Comparative Investigation of Pull-Out Bond Strength Variance of Resins \ Exudates Inhibitive and Corroded Reinforcement Embedded in Reinforced Concrete Structures, Exposed to Severely Environment

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Abstract

The bond strength exhibited by reinforcement embedded in concrete is controlled by corrosion effects. This study investigated on the comparative bond variance of uncoated and coated steel members with three resins / exudates of trees extracts from dacryodes edulis (African Pear) UBE, moringa oleifera lam and mangifera indica with paste thicknesses of 150µm, 250µm and 350µm, embedded into concrete, ponded for 28 days initial curing and exposed to laboratory corrosive medium of sodium chloride for 60days to assess the corrosion potential probability. 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.

Key Words: Corrosion, Corrosion inhibitors (Resins / Exudates), Pull-out Bond Strength, Concrete and Steel Reinforcement

1.0 INTRODUCTION

Corrosion effect of reinforcing steel embedded in concrete is a major factor that influences the bond strength between steel reinforcement and concrete, thus reducing the durability and design span / service life of the reinforced concrete structures and it is most necessary to develop methods which can increase the surface life of these structures.

In recent years there have been rapid development of various materials and methods which can be used for increasing the service life of concrete structure subjected to chloride attack. It is more likely very easy, attractive and easy application, economically attractive in the use of corrosion inhibitors.

Mansoor and Zahang [1] investigated the corrosion influenced on the bond strength of reinforcing bar on the concrete mix strength. It was observed that corrosion affected the deformed bar resulted by corrosion level, the bond strength was decreased by approximately 16% when the corrosion level increased up to 2%. Result from the experimental studies indicated decreased in bond strength with corrosion level increased.

Chung *et al*., [2] investigated the pullout bond strength and the length development due to corrosion effects. Corrosion levels of different percentages were used to corrode the reinforcement, concrete slab specimens with one steel reinforcing bar were used to investigate the bond stress and length development on tension member in flexure. It was concluded that at 2% level of corrosion, increases and fails it reaches an average bond stress.

Almusallam *et al.* [3] observed that the increase in bond strength was attributed to the production of a firm layer of rust around the reinforcing steel bar which, also

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demonstrated that in the pre-cracking stage the bond strength is increased, but with an increase in the corrosion level the slip at the ultimate bond strength reduces. 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 [4], Amleh and Mirza. [5], Auyeung *et al*. [6], Fang *et al*. [7] and Ouglova *et al.* [8]

The effect of the corrosion of steel reinforcement on structural behaviour is considered a major issue today, as demonstrated by many experimental studies (Almusallam *et al*., [3]; Lee *et al*., [9]; Lundgren, [10]; and Dahou *et al.*, [11].

Haddad *et al*. [12] investigated other factors that influence the bond strength between reinforcing bar and concrete, including environmental effects such as steel bar rusting. They found that the residual bond strength decreased slightly as the exposure temperature was raised to 350 ˚C due to the increase intensity and cracks with temperature leading to a reduction in concrete confinement of the steel reinforcement. In addition, high/low temperatures affect bond strength as reported by Royles and Morley [13],Van der Veen [14].

Otunyo and Kennedy [15] 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

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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 [16].

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 BS [17]

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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 [18]

2.1.4 Structural Steel Reinforcement

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

2.1.5 Corrosion Inhibitors (Resins / Exudates) (Dacryodes edulis (African Pear) UBE,Moringa Oleifera Lam and Mangifera indica),

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. Dacryodes edulis (African Pear) UBE
2. Moringa Oleifera Lam
3. Mangifera indica

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 (Dacryodes edulis (African Pear) UBE, Moringa Oleifera Lam and Mangifera indica), resins / eudates paste with coating thicknesses of 150µm, 250µm and 350µm 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

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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.

2.4 Pull-out Bond Strength Test

The pull-out bond strength tests on the concrete cubes were performed out after 54 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 pull-out specimens were 36 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

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standard length of corroded and non-corroded steel bars were subsequently used in the bond and flexural test.

3.0 Experimental Results and Discussion

Tables 3.1 enumerated the entire results of randomly cast cubes of 150µm (ABC) , 250µm (DEF) and 350µm (GHI) coating thicknesses of experimental work of pullout bond strength failure bond load (tensile), bond strength and maximum slip, tables 3.2 is the computed average values obtained from table 3.1, used to obtained the percentages of the behavioral characteristics of bonding and adhesive level of the resins / exudates of (Dacryodes edulis (African Pear) UBE, Moringa Oleifera lam and Mangifera indica trees extract paste to corrosion accelerated potential laboratory test.

Figures 3.1 and 3.2 are the plots of the failure bond load versus bond strength of the overall randomly concrete cubes test and computed average values (ABC) for non-corroded, corroded and resins/ exudates paste coated reinforcing steel samples.

3.1 Non-Corroded Concrete Cube Members

Experimental results from tables 3.1 are used to derive the percentile values from table 3.2 of non-corroded, corroded and resins / exudates coated steel reinforcement of pullout bond strength of failure load (tensile), bond strength and maximum slip of ABC as 27.08%, 55.90% and 47.14%.

3.2 Corroded Concrete Cube Members

From tables 3.1, 3.2 and figures 3.1 and 3.2, showed the entire experimental results of corroded average computed ABC from A-I of pullout bond strength of failure load, bond strength and maximum slip as 21.30%, 36.80%, 32.00%. This showed a decreased in percentile values when compared to non- corroded values 27.08%, 55.90% and 47.14% respectively.

3.3 (Dacryodes edulis, Moringa Oleifera Lam and Mangifera indica), Steel Bar Coated Concrete Cube Members

From tables 3.1 and 3.2 shows the results of specimens of concrete cube members randomly sampled and summarized average values computed from table 3.2. The plots of failure bond load versus bond strength as well as bond strength versus maximum slip. The computed results shows failure bond loads increase in inhibited reinforcement of

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Dacryodes edulis, Moringa Oleifera lam and Mangifera indica as 75.25%, 64.90%, and 34.49%, bond strength, 85.30%, 66.39%, 66.30%, maximum slip 97.80%, 85.57% and 85.37% while corroded are 21.30%, 36.80%, 32.00%.

From the above results, it showed cleared that the values of coated specimens were all higher as compared to corroded. The results of non-corroded of 27.08%, 55.90% and 47.14% of failure bond load, bond strength and maximum slip respectively as the controlled samples for results validation of comparison between coated and corroded specimens.

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

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		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)**		
CCkA 1-3	**Dacryodes edulis (steel bar coated specimen)**	22.97	24.25	23.15	25.60	24.98	26.70	32.50	30.78	29.99
CCkA 1-4	**Moringa Oleifera lam(steel bar coated specimen)**	23.07	23.35	21.85	25.25	23.95	25.47	28.95	28.25	26.97
CCkA 1-5	**Mangifera indica(steel**	17.98	18.85	18.05	21.18	21.72	21.25	21.18	22.72	22.25

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	bar coated specimen)									
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	**Dacryodes edulis (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	**Moringa Oleifera lam(steel bar coated specimen)**	7.35	7.44	6.97	7.35	7.87	8.13	8.30	8.17	8.18
CCkB 2-5	**Mangifera indica(steel bar coated specimen)**	4.82	5.48	4.45	6.55	6.62	6.69	6.95	7.19	7.12
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)**		
CCkC 3-3	**Dacryodes edulis (steel bar coated specimen)**	0.133	0.145	0.137	0.149	0.145	0.149	0.175	0.172	0.1615
CCkC 3-3	**Moringa Oleifera lam(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	**Mangifera indica(steel bar coated specimen)**	0.061	0.065	0.090	0.075	0.078	0.092	0.092	0.092	0.092

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

Control, Corroded and Resin Steel bar Coated

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	**Dacryodes edulis (steel bar coated specimen)**	23.46	25.76	31.09
CCkA1-4	**Moringa Oleifera lam(steel bar coated specimen)**	22.75	24.89	28.05
CCkA1-5	**Mangifera indica(steel bar coated specimen)**	18.29	21.38	22.05
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	**Dacryodes edulis (steel bar coated specimen)**	7.85	8.14	8.74
CCkB 2-4	**Moringa Oleifera lam(steel bar coated specimen)**	7.25	7.78	8.21
CCkB 2-5	**Mangifera indica(steel bar coated specimen)**	4.91	6.62	7.08

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			MPa Max. slip (mm)		
CCkC 3-1	**Non-corroded Cube**	**Control**	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	**Dacryodes edulis (steel bar coated specimen)**		0.138	0.147	0.169
CCkC 3-4	**Moringa Oleifera lam(steel bar coated specimen)**		0.100	0.133	0.156
CCkC 3-5	**Mangifera indica(steel bar coated specimen)**		0.072	0.08	0.092

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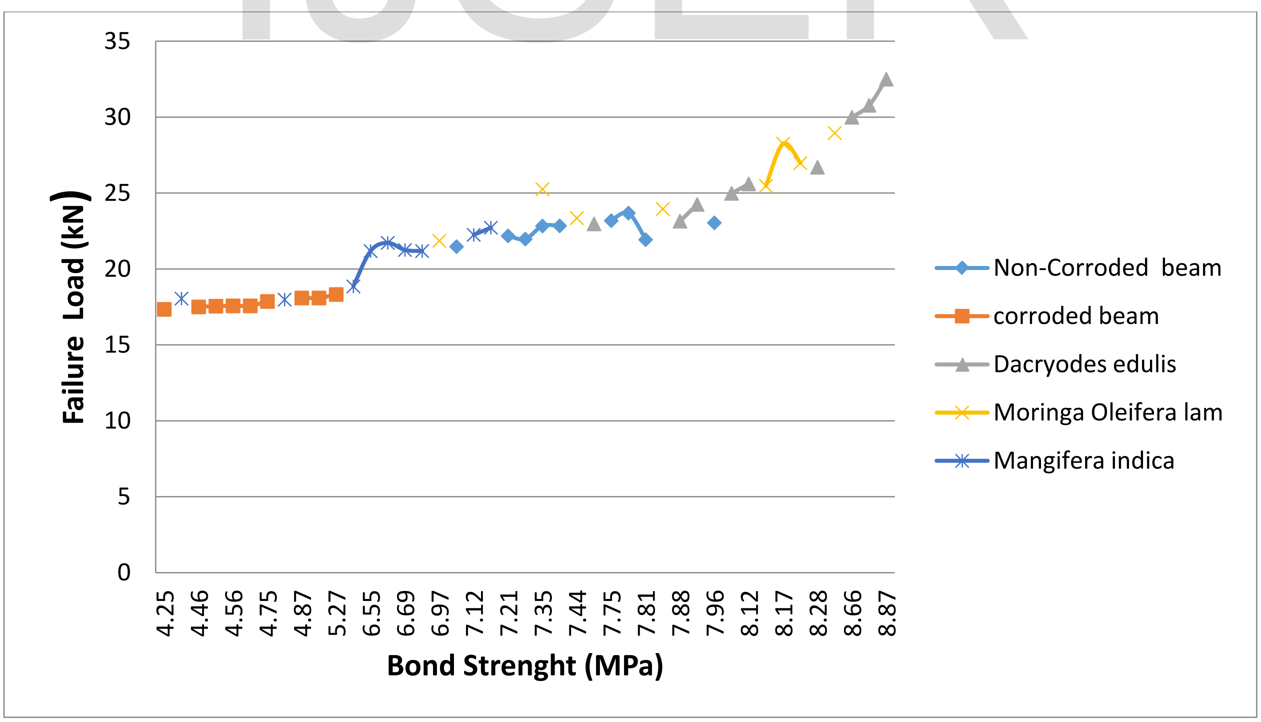

Figure 3.1: Summary Results of Pull-out Bond Strength Test (τu) (MPa)

(Failure loads versus Bond Strengths)

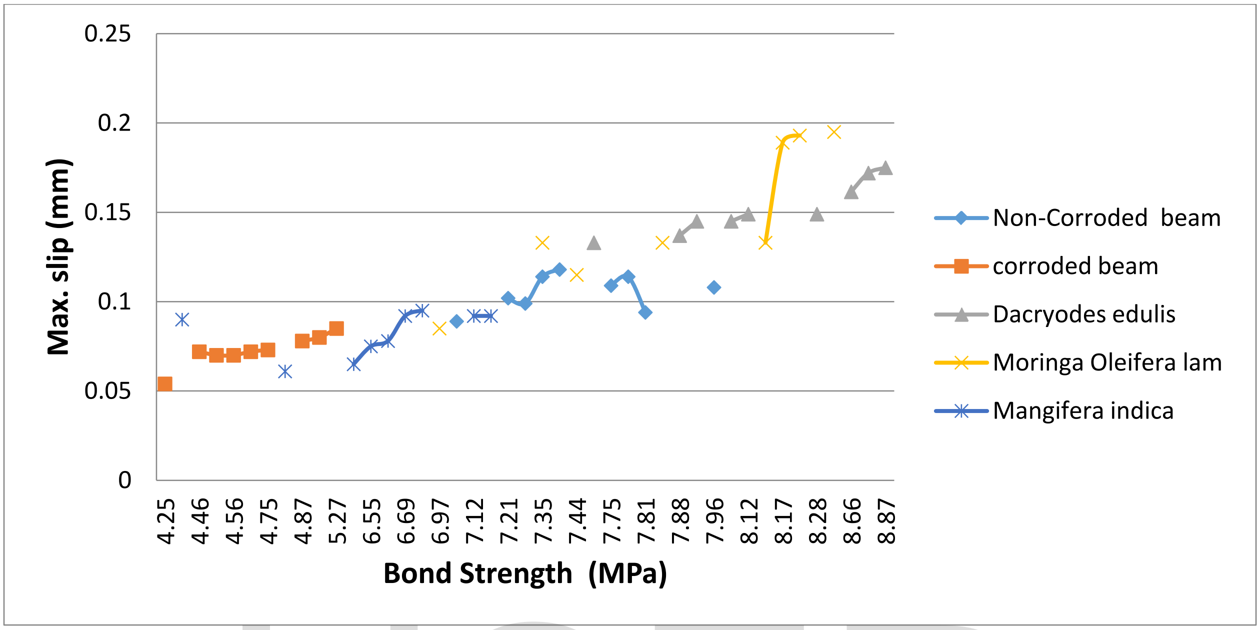

Figure 3.2: Summary Results of Pull-out Bond Strength Test (τu) (MPa)
(Bond Strength versus Maximum Slip)

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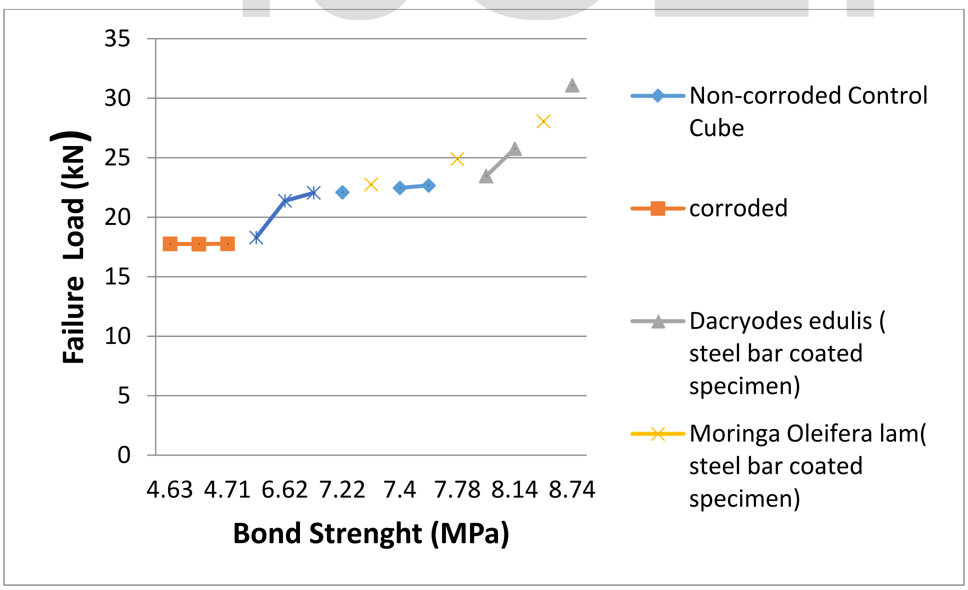

Figure 3.3: Average Results of Pull-out Bond Strength Test (τu) (MPa)
(Bond Strength versus Maximum Slip)

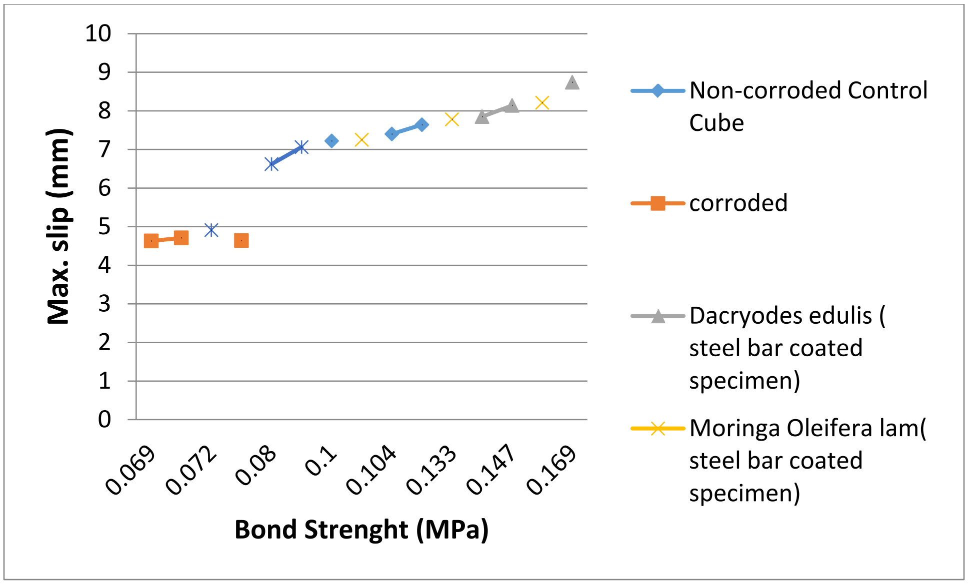

Figure 3.4: Average Results of Pull-out Bond Strength Test (τu) (MPa) (Bond Strength versus Maximum Slip)

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4.0 Conclusion

From the experimental investigations, the following conclusions were drawn:

i. Increased values recorded in all coated specimens than that of corroded
ii. Bonding characteristics are recorded in coated specimens
iii. Thicknesses coatings formed a controlling factor to bonding rate.
iv. Uncoated reinforcing steel bar forms corrosion potential due to attack by Nacl
v. Stress formation in the surrounding concrete was witnessed

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