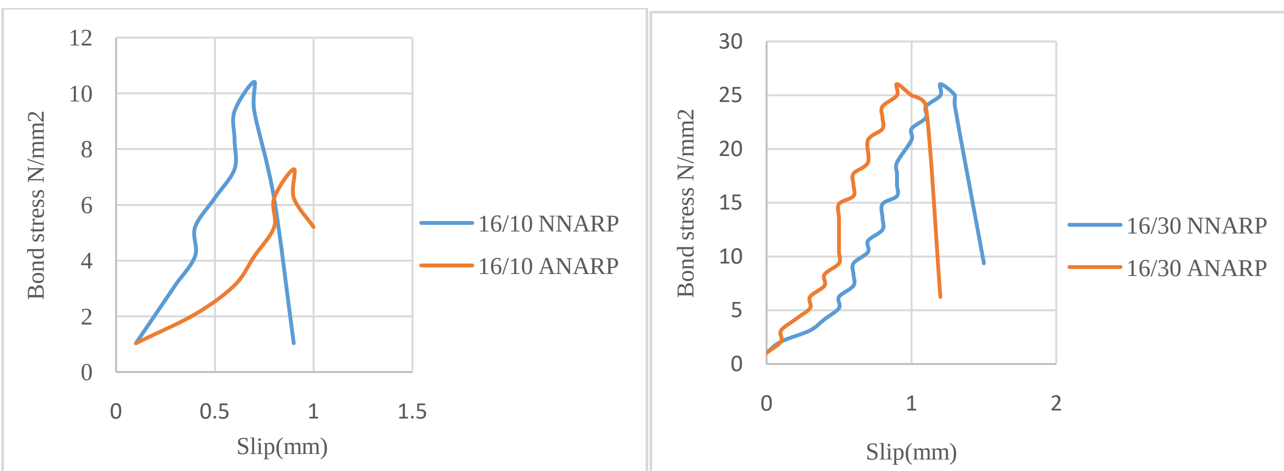

Fig 5: Bond-Slip relation for 16/10 and 16/30 NNARP and ANARP

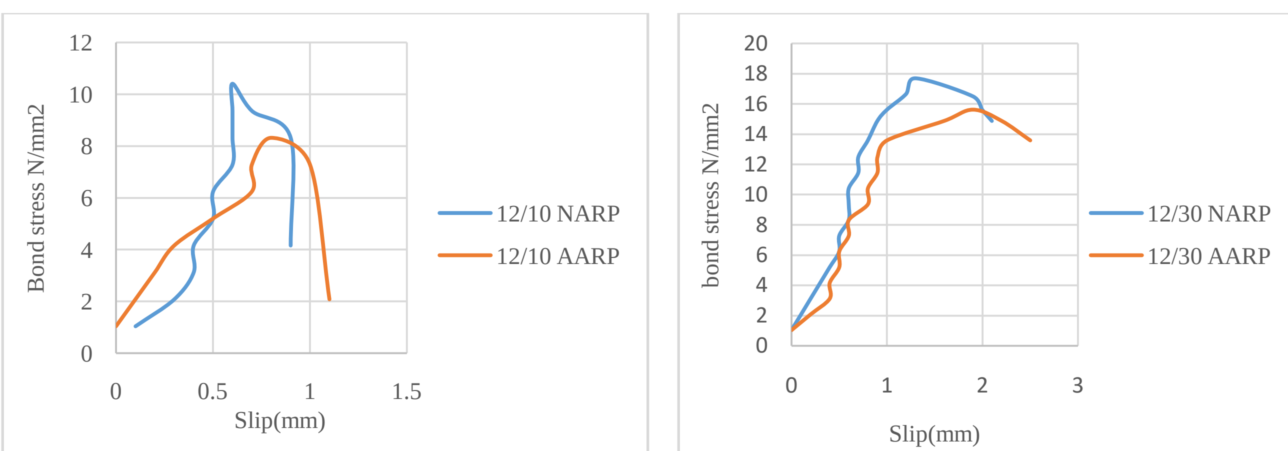

Fig 6: Bond-Slip relation for 12/10 and 12/30 NARP and ARP

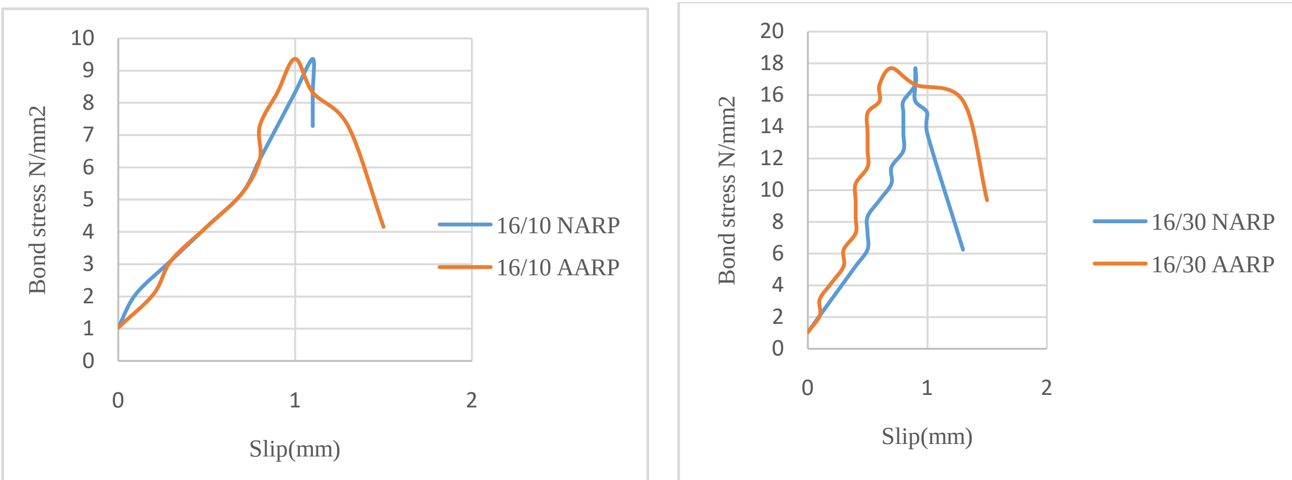

Fig 7: Bond-Slip relation for 16/10 and 16/30 NARP and AARP

The obtained results significantly show that the initial stage of eachcurve has same slop which gives an indication that bond stress at this stage is negligible and the chemicalbonding between steel bars and concrete is sufficient to carry the applied stresses. This stage of bondstress-slip curve is approximately linear called linear elastic stage and the stiffness is still appearing high.With increasing the load, the stress in bar is increased with initiation relative displacement betweenteel bar and concrete. The chemical bonding between steel bar and concrete start to disappear and theinterlocking between ribs and surrounding concrete becomes an important parameter in resisting the bondstresses. The micro cracks start to develop at the contact between ribs and concrete. The crushing ofsurrounding concrete around the ribs has obtained at the advanced stage of loading.The relative displacement between steel bar and concrete start to increase until failure by pulling outdue to an increase the diameter of hole around the steel bar.

Fig 12: Splitted Prism

Fig 13: Tested specimen

V. CONCLUSIONS

Most of the 12/30 and 16/30 deformed bars specimens failed by splitting the concrete prism in two parts as shown in fig 12. 12/10 deformed bars damaged the upper part of the specimen before the bars came out and in case of 16/10 bars came out by splitting the upper part of the specimen as shown in fig12. There was cracking in concrete observed at load reversal after reaching to the maximum load. NARP and ARP has shown significant results in some cases and shown almost same results in some cases are listed below.

- Alkaline cured short embedded length(12/10) specimen creates less bond and more slip in both case NARP and ARP bars.
- In case of 12/30, ARP bars generated less slip for long embedment length and more bond stress.
- For 16/10 NNARP has better performance than ANARP and ARP bars has almost same performance.
- Non ARP bars in case of 16/30 has shown more bond stress and slip than ARP bars in both alkaline and normal curing.

REFERENCES

[1] Thangavel, K. And Rongaswamy, N.S. (1998), "Relationship Between Chloride/Hydroxide Ratio and Corrosion Rate of Steel In Concrete", Cement And Concrete Composites, Vol. 20, Pp. 283-292.

[2] Broomfield, J.G. (1997), "Corrosion of Steel in Concrete: Understanding, Repair and Investigation", First Edition, E andFN Spon, UK.

[3] Ahmad, S. (2003), "Reinforcement Corrosion in Concrete Structures, Its Monitoring and Service Life Prediction", Cement andConcrete Composites, Vol. 25, Pp. 459-471.

[4] Scully, J.C. (1975), "The Fundamentals of Corrosion", International Series Onmaterial Science and Technology, Second Edition, UK.

[5] Elhoud, A., Renton, N.C., And Deans, W.F. (2007), "Effect of Surface Roughness onPitting Corrosion Of 25 Cr Duplex Stainless Steel in Chloride Solution". The 9th LibyanCorrosion Conference, Tripoli-Libya, Pp. 350-362.

[6] Chung, L., Kim, J.H. And Yi, S.T. (2008), "Bond Strength Prediction for Reinforced Concrete Members with Highly Corroded Reinforcing Bars", Cement andConcreteComposites, Vol. 30, Pp. 603-611.

[7] Abd El Aal, E.E., Abd El Wanees, S., Diab, A. And Abd El Haleem, S.M. (2009),"Environmental Factors Affecting the Corrosion Behaviour Of Reinforcing Steel III: Measurement of Pitting Corrosion Currents of Steel In Calcium Hydroxide Solutions Under Natural Corrosion Conditions", Corrosion Science, Vol. 51, Pp. 1611-1618.

[8] Robert G Mathey, James R.Clifton, Erik D. Andersonhugh F. Beeghley,(1973), " PerformanvceOf CoateSteel Reinforcement In Concrete. Part 1. Investigation of Bond onPull Out Specimen", NBSIR 73-401

[9] Jikai Zhou, Xudong Chen, And ShixueChen,(2012), "Effect Of Different Environments On Bond Strength Of Glass Fibre Reinforced Polymer And Steel Reinforcing Bars", KSCE Journal Of Civil Engineering, Vol 16(6), PP. 994-1002.

[10] Warren, George Edward, "Anchorage Strength of Tensile Steel in Reinforced Concrete Beams " (1969). Retrospective Theses andDissertations. 3806.

[11] Esraa Kamal Jaafar, Experimental Study onAnchorage Bond inHigh Strength, Reinforced Concrete Beams. International Journal ofCivil Engineering andTechnology, 8(1), 2017, Pp. 63–71.

[12] Dr.Ala'a H. Al-Zuhairi,Wjdan Dh. Al-Fatlawi, (2009), "Bond Slip Relationship of Reinforcing Steel Bars Embedded in Concrete", 6th Engineering Conference, College Of Engineering 5-7, Vol 1 Civil Engineering, Pp. 18-35.

[13] P. Máca, E. Panteki& M. Curbach, (2016), "BOND STRESS-SLIP BEHAVIOUR OF CONCRETE AND STEEL UNDER HIGH-LOADING RATES", WIT Conferences, ISSN: 2046-0546 (Paper Format), ISSN: 2046-0554 (Online), VOL 4,PP-221-230.

[14] Sungnam Hong And Sun-Kyu Park,(2012), "Uniaxial Bond Stress-Slip Relationship OfReinforcingBars In Concrete", Advances In Material Science And Engineering, Vol 2012, Article ID 328570,PP1-12.