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BOND-SLIP MECHANISMS OF CORRODED AND EXUDATES / RESINS COATED MEMBERS IN REINFORCED CONCRETE STRUCTURES

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ABSTRACT

The mechanical interlock between the ribs of steel, concrete and friction especially between the steel bar surface and concrete are weakened by corrosion activities in structures with the influenced of chloride attack. This study evaluated the influenced of non-coated and grewia exudate/resin coated on the bond strength parameters of reinforced concrete structures subjected to harsh corrosive environment. Concrete cubes of 150mm x 150mm x150mm were cast and reinforcement of non-coated and coated with paste thickness of 150µm, 300µm, 450µm, embedded into concrete, exposed to harsh and saline environments (NaCl solution). Results of corroded averaged failure bond load are 16.8333kN, 16.8666kN and 16.80667kN, summed to 16.835kN, represented -41.613% against 71.271% and 69.660% percentile difference of control and coated exudates/resin member. Corroded averaged bond strength load are 6.08333MPa, 6.26333MPa, 6.086667MPa summed to 6.144MPa, represented percentile value of -35.185% against 54.285% and 81.446% percentile difference of control and coated. Corroded averaged maximum slip values are 0.0819mm, 0.08923mm, 0.085567mm, summed to 0.216mm, represented -25.966% against 35.073% and 153.019% percentile difference of control and coated. Relatively, corroded specimens showed lower failure load and bond strength properties to exudates coated and controlled specimens. Higher values of pullout bond tests of failure load, bond strength and maximum slips of exudates/resins coated specimens were recorded over corroded specimens. Grewia exudates/resin proved to be inhibitory to corrosion effect on reinforcement embedded in concrete structures and a protective coating against corrosion attack.

Index Terms: Corrosion, Corrosion inhibitors, Pull-out Bond Strength, Concrete and Steel Reinforcement

1.0 INTRODUCTION

Corrosion of steel reinforcement manifestation occurred in two principal forms: spalling and cracking of concrete cover resulting from the formation of unrestrained corrosion yield and local pitting of reinforcement at the anode which causes great reduction of the bar cross-sectional area and bond characteristics between steel and concrete. The formation of surface films covering the metal, while generally protective, can give rise to localized corrosion attack and pitting (Scully [1]) Bertolini et al.[2], Lounis et al.[3], Elsener [4]), concluded that there is instantaneous film formation in steel in an oxidizing atmosphere such as air, and once the formation of layer is noticed, metal is "passivated" and the oxidation or "rusting" rate will slow down to less than 0.04 mills per year (mpy). The bond between reinforcing bar and concrete comprises three distinct mechanisms: chemical adhesion,

friction and mechanical interlock. This shear bond becomes more significant with increasing relative displacement under composite mechanisms. The force transfer mechanism is primarily due to the mechanical interlocking between the ribs of steel and concrete and friction especially between the steel bar surface and concrete. The friction force plays a significant role between the concrete and the deformed bar.
Charles et al. [5] Studied and evaluated the effect of corrosion on bond existing between steel and concrete interface of corroded and resins / exudates coated reinforcement with ficus glumosa extracts from trees. Experimental samples were subjected to tensile and pullout bond strength and obtained results indicated failure load, bond strength and maximum slip values of coated were higher by 33.50%, 62.40%, 84.20%, non- corroded by 27.08%, 55.90% and 47.14% respectively. For corroded cube concrete members, the values were lower by 21.30%, 38.80% and 32.00% on failure load, bond strength and maximum slip to those ones obtained by Control and coated members. The entire results showed good bonding characteristic a

Charles et al. [6] investigated the primary causes of the reduction of service life, integrity and capacity of reinforced concrete structures in the marine environment of saline origin is corrosion. Results obtained on comparison showed failure bond load, bond strength and maximum slip decreased in corroded specimens to 21.30%, 38.80% and 32.00% respectively, while coated specimens 51.69%, 66.90%, 74.65%, for Control specimen, 27.08%, 55.90% and 47.14%. Entire results showed lower percentages in corroded and higher in coated members. This justifies the effect of corrosion on the strength capacity of corroded and coated members.
Charles et al. [7] Investigated the Corrosion of steel reinforcement in concrete is one of the principal factor that caused the splitting failures that occurred between steel and concrete, the used of epoxy, resin/exudates has been introduced to curb this trend encountered by reinforced structures built within the saline environment. Pullout bond strength test results of failure bond load, bond strength and maximum slip were 21.30%, 36.80% and 32.00% for corroded members, 36.47%, 64.00% and 49.30% for coated members respectively. The values of corroded members were lower compared to coated members. Results showed that resins / exudates enhances strength to reinforcement and serves as protective coat against corrosion.
Charles et al. [8] investigated the effect of corroded and inhibited reinforcement on the stress generated on pullout bond splitting of control, corroded and resins / exudates paste coated steel bar. In comparison, failure loads of Symphonia globulifera linn, Ficus glumosa, Acardium occidentale l are 36.47%, 32.50% and 29.59% against 21.30% corroded, bond strength are 64.00%, 62.40%, 66.90 against 38.88% and maximum slip are 89.30%, 84.20%, 74.65% against 32.00% corroded. Entire results showed values increased in coated compared to corroded specimens resulted to adhesion properties from the resins / exudates also enhances strength to reinforcement and serves as protective coat against corrosion.
Charles et al. [9] Studied the bond strength exhibited by reinforcement embedded in concrete is controlled by corrosion effects. Pullout bond strength results of failure load, bond strength and maximum slip for dacryodes edulis are 75.25%, 85.30%, 97.80%, moringa oleifera lam; 64.90%, 66.39%, 85.57%, magnifera indica; 36.49%, 66.30% and 85.57%, for Control, 27.08%, 5590% and 47.14% while corroded are 21.30%, 36.80% and 32.00%. The entire results showed lower values in corroded specimens as compared to coated specimens, coated members showed higher bonding characteristics variance from dacryodes edulis (highest), moringa oleifera lam (higher) and magnifera indica (high) and coated serves as resistance and protective membrane towards corrosion effects.
Han-Seung et.al [10] Evaluated the degree of corrosion of reinforcement as the function of bond properties between concrete and reinforcement. Pull out test were conducted and evaluated to ascertain the effects of reinforcement corrosion on the bond behavior between corroded reinforcement and concrete. Rebars were corroded with the accelerated corrosion method inside the pull-out test specimen to the desired level. Pull-out tests were conducted on specimens with and without confinement reinforcement. The load versus free end slip behavior was studied. A finite element analysis was also carried out on the basis of the results of the pull-out tests. It was found that the maximum bond strength and bond rigidity decreased in proportion with increase in corrosion percentage. The equations for calculating the maximum bond strength and the bond rigidity necessary for a Finite Element analysis of reinforced concrete members with corroded reinforcement were obtained by the experiments.

Otunyo and Kennedy [11] Investigated the effectiveness of resin/exudates in corrosion prevention of reinforcement in reinforced concrete cubes. Results obtained indicated that the failure bond strength, pull out bond strength and maximum slip of the resin coated reinforced cubes were higher by (19%), (84%) and (112%). respectively than those obtained from the controlled tests. Similar results were obtained for the maximum slip (the resin coated and Control steel members) had higher values of maximum slip compared to the cubes that had corroded steel reinforcements. For the corroded beam members, the failure bond strength, pull out bond strength and maximum slip of the resin coated reinforcements were lower by (22%), (32%) and (32%). respectively than those obtained from the controlled tests.

Tepfers [12] Stated that a certain displacement occurs in this stage, even though no bar slip is noticed. This displacement is due to the localized strains which are result of high localized stresses arising close to the interface. For that Tepfers reported that the relative displacement of a bar in this stage consists of the relative slip at the interface and the shear deformation in the concrete.

Cairns and Abdullah [13] Affirmed that the split from concrete surrounding resulted from bearing action of ribs that generates bursting forces, the resultant compressive force exerted by the ribs on the concrete is inclined at an angle to the bar axis. A ring tension in the concrete cover around the bar is created by the radial component of the exerted force. As soon as tensile capacity of the ring is exceeded during the development of the bond action, a splitting failure occurs by fracturing the concrete cover surrounding the reinforcement. If the concrete confinement was enough to counterbalance the force generated by bond.

2.0 Experimental program

The present study involves direct application of resins / exudates of trees extract known as inorganic inhibitor, coated on the reinforcing steel surface were studied in this test program. The main objective of this study was to determine the effectiveness of locally available surface-applied corrosion inhibitors under severe corrosive environments and with chloride contamination. The test setup simulates a harsh marine environment of saline concentration in the concrete in the submerged portion of the test specimens, corrosion activity of the steel cannot be sustained in fully immersed samples. The samples were designed with sets of reinforced concrete cubes of 150 mm × 150 mm × 150 mm with a single ribbed bar of 12 mm diameter embedded in the centre of the concrete cube specimens for pull out test and was investigated. To simulate the ideal corrosive environment, concrete samples were immersed in solutions (NaCl) and the depth of the solution was maintained.

2.1 Materials and Methods for Experinment

2.1.1 Aggregates

The fine aggregate and coarse aggregate were purchased. Both met the requirements of BS 882; 1992 [14]

2.1.2 Cement

Portland limestone cement grade 42.5 is the most and commonly type of cement in Nigerian Market. It was used for all concrete mixes in this investigation. The cement met the requirements of BS EN 196-6 [15]

2.1.3 Water

The water samples were clean and free from impurities. The fresh water used was gotten from the tap at the Civil Engineering Department Laboratory, Kenule Beeson Polytechnic, Bori, and Rivers State. The water met the requirements of BS 12390-5 [16]

2.1.4 Structural Steel Reinforcement

The reinforcements are gotten directly from the market in Port Harcourt. BS 12390-5; 2005 [17]

2.1.5 Corrosion Inhibitors (Resins / Exudates) Grewia

The study inhibitor (Grewia) is of natural tree resin /exudate substance extracts.

2.2 Experimental Procedures

2.2.1 Experimental method

2.2.2 Sample preparation for reinforcement with coated resin/exudate

Corrosion tests were performed on high yield steel (reinforcement) of 12 mm diameter with 550 mm lengths for cubes, Specimen surfaces roughness was treated with sandpaper / wire brush and specimens were cleaned with distilled water, washed by acetone and dried properly, then polished and coated with (grewia exudate), resin pastes with coating thicknesses of 150µm, 300µm and 450µm before corrosion test. The test cubes and beams were cast in steel mould of size 150 mm × 150 mm × 150 mm. The specimens were cured at room temperature in the curing tanks for accelerated corrosion test process and testing procedure allowed for 120 days first crack noticed and a further 30 days making a total of 150 days for further observations on corrosion acceleration process.

2.3 Accelerated corrosion set-up and testing procedure

In real and natural conditions the development of reinforcement corrosion is very slow and can take years to be achieved; as a result of this phenomenon, laboratory studies necessitate an acceleration of corrosion process to achieve a short test period. After curing the cubes specimens for 28 days, specimens were lifted and shifted to the corrosion tank to induce desired corrosion levels. Electrochemical corrosion technique was used to accelerate the corrosion of steel bars embedded in cubes specimens. Specimens were partially immersed in a 5% NaCl solution for duration of 150 days, to examine the surface and mechanical properties of rebar.

2.3 Pull-out Bond Strength Test

The pull-out bond strength tests on the concrete cubes were performed 9 specimens each of non-corroded, corroded and exudates/resins coated specimens, totaling 27 specimens on Universal Testing Machine of capacity 50KN in accordance with BS EN 12390-2. The dimensions of the pull-out specimens were 27 cubes 150 mm × 150 mm × 150 mm with a single ribbed bar of 12mm diameter embedded in the centre of the concrete cube. After 150 days, the accelerated corrosion subjected samples were examined to determine bond strength effects due to corrosion and corrosion inhibited samples. Specimens of 150 mm x150 mm x150 mm concrete cube specimens were also prepared from the same concrete mix used for the cubes, cured in water for 28 days, and accelerated with 5% NaCl solution for same 150 days making a total of 178 days was consequently tested to determine bond strength.

2.4 Tensile Strength of Reinforcing Bars

To ascertain the yield and tensile strength of tension bars, bar specimens of 12 mm diameter of Control, corroded and coated were tested in tension in a Universal Testing Machine and were subjected to direct tension until failure; the yield, maximum and failure loads being recorded. To ensure consistency, the remaining cut pieces from the standard length of corroded and Control steel bars were subsequently used in the bond and flexural test.
of corroded and Control steel bars were subsequently used in the bond and flexural test.

3.0 Experimental Results and Discussion

Tables 1, 2 and 3 are the detailed results of pullout bond strength test of failure bond load, bond strength and maximum slip obtained from 27 samples of control, corroded and grewia exudates/ resins steel bar coated specimens paste on reinforcement embedded in concrete cubes member. Table 4 and 5 showed the results of average and summary pull-out bond strength values of failure load, bond strength and maximum slip of control, corroded and resins/exudates coated specimens. Figures 1 and 2 are the plots of entire failure bond load versus bond strength and bond strength versus maximum slip, while figures 3 and 4 are the plots of average failure bond load versus maximum slip obtained from tables 1, 2 and.3

3.1 Control Concrete Cube Members

Results of table 1, into tables 4 and 5 as represented graphically in figures 1 – 4, of average values failure load are 28.35kN, 29.2266kN and 28.9266kN, summed to 28.834kN and represented 71.271% percentile value. Averaged bond strength values are 9.20MPa, 9.62MPa and 9.62MPa, into 9.48MPa and percentile value of 54.285%. Averaged maximum slip values are 0.11046mm, 0.11946mm, and 0.1168mm summed to 0.115mm represented 35.073% percentile values.

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3.2 Corroded Concrete Cube Members

Results of table 1, into 4 and 5, as shown in figures 1 – 4, averaged failure bond load are 16.8333kN, 16.8666kN and 16.80667kN, summed to 16.835kN, represented -41.613% against 71.271% and 69.660% percentile difference of control and coated exudates/resin member. Averaged bond strength load are 6.08333MPa, 6.26333MPa, 6.086667MPa summed to 6.144MPa, represented percentile value of -35.185% against 54.285% and 81.446% percentile difference of control and coated. Averaged maximum slip values are 0.0819mm, 0.08923mm, 0.085567mm, summed to 0.216mm, represented -25.966% against 35.073% and 153.019% percentile difference of control and coated. Relatively, corroded specimens showed lower failure load and bond strength properties to exudates coated and controlled specimens.

3.3 Grewia Exudates/ Resins Steel Bar Coated Specimens Steel Bar Coated Concrete Cube Members

Results from table 3 into 4 and 5, as shown in figures 1 – 4, averaged failure bond load values are 27.653kN, 28.9666kN, 29.07kN summed to 28.563kN, represented 69.660% over -41.613% corroded percentile differences, averaged bond strength values are 10.77MPa, 10.91MPa, 11.7666MPa summed to 11.148MPa, represented 81.446% over -35.185% and averaged maximum slip values are 0.1955mm, 0.20383mm, 0.25016mm summed to 0.216mm represented 153.019% over -25.966% corroded percentile differences. Higher values of pullout bond tests of failure load, bond strength and maximum slips of exudates/resins coated specimens were recorded over corroded specimens.

Table 1. Results of Pull-out Bond Strength Test (τu) (MPa)

S/no		Control Cube Specimens								
Concrete Cube	**Sample**	ACU1	BCU1	BCU1	DCU1	ECU1	FCU1	GCU1	HCU1	ICU1
TCXY1-1	Failure Bond Loads (kN)	29.09	28.23	27.73	29.94	28.44	29.3	29.44	28.24	29.1
TCXY1-2	Bond strength (MPa)	9.33	9.2	9.07	9.73	9.19	9.94	9.73	9.79	9.34
TCXY1-3	Max. slip (mm)	0.1238	0.1088	0.0988	0.1288	0.1118	0.1178	0.1188	0.1038	0.1278
TCXY1-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 2. Results of Pull-out Bond Strength Test (τu) (MPa)

S/no		**Corroded Cube Specimens**								
Concrete Cube	**Sample**	ACU2	BCU2	BCU2	DCU2	ECU2	FCU2	GCU2	HCU2	ICU2
TCXY 2-1	Failure Bond load (KN)	16.41	17.16	16.93	17.39	16.64	16.57	17.16	16.64	16.62
TCXY 2-2	Bond strength (MPa)	5.7	6.35	6.2	6.72	6.16	5.91	6.32	6.01	5.93
TCXY 2-3	Max. slip (mm)	0.0669	0.0929	0.0859	0.0979	0.0849	0.0849	0.0909	0.0829	0.0829
TCXY2-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 3. Results of Pull-out Bond Strength Test (τu) (MPa)

		Grewia Exudate (steel bar coated specimen)								
S/no		**(150µm) coated**			**(300µm) coated**			**(450µm) coated**		
Concrete Cube	**Sample**	ACU3	BCU3	BCU3	DCU3	ECU3	FCU3	GCU3	HCU3	ICU3
TCXY3-1	Failure load (KN)	27.74	27.29	27.93	28.52	29.34	29.04	29.25	29.42	28.54
TCXY3-2	Bond strength (MPa)	11.14	11.34	9.83	10.34	11.14	11.25	12.24	11.54	11.52
TCXY3-3	Max. slip (mm)	0.2055	0.1955	0.1855	0.2025	0.1955	0.2135	0.2415	0.2555	0.2535
TCXY3-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 4. Results of Average Pull-out Bond Strength Test (τu) (MPa)

		Control, Corroded and Resin Steel bar Coated								
S/no		**Control Cube**			**Corroded Cube Specimens**			**Exudate steel bar coated specimens**		
Concrete Cube	**Sample**	**Control Specimens Average Values**			**Corroded Specimens Average Values**			**Coated Specimens Average Values of 150µm, 300µm, 450µm)**		
TCXY4-1	Failure load (KN)	28.35	29.2266	28.9266	16.8333	16.8666	16.80667	27.653	28.9666	29.07
TCXY4-2	Bond strength (MPa)	9.2	9.62	9.62	6.08333	6.26333	6.086667	10.77	10.91	11.7666
TCXY4-3	Max. slip (mm)	0.11046	0.11946	0.1168	0.0819	0.08923	0.085567	0.1955	0.20383	0.25016
TCXY4-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

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Table 5. Results of Average Pull-out Bond Strength Test (τu) (MPa)

		Control Cube			Corroded Cube Specimens			Exudate steel bar coated specimens		
		Summary Specimens Average Values of Control, Corroded and Exudate Steel bar Coated			Summary of Percentile Values of Control, Corroded and Exudate Steel bar Coated			Percentile Difference of Control, Corroded and Exudate Steel bar Coated		
TCXY5-1	Failure load (KN)	28.834	16.835	28.563	171.271	58.386	169.660	71.271	-41.613	69.660
TCXY5-2	Bond strength (MPa)	9.48	6.144	11.148	154.285	64.814	181.446	54.285	-35.185	81.446
TCXY5-3	Max. slip (mm)	0.115	0.085	0.216	135.073	74.033	253.019	35.073	-25.966	153.019
TCXY5-4	Bar diameter (mm)	12	12	12	100	100	100	0	0	0

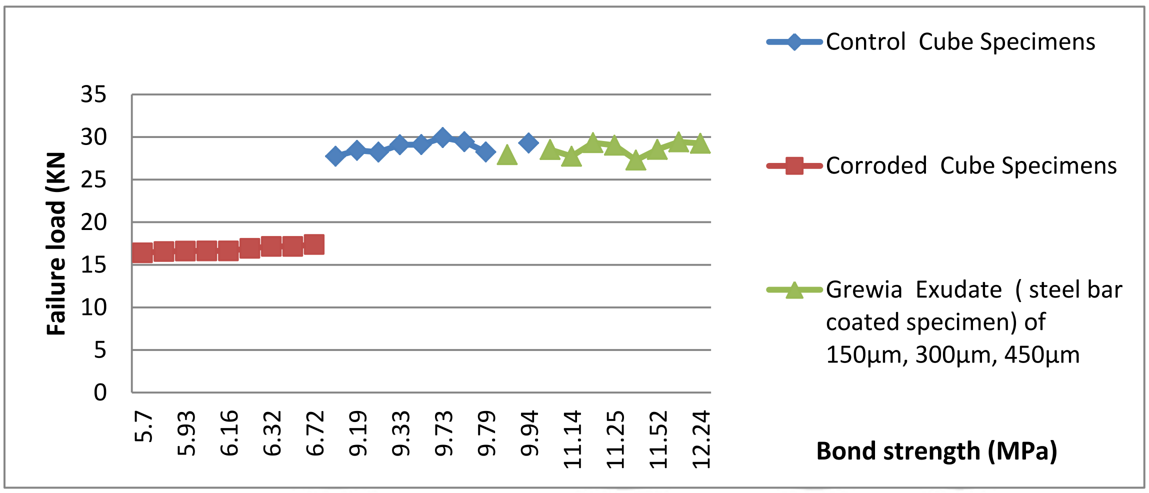

Fig. 3 Summary Results of Pull-out Bond Strength Test (τu) (MPa)

(Failure loads versus Bond Strengths

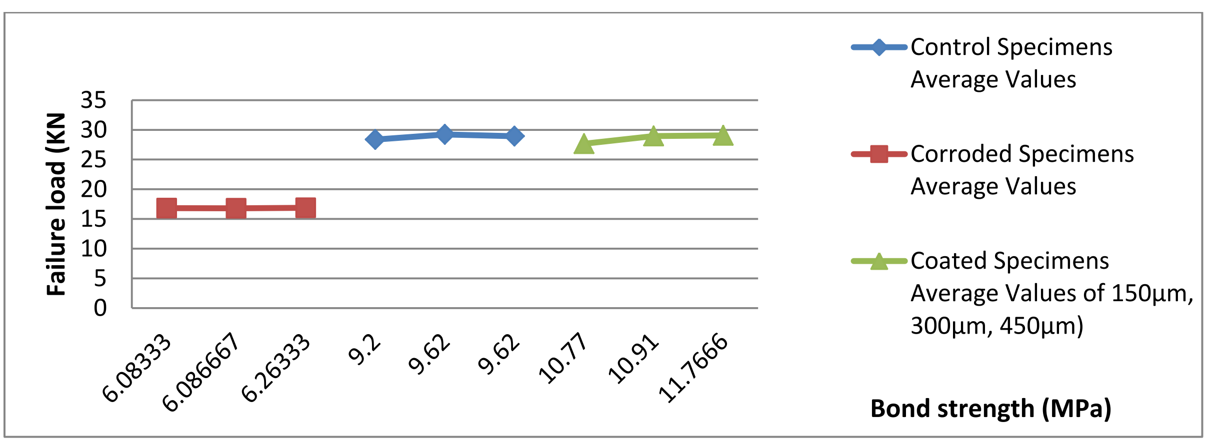

Fig. 2 Average Results of Pull-out Bond Strength Test (τu) (MPa)

(Failure loads versus Bond Strengths)

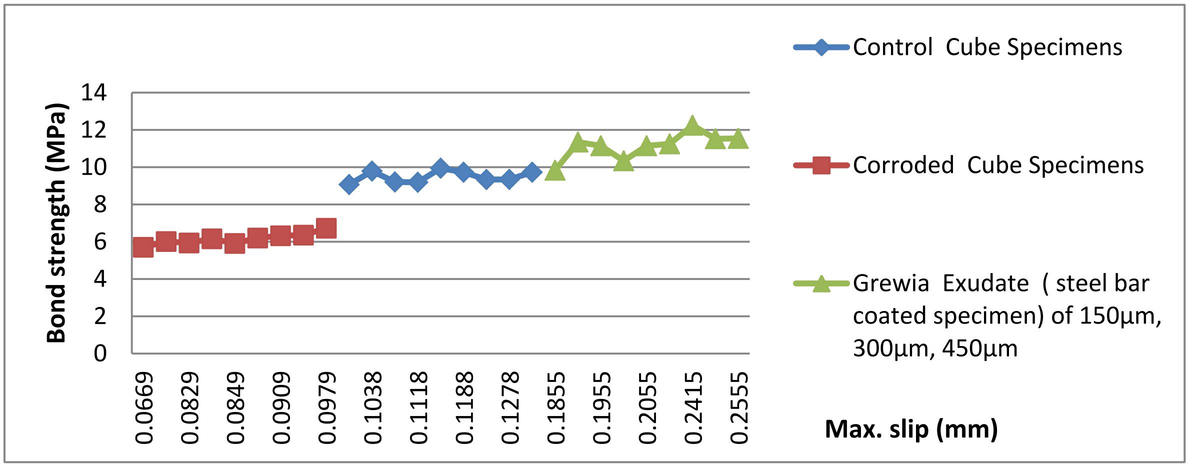

Fig. 3 Summary Results of Pull-out Bond Strength Test (τu) (MPa)
(Bond Strength versus Maximum Slip)

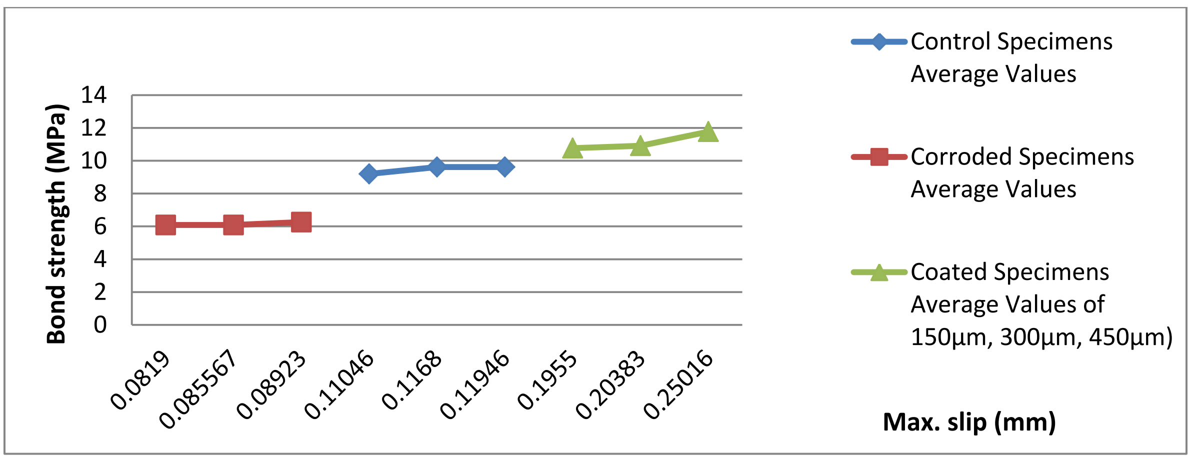

Fig. 4 Average Results of Pull-out Bond Strength Test (τu) (MPa)
(Bond Strength versus Maximum Slip)

4.0 CONCLUSION

Experimental results showed the following conclusions:

i. Grewia exudates/ resins coated specimens showed high protective and resistance membrane to corrosion
ii. Exudates/resins coated steel specimens showed higher pull out failure load over corroded specimens
iii. Higher bond strengths and maximum slips were exhibited by coated over corroded specimens
iv. Low strength capacities of corroded specimens were recorded with higher failure bond load.
v. Summarized results showed higher values of pullout bond strength in control and exudates/ resins coated to corroded specimens
vi. Higher bond stresses were experienced in exudates /resin coated reinforcements over controlled specimens
vii. Grewia exudates/ resins showed potential of corrosion inhibitive characteristic

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