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Pullout Bond Splitting Effects of Reinforced Concrete Structures with Corroded and Inhibited Reinforcement in Corrosive Environment of Sodium Chloride

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Abstract

This study 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 of 150µm, 250µm and 350µm thicknesses from three trees extract of symphonia globulifera linn, ficus glumosa, acardium occidentale l. Uncoated and coated members were embedded into concrete cubes and exposed to laboratory severely / corrosive environment and enumerated the effects on surface condition of reinforcing steel for 90 days after initial 30 days curing and 60days ponding in an accelerated medium. Results obtained showed potentiality of corrosion on uncoated concrete cube members. 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.

Key Words: Corrosion, Corrosion inhibitors, Pull-out Bond Strength, Concrete and Steel Reinforcement

1.0 INTRODUCTION

Corrosion generates tensile stresses in steel reinforcement surroundings in the concrete, resulting to early cracks, pitting and spalling which in turn can reduce 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 (Mehta & Gerwick, [1]). Corrosion reduces the tensile force transfer from concrete to reinforcing steel and its effect steel reinforcement on structural behavior is as global phenomena, as demonstrated by many experimental studies (Almusallam et al., [2]; Lee *et al*., [3]; Lundgren, [4]; Fang *et al*., [5] and Dahou *et al*., [6].

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. The failure load may be limited by the resistance provided to these bursting forces by concrete cover and confining reinforcement. Experimental studies showed an increase in bond strength during the initial corrosion level to about 2%. In agreement with the above results, significant literature has been published in this area by Cabrera [7], Amleh and Mirza. [8], Auyeung *et al*. [9], and Ouglova *et al*. [10].

Otunyo and Kennedy [11] investigated the effectiveness of resin/exudates in corrosion prevention of reinforcement in reinforced concrete cubes. The reinforced concrete cubes of dimension (150mm x 150mm x 150mm) were coated with dacryodes edulis resin paste of various thicknesses: 150um, 250um, and 300um the reinforced concrete cubes were exposed to a corrosive environment for 60days after 28 days of curing. 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%). 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%).

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 FOR EXPERINMENT

2.1.1 Aggregates

The fine aggregate was gotten from the river, washed sand deposit, coarse aggregate was granite a crushed rock of 12 mm size and of high quality. Both aggregates met the requirements of BS 882.

2.1.2 Cement

The cement used was Eagle Portland Cement; 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, University of Uyo, Uyo. Akwa - Ibom State. The water met the requirements of

2.1.4 Structural Steel Reinforcement

The reinforcements are gotten directly from the market in Port Harcourt.

2.1.5 Corrosion Inhibitors (Resins / Exudates) (Symphonia globulifera linn, Ficus glumosa, Acardium occidentale l.)

The study inhibitors are of natural tree resins/Exudates substances extracts. They are abundantly found in Rivers State bushes and they are sourced from plantations and bushes of Odioku communities, Ahoada West

Local Government areas, Rivers State, from existed and previously formed and by tapping processes for newer ones. They are:

1. Symphonia globulifera linn

2. Ficus glumosa

3. Acardium occidentale l.

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 (Symphonia globulifera linn, Ficus glumosa, Acardium occidentale l), resin pastes with coating thicknesses of 150µm, 250µm and 300µm before corrosion test. The test cubes and beams were cast in steel mould of size 150 mm × 150 mm × 150 mm. Fresh concrete mix for each batch was fully compacted by tamping rods, to remove trapped air, which can reduce the strength of the concrete and 12 mm reinforcements of coated and non-coated were spaced at 150 mm with concrete cover of 25 mm had been embedded inside the slab and projection of 100 mm for half cell potential measurement. Specimens were demoulded after 24hrs and cured for 28 days. The specimens were cured at room temperature in the curing tanks which then gave way for accelerated corrosion test process and testing procedure allowed for 39 days first crack noticed and a further 21 days making a total of 60 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 of beams and 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 beams specimens. Specimens were partially immersed in a 5% NaCl solution for duration of 60 days, to examine the surface and mechanical properties of rebars.

2.3 Pull-out Bond Strength Test

The pull-out bond strength tests on the concrete cubes were performed out after 45 specimens on Universal Testing Machine of capacity 50KN in accordance with BS EN 12390-2. After curing for 28days, 6 controlled cubes (non-corroded) was kept in a control condition as against corrosion as to ascertain bond difference effects, 48 cubes samples of non-coated and resins / exudates coated were partially place in ponding tank for 39 days placed to examine accelerated corrosion process. After 39 days, the accelerated corrosion subjected samples were examined to determine bond strength effects due to corrosion and corrosion inhibited samples.

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. The bond length of the bar was placed at the centre of the concrete cube with 40mm of length protruding from the top of the specimen and with the outer 75 mm of the reinforcing bar enclosed in a PVC tube to ensure that these sections remained un-bonded. Additionally, the reinforcement bar was covered with tape for a distance of 75 mm from both ends of the cube so that the corrosion could take place only within the 50 mm bonded length. The pull-out bond tests were conducted using an Instron Universal Testing Machine of 50KN capacity at a slow loading rate of 1 mm/min. 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 39 days and a further 21 days making a total of 60 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 non-corroded, 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 non-corroded steel bars were subsequently used in the bond and flexural test.

3.0 Experimental results and discussion

Table 3.1 shows the results of the entire experimental conducted on 45concrete cube members of non-corroded, corroded and resins / exudates paste coated steel bar with Symphonia globulifera linn, Ficus glumosa, Acardium occidentale l of thicknesses 150µm, 250µm and 350µm, of pullout bond strength failure load, bond strength and maximum slip, and table 3.2, the results of computed average derived from table 3.1 of A – I to ABC. Figures 3.1 and 3.3 are the graphical representations of the plots of failure bond load versus bond strength and figures 3.2, 3.4 are the plots of bond strength versus maximum slip. The percentile values were derived from table 3.2.

3.1 Non-Corroded Concrete Cube Members

Results of table 3.1 from A – I and summarized into averages in table 3.2, enumerated the results of the pullout bond strength of failure load, bond strength and maximum slip of
27.08%, 55.90% and 47.14%. as represented in figures 3.3 and 3.4.

3.2 Corroded Concrete Cube Members

Results of tables 3.1(A – I) and 3.2 (ABC), showed the behavior of non-corroded, corroded and coated reinforcing bars of the pullout bond strength of failure load (tensile), bond strength and maximum slip summarized values in table 3.2 are 21.30%, 36.80%, 32.00% represented a decreased values as compared to non- corroded (controlled) of 27.08%, 55.90% and 47.14% respectively.

3.3 Symphonia globulifera linn, Ficus glumosa, Acardium occidentale l), Steel Bar Coated Concrete Cube Members

Computed results from tables 3.1 to3.2, summarizes the average values of the pullout bond strength failure load, bond strength and maximum slip of three different trees extract of Symphonia globulifera linn, Ficus glumosa, Acardium occidentale l were presented in figure 3.1 and 3.4 shows the plotted values of non-corroded, corroded and coated reinforcing steel bar of failure load versus bond strength and bond strength versus and maximum slip at summary and average results. 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 values showed and increased in coated compared to corroded specimens resulted to adhesion properties from the resins / exudates.

Table 3.1 Summary Results of Pull-out and Bond Strength Test (τu) (MPa) Control, Corroded and Resin Steel bar Coated

		Cube Samples								
S/N0		A	B	C	D	E	F	G	H	I
Concrete Cube										
1		**Failure Bond Loads (kN)**								
CCkA 1-	**Non-corroded Control Cube**	22.83	21.97	21.47	23.68	22.18	23.04	23.18	21.98	22.84
CCkA 1-2	**Corroded**	17.34	18.09	17.86	18.32	17.57	17.50	18.09	17.57	17.55
		Coated specimens								
		(150μm) coated (A, B, C)			**(250μm) coated(D,E, F)**			**(350μm) coated (G,H,I)**		

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CCkA 1-3	**Ficus glumosa (steel bar coated specimen)**	21.23	22.06	21.35	23.55	23.47	22.85	25.39	27.52	25.60
CCkA 1-4	**Symphonia globulifera linn (steel bar coated specimen)**	20.45	21.82	20.90	23.90	24.75	24.20	24.90	26.75	29.30
CCkA 1-5	**Acardium occidentale l. (steel bar coated specimen)**	22.15	23.15	22.68	22.45	25.35	25.75	25.45	27.35	27.75
2		**Bond strength (MPa)**								
CCkB 2-1	**Non-corroded Control Cube**	7.35	7.22	7.09	7.75	7.21	7.96	7.75	7.81	7.36
CCkB 4-2	**Corroded**	4.25	4.90	4.75	5.27	4.71	4.46	4.87	4.56	4.48
		Coated Specimens								
		(150µm) coated (A, B, C)			**(250µm) coated(D,E, F)**			**(350µm) coated (G,H,I)**		
CCkB 2-3	**Ficus glumosa (steel bar coated specimen)**	7.73	7.95	7.88	8.12	8.02	8.28	8.87	8.70	8.66
CCkB 2-4	**Symphonia globulifera linn (steel bar coated specimen)**	6.55	7.15	6.45	7.45	7.95	7.75	8.10	8.35	8.35
CCkB 2-5	**Acardium occidentale l. (steel bar coated specimen)**	7.05	7.38	7.19	7.15	8.05	8.09	8.15	7.85	8.23
3		**Max. slip (mm)**								
CCkC 3-1	**Non-corroded Control Cube**	0.114	0.099	0.089	0.119	0.102	0.108	0.109	0.094	0.118
CCkC 3-2	**Corroded**	0.054	0.080	0.073	0.085	0.072	0.072	0.078	0.070	0.070
		Coated specimens								
		(150µm) coated (A, B, C)			**(250µm) coated(D,E, F)**			**(350µm) coated (G,H,I)**		

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CCkC 3-3	**Ficus glumosa (steel bar coated specimen)**	0.101	0.125	0.101	0.132	0.132	0.128	0.139	0.153	0.133
CCkC 3-3	**Symphonia globulifera linn (steel bar coated specimen)**	0.100	0.115	0.085	0.133	0.133	0.133	0.195	0.189	0.193
CCkD 3-4	**Acardium occidentale l. (steel bar coated specimen)**	0.091	0.108	0.093	0.092	0.122	0.126	0.122	0.166	0.185

Table 3.2: Summary Results of Average Pull-out and Bond Strength Test (τu) (MPa) Control, Corroded and Resin Steel bar Coated

		Cube Samples		
S/N0		A	B	C
Concrete Cube		Failure Bond Loads (kN		
CCkA1-1	**Non-corroded Control Cube**	22.09	22.46	22.66
CCkA1-2	**Corroded**	17.76	17.77	17.74
			Coated specimens	
		(150μm) coated (A)	**(250μm) coated(B)**	**(350μm) coated (C)**
CCkA1-3	**Ficus glumosa (steel bar coated specimen)**	21.54	23.29	26.17
CCkA1-4	**Symphonia globulifera linn (steel bar coated specimen)**	21.05	24.28	26.98
CCkA1-5	**Acardium occidentale l. (steel bar coated**	22.09	22.46	22.66

specimen)

2		**Bond strength (MPa)**		
CCkB 2-1	**Non-corroded Control Cube**	7.22	7.20	7.64
CCkB 2-2	**Corroded**	4.63	4.71	4.64
		Coated specimens		
		(150µm) coated (A)	**(250µm) coated(B)**	**(350µm) coated (C)**
CCkB 2-3	**Ficus glumosa (steel bar coated specimen)**	6.57	7.65	8.19
CCkB 2-4	**Symphonia globulifera linn (steel bar coated specimen)**	6.72	7.72	8.26
CCkB 2-5	**Acardium occidentale l. (steel bar coated specimen)**	7.22	7.40	7.64

		MPa Max. slip (mm)		
CCkC 3-1	**Non-corroded Control Cube**	0.100	0.104	0.107
CCkC 3-2	**Corroded**	0.069	0.0.72	0.073
		Coated specimens		
		(150µm) coated (A)	**(250µm) coated(B)**	**(350µm) coated (C)**
CCkC 3-3	**Ficus glumosa (steel bar coated specimen)**	0.109	0.131	0.147
CCkC 3-4	**Symphonia globulifera linn (steel bar coated specimen)**	0.079	0.119	0.147
CCkC 3-5	**Acardium occidentale l. (steel bar coated specimen)**	0.097	0.113	0.157

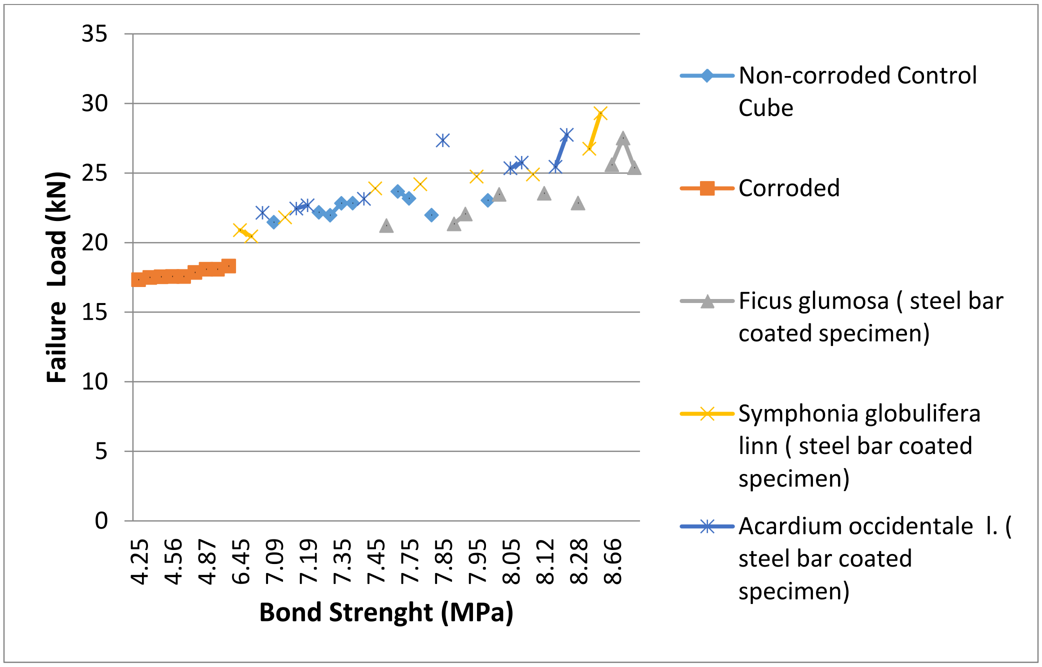

Figure 3.1: Summary Results of Pull-out Bond Strength Test (τu) (MPa) (Failure loads versus Bond Strengths)

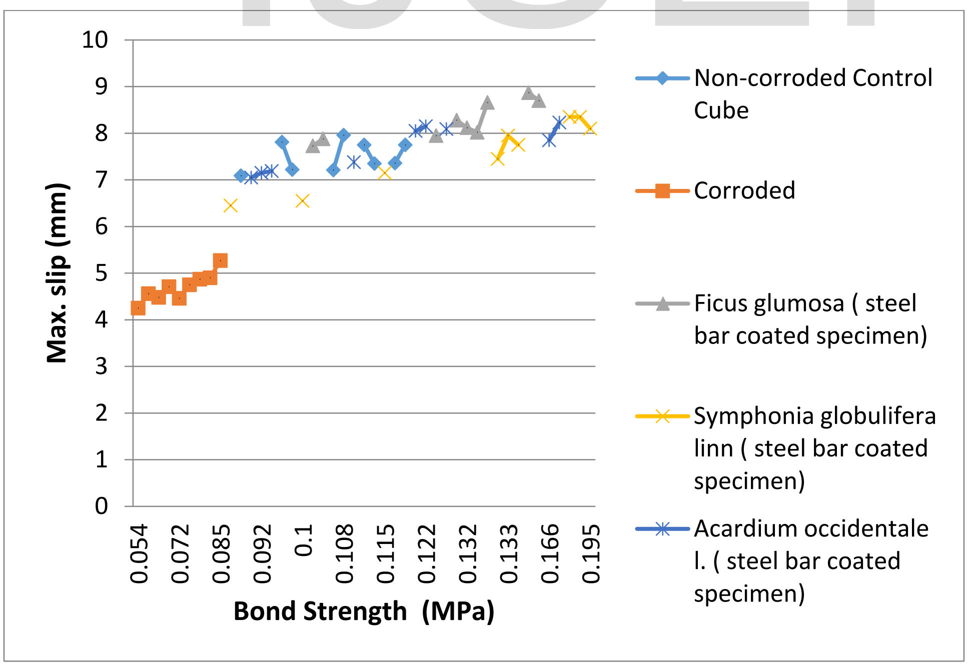

Figure 3.2: Summary Results of Pull-out Bond Strength Test (τu) (MPa) (Bond Strength versus Maximum Slip)

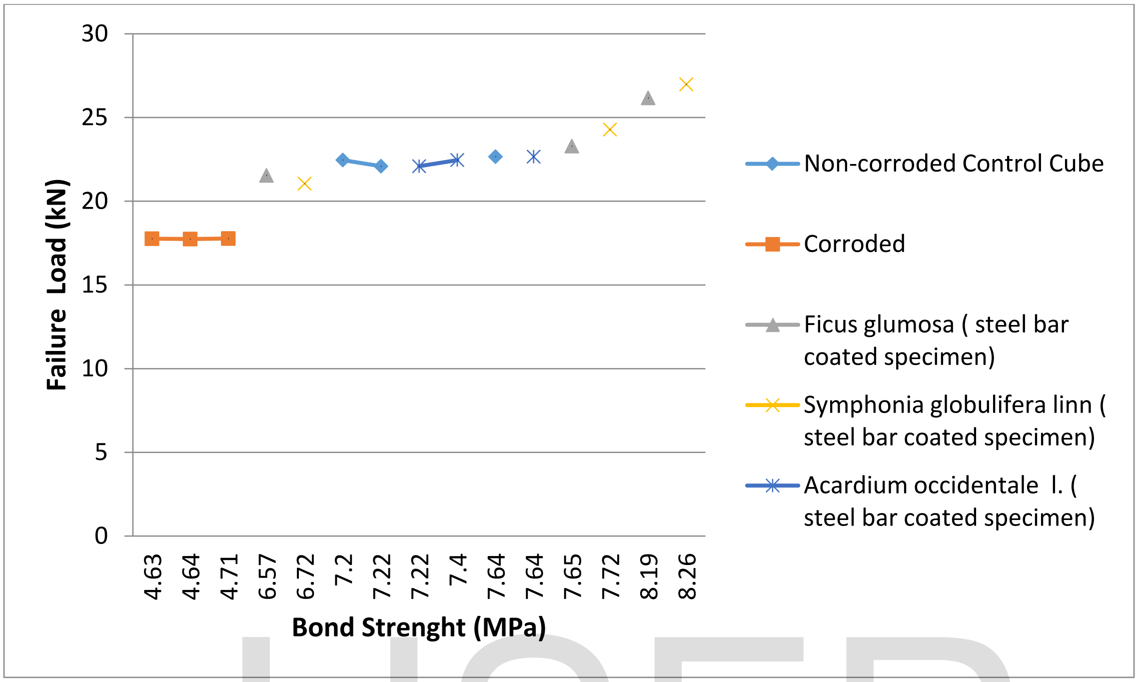

Figure 3.3: Average Results of Pull-out Bond Strength Test (τu) (MPa) (Failure loads versus Bond Strengths)

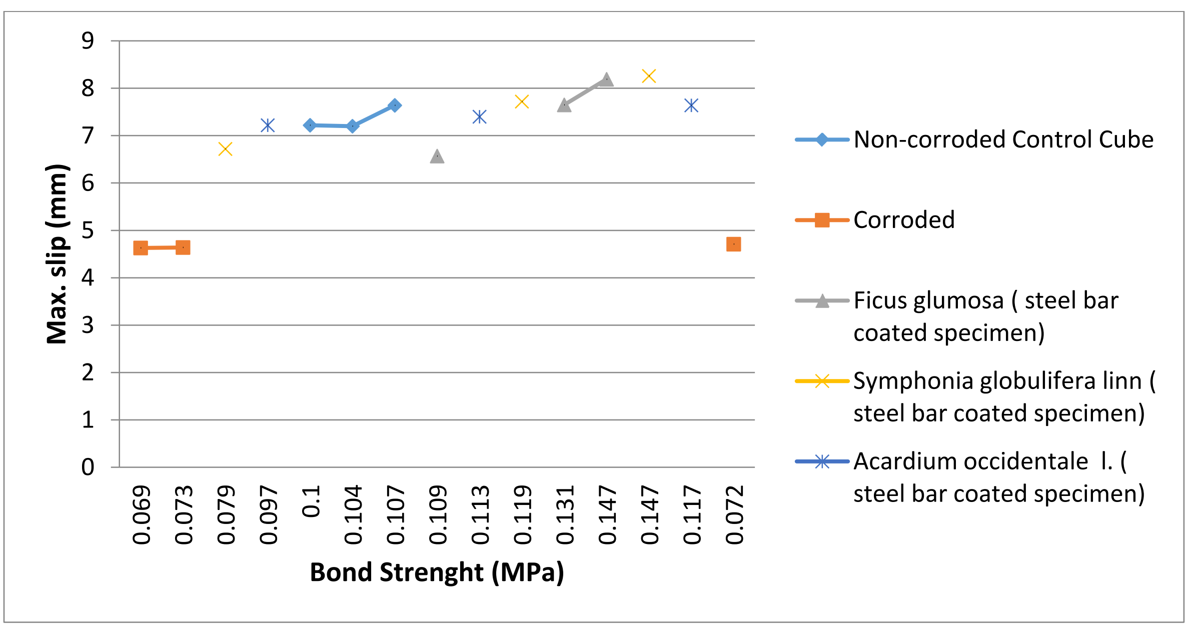

Figure 3.4: Average Results of Pull-out Bond Strength Test (τu) (MPa)

(Bond Strength versus Maximum Slip)

4.0 Conclusion

From the experimental investigations, the following conclusions were drawn:

i. Results showed and increased in coated compared to corroded specimens
ii. Results showed that resins / exudates enhances strength to reinforcement and serves as protective coat against corrosion.
iii. Bonding characteristics are higher in inhibited reinforcements compared to the corroded specimens.
iv. Corrosion levels is a controlling factor to bonding rate

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