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Pullout Bond Splitting Effects Of Corroded And Inhibited Reinforcement In Corrosive Media

Charles Kennedy[1], Ogunjiofor Emmanuel Ifeanyi[2] , Terence Temilade Tam Wokoma[3]
[1]Faculty of Engineering, Department of Civil Engineering,
Rivers State University, Nkpolu, Port Harcourt, Nigeria.
[2]Department of Civil Engineering,
Chukwuemeka Odumegwu Ojukwu University,
Uli, Anambra State, Nigeria.
[3,]School of Engineering, Department of Civil Engineering,
Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria.
Authors E-mail: [1]ken_charl@yahoo.co.uk, [2]ogunjioforemmanuel@gmail.com, [3]terencett.wokoma@gmail.com

Abstract-Corrosion of steel has great impact on the reduction of the tensile force transfer from concrete to reinforcing steel, bond interaction between steel reinforcement - concrete and its effect on steel reinforcement structural behavior. This experimental work examined on the bond strength of non- corroded, corroded and exudates / resin coated specimens of reinforced concrete structures of standard cubes 150mm x 150mm x150mm, immersed in corrosive media for 150days accelerated periods with embedded non-coated and coated reinforcements. Average results of percentile failure bond load of corroded are -41.3377% against 70.4673% and 74.7071% percentile difference of control and coated exudates/resin members. Average percentile bond strength load of corroded is -31.8011% against 46.6300% and 72.9432% percentile difference of control and coated. Average percentile maximum slip values is -58.9045% against 143.336% and 177.493% percentile difference of control and coated. Collated results proved that corroded specimens have low bond strength with weak maximum slip during splitting test and high failure load. Non-corroded and exudates/resin coated specimens have higher bond strength and low failure load. Exudate/resin specimens showed high protective characteristics against corrosion effects thus serves as inhibitors. Exudates/resins coated specimens' demonstrated inhibitory properties with high performance to bonding strength and maximum slip with low failure in comparison to corroded specimens.

Keywords—Corrosion, Corrosion inhibitors, Pull-out Bond Strength, Concrete and Steel Reinforcement

1. INTRODUCTION

Corrosion effect on reinforced concrete structures has great impact that led to reduction on the tensile force transfer from concrete to reinforcing steel, bond interaction between steel reinforcement - concrete and its effect steel reinforcement on structural behavior is as global phenomena, as demonstrated by many experimental studies ([1],[2],[3],[4]). Bond strength primarily originates from weak chemical bonds between steel and hardened cement, but this resistance is broken at a very low stress. Once slip occurs, friction contributes to bond. In plain reinforcing steel bars, friction is the major component of strength. Deformed (ribbed) reinforcing steel bars, and under increasing slip bond depend principally on the bearing, or mechanical interlock, between ribs rolled on the surface of the bar and the surrounding concrete. In this stage, the reinforcing bar generates bursting forces which tend to split the surrounding concrete. Corrosion causes early cracks, spailling and pitting which generates tensile stresses in steel reinforcement surroundings in the concrete, reduces the overall strength and stiffness of the concrete structure and accelerate the ingress of aggressive ions, leading to other types of concrete deterioration and resulting in further cracking [5].

Reference [6] 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 non-corroded and coated members. The entire results showed good bonding characteristic and effectiveness in the use of ficus glumosa resins / exudates as protective materials against corrosion.

Reference [7] 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 non-corroded 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.

Reference [8] 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 non-corroded 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.

Reference [9] 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.

Reference [10] investigated the effect of corroded and inhibited reinforcement on the stress generated on pullout bond splitting of non-corroded, 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.

Reference [11] studied the bond strength exhibited by reinforcement embedded in concrete is controlled by corrosion effects. Results showed that uncoated specimens corrosion potential with signs associated with cracks, spalling and pitting. 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 non-corroded, 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.

2. Experimental Program

The present study involves direct application of resins / exudates of trees extract known as inorganic inhibitor, coated on the reinforcing steel surface and 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 [12]

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 [13]

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 [14]

2.1.4 Structural Steel Reinforcement

The reinforcements are gotten directly from the market in Port Harcourt, [15]

2.1.5 Corrosion Inhibitors (Exudate/Resin) Milicia excelsa

The study inhibitor (Milicia excelsa) 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 Exudate/Resin

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 (Milicia excels 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.

3. Experimental Results and Discussion

Tables 3.1, 3.2 and 3.3 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 Milicia excelsa exudates/ resins steel bar coated specimens paste on reinforcement embedded in concrete cubes member. Table 3.4 and 3.5 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 3.1 and 3.2 are the plots of entire failure bond load versus bond strength and bond strength versus maximum slip, while figures 3.3 and 3.4 are the plots of average failure bond load versus maximum slip obtained from tables 3.1, 3.2 and 3.3

3.1 Control Concrete Cube Members

Tables 3.1 were specimens arbitrarily sampled and summarized into tables 3.4 and 3.5, with graphically represented in figures 3.1–3.4. Average obtained failure bond load values are 29.425kN, 30.3016kN and 30.001kN, summed up to 29.9094kN and represented 70.4673% percentile value. Average bond strength values are 9.80MPa, 10.22MPa and 10.22MPa, into 10.08MPa and percentile value of 46.6300%. Average maximum slip values are 0.19166mm, 0.20066mm, and 0.198mm summed up to 0.19677mm represented 143.336% percentile values.

3.2 Corroded Concrete Cube Members

Tables 3.1 were specimens arbitrarily sampled and summarized into tables 3.4 and 3.5, with graphically represented in figures 3.1–3.4. Average failure bond load are 17.543kN, 17.5766kN and 17.516kN, summed up to 17.5455kN and represented -41.3377% against 70.4673% and 74.7071% percentile difference of control and coated exudates/resin members. Average bond strength load 6.813MPa, 6.993MPa, 6.816MPa summed up to 6.87444MPa and represented percentile value of -31.8011% against 46.6300% and 72.9432% percentile difference of control and coated. Average maximum slip values are 0.0772mm, 0.08453mm, 0.0808mm, summed up to 0.08086mm, represented -58.9045% against 143.336% and 177.493% percentile difference of control and coated. Collated results proved that corroded specimens have low bond strength with weak maximum slip during splitting test and high failure load. Non-corroded and exudates/resin coated specimens have higher bond strength and low failure load. Exudates/resin specimens showed high protective characteristics against corrosion effects thus serves as inhibitors.

3.3 Milicia excelsa Exudates/ Resins Steel Bar Coated Specimens Steel Bar

(Concrete Cube Members)

Tables 3.1 were specimens arbitrarily sampled and summarized into tables 3.4 and 3.5, with graphically represented in figures 3.1–3.4. Average obtained failure load values are 29.743kN, 31.056kN, 31.160kN summed up to 30.6533kN and represented 74.7071% over -41.3377% corroded percentile differences, average bond strength values are 11.510MPa, 11.650MPa, 12.506MPa summed up to 11.8888MPa and represented 72.9432% over -31.8011%, while average maximum slip values are 0.2034mm, 0.2117mm, 0.2580mm summed up to 0.2244mm and represented 177.493% over -58.9045% corroded percentile differences. Exudates/resins coated specimens demonstrated an inhibitory property with high performance to bonding strength and maximum slip with low failure in comparison to corroded specimen .

Table 3.1: Results of Pull-out Bond Strength Test (τu) (MPa)

S/no		Non-corroded Control Cube Specimens								
Concrete Cube	**Sample**	XAC	XBC	XCC	XDC	XEC	XFC	XGC	XHC	XIC
CCH1-1	Failure Bond Loads (kN)	30.165	29.305	28.805	31.015	29.515	30.375	30.515	29.315	30.175
CCH1-2	Bond strength (MPa)	9.93	9.8	9.67	10.33	9.79	10.54	10.33	10.39	9.94
CCH1-3	Max. slip (mm)	0.205	0.19	0.18	0.21	0.193	0.199	0.2	0.185	0.209
CCH1-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 3.2: Results of Pull-out Bond Strength Test (τu) (MPa)

S/no		Corroded Cube Specimens								
Concrete Cube	**Sample**	XAC2	XBC2	XBC2	XDC2	XEC2	XFC2	XGC2	XHC2	XIC2
CCH 2-1	Failure Bond load (KN)	17.12	17.87	17.64	18.1	17.35	17.28	17.87	17.35	17.33
CCH 2-2	Bond strength (MPa)	6.43	7.08	6.93	7.45	6.89	6.64	7.05	6.74	6.66
CCH 2-3	Max. slip (mm)	0.0622	0.0882	0.0812	0.0932	0.0802	0.0802	0.0862	0.0782	0.0782
CCH2-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 3.3: Results of Pull-out Bond Strength Test (τu) (MPa)

		Milicia excelsa exudates (steel bar coated specimen)								
S/no		(150μm) coated			(300μm) coated			(450μm) coated		
Concrete Cube	**Sample**	XAC3	XBC3	XBC3	XDC3	XEC3	XFC3	XGC3	XHC3	XIC3
CCH3-1	Failure load (KN)	29.83	29.38	30.02	30.61	31.43	31.13	31.34	31.51	30.63
CCH3-2	Bond strength (MPa)	11.88	12.08	10.57	11.08	11.88	11.99	12.98	12.28	12.26
CCH3-3	Max. slip (mm)	0.2134	0.2034	0.1934	0.2104	0.2034	0.2214	0.2494	0.2634	0.2614
CCH3-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 3.4: Results of Average Pull-out Bond Strength Test (τu) (MPa)

S/no		Non-corroded Control Cube			Corroded Cube Specimens			Exudate steel bar coated specimens		
Concrete Cube	**Sample**	**Non-Corroded Specimens Average Values**			**Corroded Specimens Average Values**			**Coated Specimens Average Values of 150μm, 300μm, 450μm)**		
CCH4-1	Failure load (KN)	29.425	30.3016	30.001	17.543	17.5766	17.516	29.743	31.056	31.160
CCH4-2	Bond strength (MPa)	9.80	10.22	10.22	6.813	6.993	6.816	11.510	11.650	12.506
CCH4-3	Max. slip (mm)	0.19166	0.20066	0.198	0.0772	0.08453	0.0808	0.2034	0.2117	0.2580
CCH4-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 3.5: Results of Average Pull-out Bond Strength Test (τu) (MPa)

		Non-corroded 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**		
CCH5-1	Failure load (KN)	29.9094	17.5455	30.6533	170.467	58.6622	174.707	70.4673	-41.3377	74.7071
CCH5-2	Bond strength (MPa)	10.08	6.87444	11.8888	146.630	68.1988	172.943	46.6300	-31.8011	72.9432
CCH5-3	Max. slip (mm)	0.19677	0.08086	0.2244	243.336	41.0954	277.493	143.336	-58.9045	177.493
CCH5-4	Bar diameter (mm)	12	12	12	100	100	100	0	0	0

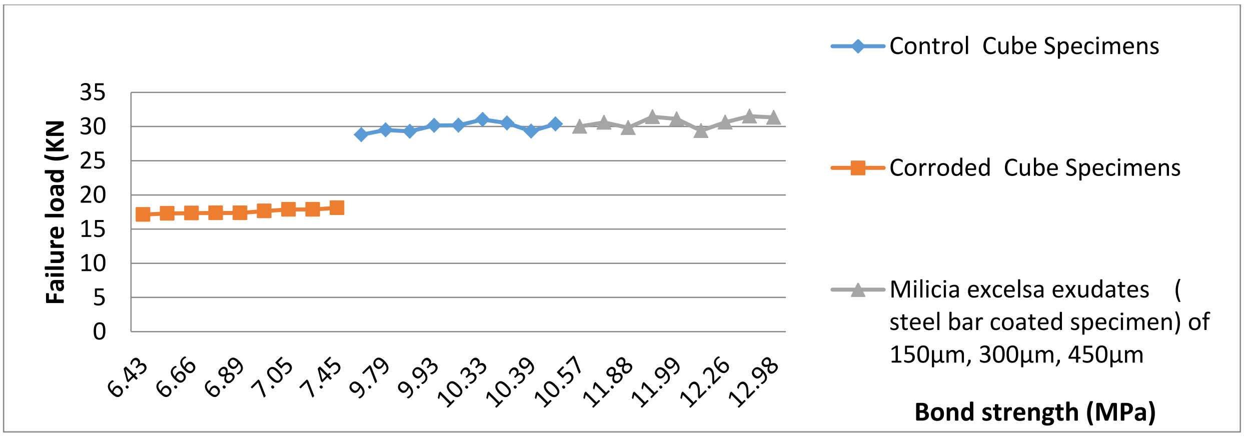

Figure 3.1: Summary Results of Pull-out Bond Strength Test (τu) (MPa)

(Failure loads versus Bond Strengths

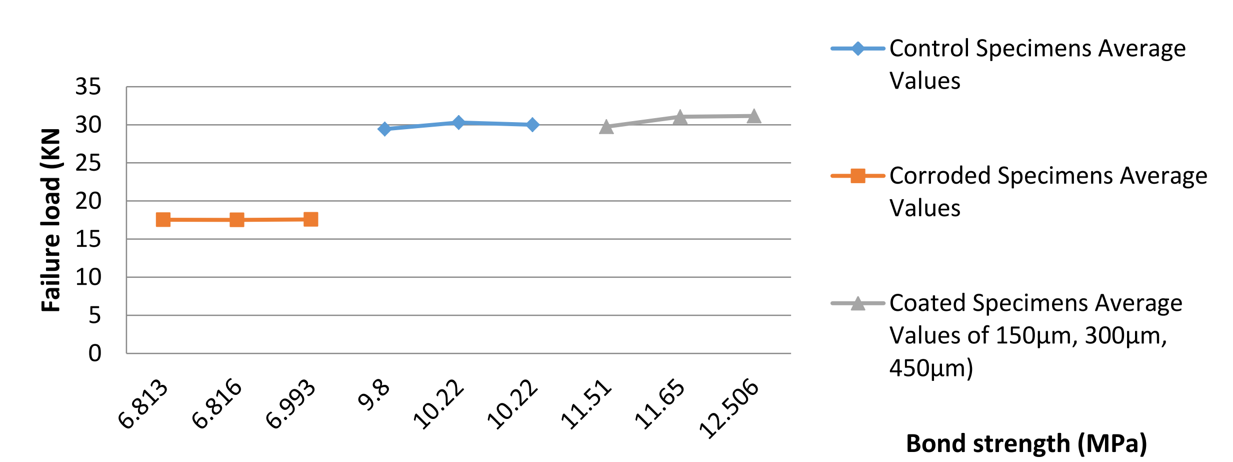

Figure 3.2: Average Results of Pull-out Bond Strength Test (τu) (MPa)

(Failure loads versus Bond Strengths)

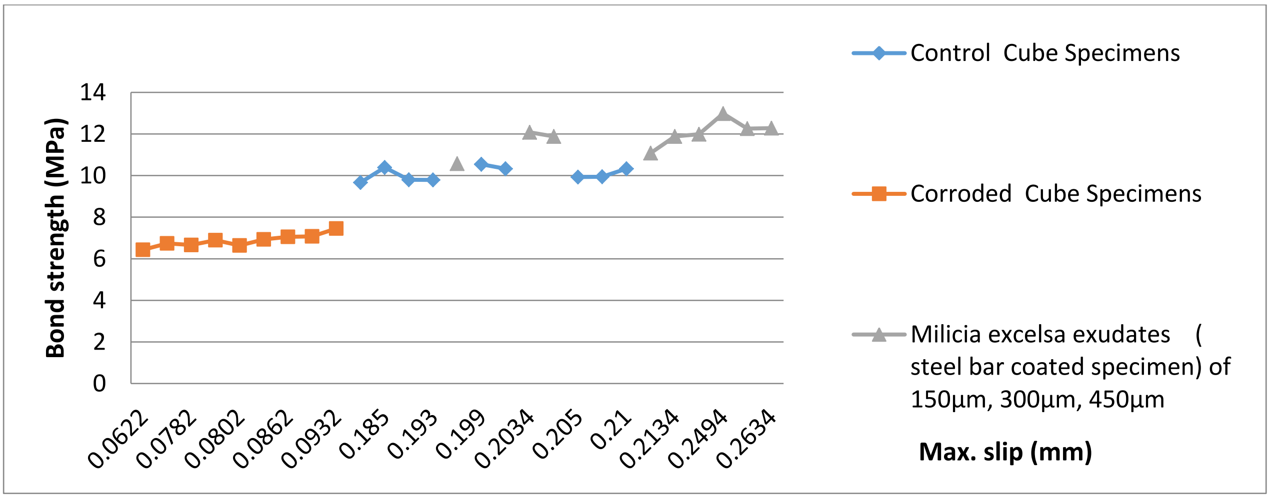

Figure 3.3: Summary Results of Pull-out Bond Strength Test (τu) (MPa)

(Bond Strength versus Maximum Slip)

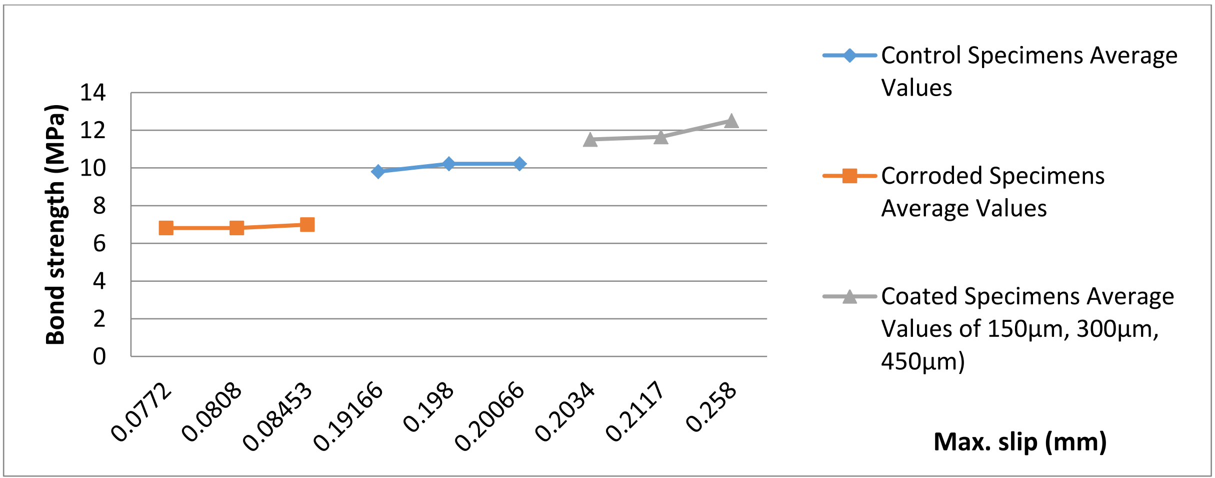

Figure 3.4: Average Results of Pull-out Bond Strength Test (τu) (MPa)

(Bond Strength versus Maximum Slip)

4. CONCLUSION

Experimental results showed the following conclusions:

i. Exudate/resin coated specimens' demonstrated inhibitory properties with high performance to bonding strength and maximum slip with low failure in comparison to corroded specimens.
ii. Collated results proved that corroded specimens have low bond strength with weak maximum slip during splitting test and high failure load.
iii. Non-corroded and exudates/resin coated specimens have higher bond strength and low failure load.
iv. Exudate/resin specimens showed high protective characteristics against corrosion effects thus serves as inhibitors.

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