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EFFECT OF CORROSION ON PULLOUT BOND STRENGTH OF CORRODED AND INHIBITED REINFORCED CONCRETE CUBE UNDER SODIUM CHLORIDE

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ABSTRACT
The study evaluated effect of influence of corrosion on the pullout bond strength of reinforced concrete with corroded and inhibited resin reinforcement. Direct application of moringa oleifera lam resins / exudates of trees extract known as inorganic inhibitor resin pastes with coated thicknesses of 150µm, 250µm and 300µm on reinforcement concrete cubes and standard 150mm x 150mm x150mm were cast and reinforcement embedded into concrete, exposed to harsh and saline environments (NaCl solution) on the bond strength of reinforced concrete cubes. Accelerated corrosion test, pull-out bond, and tensile strength test were performed to assess corrosion potential, bond strength characteristics of steel bars embedded in concrete. Results of pull out bond strength of failure bond load , bond strength and maximum slip indicated decreased in percentages to 21.30%, 38.80% and 32.00% of corroded cube members and increased in both non-corroded by 27.08%, 55.90% and 47.14% and 64.9%, 66.39% and 85.57% coated respectively. Entire results showed that moringa oleifera lam resins / exudates of trees extract exhibited good potential in bonding.

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

INTRODUCTION

Generally, the occurrence of corrosion may result due to chloride contamination or carbonation of the reinforced concrete structure, the end results of steel corrosion are manifested as a reduction in the bar diameter, wear and tear of the mechanical properties of the reinforcing steel. Deteriorations, failures do occurred and acceralated in reinforced concrete structures exposed to costal marine and harsh environments. When steel reinforcement corrodes, the life span, service and the intended purpose and its integrity and capacity of the structure is affected as well as reduced. Reinforced concrete structures built within the marine environment are at risk due to chloride-induced corrosion of reinforcement which resulted from the presence of high chloride concentrations and humid or saturated conditions Reinforced concrete structures built within the marine environment are at risk due to chloride-induced corrosion of reinforcement resulted from the presence of high chloride concentrations and humid or saturated conditions. Corrosion is one of the main causes for the limited durability of reinforced concrete [1]. Corrosion of reinforcing steel is widely accepted as the primary cause of premature deterioration in reinforced concrete structures [2]. Bond strength influenced by bar geometries, concrete properties, the presence of confinement around the bar, as well as surface conditions of the bar [3] .

[4] studied on the bond behavior of corroded reinforcement bars and have found that when the mass loss of the reinforcement due to corrosion reaches approximately 2%, concrete cracks along the bar. A small amount of corrosion increases both the bond strength and bond stiffness, but the slip at failure decreases considerably. However, they stated that when the mass loss exceeds 2%, bond stiffness decreases considerably.

[5] investigated the effect of the diameter of the steel bar, and the thickness of the cover on the degree of corrosion of mild steel bars embedded in mortar. They found that there is a significant effect of rebar diameter, cover thickness, and specimen size on the corrosion intensity.

[6] 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

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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. 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.
[7] indicated that the cover over reinforcement has the most significant effect on the extent of rebar corrosion.
[9] based on their field and laboratory results, recommended the following cover for structures serving in various environments of the Arabian Gulf:

- Building components which are permanently exposed to the salt - laden corrosive atmosphere
- Building components which are protected against weather and the aggressive conditions of exposure: 1.0 to 1.5 inch 28.
- Concrete components exposed to seawater and footings as well as other main structural members cast against the ground: 3.0 inch.

This study investigate the effect of reinforcement corrosion and inhibitor on bond and pull out capacity of degraded and inhibited steel reinforcement and monitor significant changes on the surface conditions of steel reinforcing bars embedded in concrete.

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.

MATERIALS FOR EXPERINMENT

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 [8]

Cement

The cement used was Eagle Portland Cement, it was used for all concrete mixes in this investigation. The cement met the requirements of [9]

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 [10]

Structural Steel Reinforcement

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

Corrosion Inhibitors (Resins / Exudates) Dacryodes edulis (African Pear) UBE

The study inhibitor (Moringa Oleifera Lam is of natural tree resin /exudate substance 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.

EXPERIMENTAL PROCEDURES

Experimental method

Sample preparation for reinforcement with coated resin/exudate

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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 Moringa Oleifera Lam 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.

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 phenomena, 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.

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 resin / exudated 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.

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.

The complete load-elongation, hence stress-strain plots, were obtained. From the stress-strain plots, yield strength and tensile strength of the bars were determined. An extensometer, of 50 mm gauge length, was used to measure the extension of the bars during the test and a data logger connected to a computer recorded the load and the corresponding extension of the bar as the test progressed

Experimental Results and Discussion

Results from tables 3.1, 3.2 and 3.3 shows the experimental results of pull-out bond strength test of 27 specimens, non-corroded, corroded and resins / exudates paste coated with (moringa oleifera lam) trees extract of 150µm, 250µm and 350µm coating thicknesses of samples A – I. Tables 3.4, 3.5 and 3.6 showed obtained values of A,B and C summed average from tables 3.1, 3.2 and 3.2 and were used to derive percentages of investigated experiment.

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Figures 3.1 and 3.3 are the plot of failure bond load versus bond strength and figures 3.2 and 3.4 are the plots of bond strength versus maximum slips. The plots of 3.1 – 3.4 explained the behavior of the steel reinforcement effect due to corrosion potential.

Non-corroded Concrete Cube Members

Results obtained of non-corroded pullout bond strength from tables 3.1, 3.4 and figures 3.1, 3.4 showed failure bond load (tensile strength) of 27.08%, bond strength 55.90% and maximum slip 47.14%.

Corroded Concrete Cube Members

In comparison to non – corroded, as represented in tables 3.2, 3.5 and figures 3.1-3.4, pullout bond strength failure load (tensile strength), bond strength and maximum slip all decreased by 21.30%, 36.80%, 32.00% respectively.

Moringa oleifera lam Steel Bar Coated Concrete Cube Members

Tables 3.3, 3.6, , figure 3.1 – 3.4 represented the results of resins / exudates extracts paste coated specimens, comparing results indicated increased values of failure bond load, bond strength and maximum slip of 42.00%, 68.23% and 47.10% respectively as against 21.30%, 38.80% and 32.00% of corroded specimens.

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

Control, Corroded and Resin Steel bar Coated										
S/N0		A	B	C	D	E	F	G	H	I
Concrete Cube	**Non-corroded Control Cube**									
CCk1-1	Failure Bond Loads (kN)	22.83	21.97	21.47	23.68	22.18	23.04	23.18	21.98	22.84
CCk1-2	Bond strength (MPa)	7.35	7.22	7.09	7.75	7.21	7.96	7.75	7.81	7.36
CCk1-3	Max. slip (mm)	0.114	0.099	0.089	0.119	0.102	0.108	0.109	0.094	0.118
CCk1-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12
2	**Corroded**									
CCk 2-1	Failure Bond load (KN)	17.34	18.09	17.86	18.32	17.57	17.50	18.09	17.57	
CCk 2-2	Bond strength (MPa)	4.25	4.90	4.75	5.27	4.71	4.46	4.87	4.56	4.48
CCk 2-3	Max. slip (mm)	0.054	0.080	0.073	0.085	0.072	0.072	0.078	0.070	0.070
3	**Coated spemens**									
		(150µm) coated (A, B, C)			**(250µm) coated(D,E, F)**			**(350µm) coated (G,H,I)**		
	Moringa Oleifera lam(steel bar coated specimen)									
CCk 3-1	Failure load (KN)	23.07	23.35	21.85	25.25	23.95	25.47	28.95	28.25	
CCk 3-2	Bond strength (MPa)	7.35	7.44	6.97	7.35	7.87	8.13	8.30	8.17	8.18

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CCk 3-3	Max. slip (mm)	0.100	0.115	0.085	0.133	0.133	0.133	0.195	0.189	0.193
CCk 3-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	

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

S/N0		A	B	C
1A Concrete Cube	**Non-corroded Control Cube**			
CCk1A-1	Failure Bond Loads (kN)	22.09	22.46	22.66
CCkA1-2	Bond strength (MPa)	7.22	7.40	7.64
CCk1A-3	Max. slip (mm)	0.100	0.104	0.107
CCk1A-4	Bar diameter (mm)	12	12	12
2	**Corroded**			
CCk 2A-1	Failure Bond load (KN)	17.76	17.77	117.74
CCk 2A-2	Bond strength (MPa)	4.63	4.71	4.64
CCk 2A-3	Max. slip (mm)	0.069	0.0.72	0.073
CCk 2A-4	Bar diameter (mm)	12	12	12
3A	**Coated Specimens**			
		150µm) coated (A,)	**(250µm)coated(B)**	**(350µm) coated (C**
	Moringa Oleifera lam (Steel bar Coated specimen)			
CCk 3A-1	Failure load (KN)	22.75	24.89	28.05
CCk 3A-2	Bond strength (MPa)	7.25	7.78	8.21
CCk 3A-3	Max. slip (mm)	0.100	0.133	0.156

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CCk 3A-4	Bar diameter (mm)	12	12	12

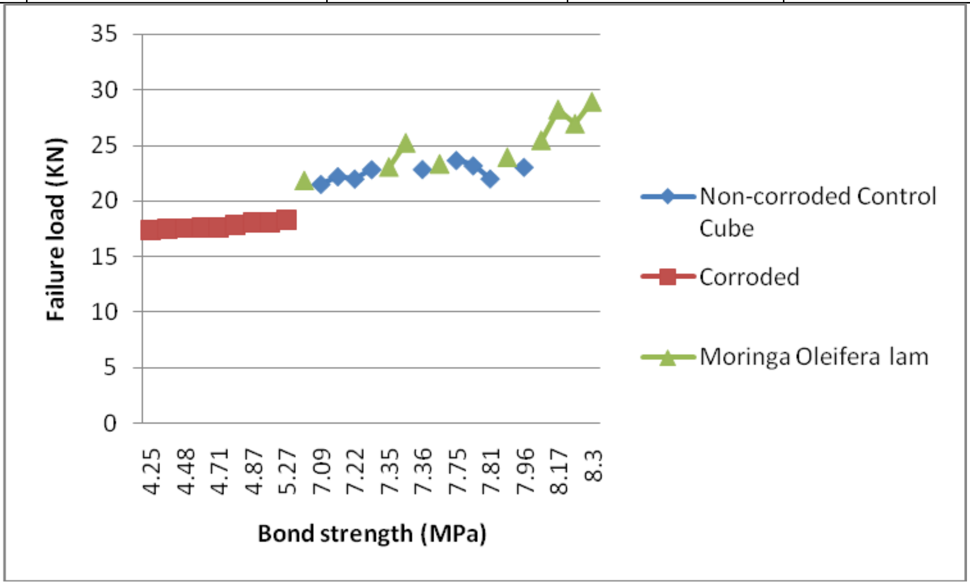

Figure 3.1: Summary Results of Pull-out Bond Strength Test (τu) (MPa) (Failure loads versus Bond Strengths)

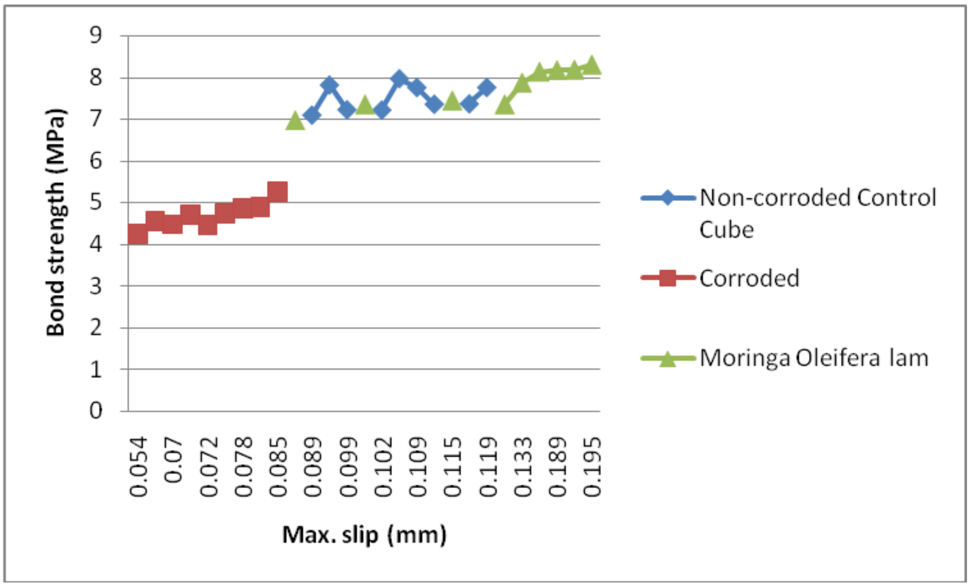

Figure 3.2: Summary Results of Pull-out Bond Strength Test (τu) (MPa) (Bond Strength versus Maximum Slip)

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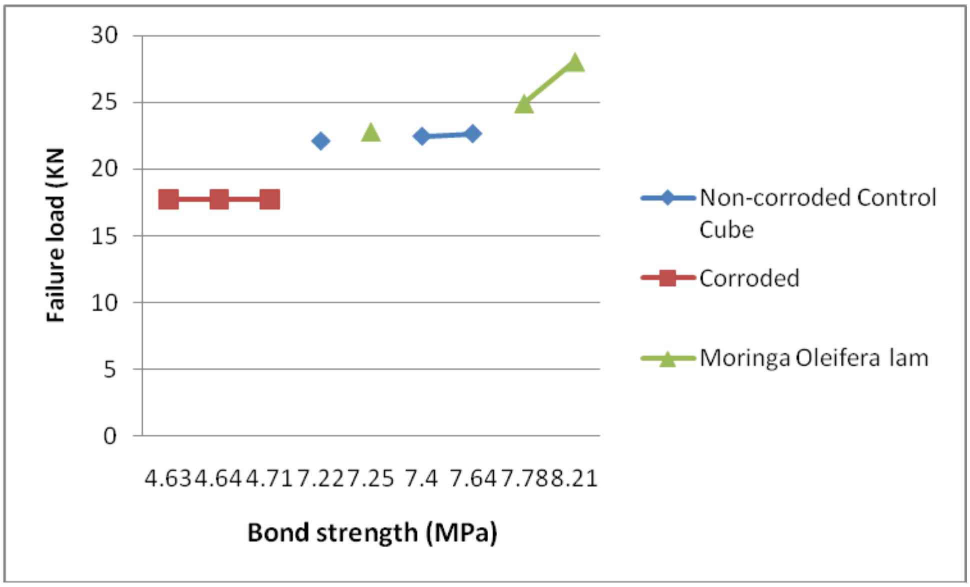

Figure 3.3: Average Results of Pull-out Bond Strength Test (τu) (MPa)
(Failure loads versus Bond Strengths)

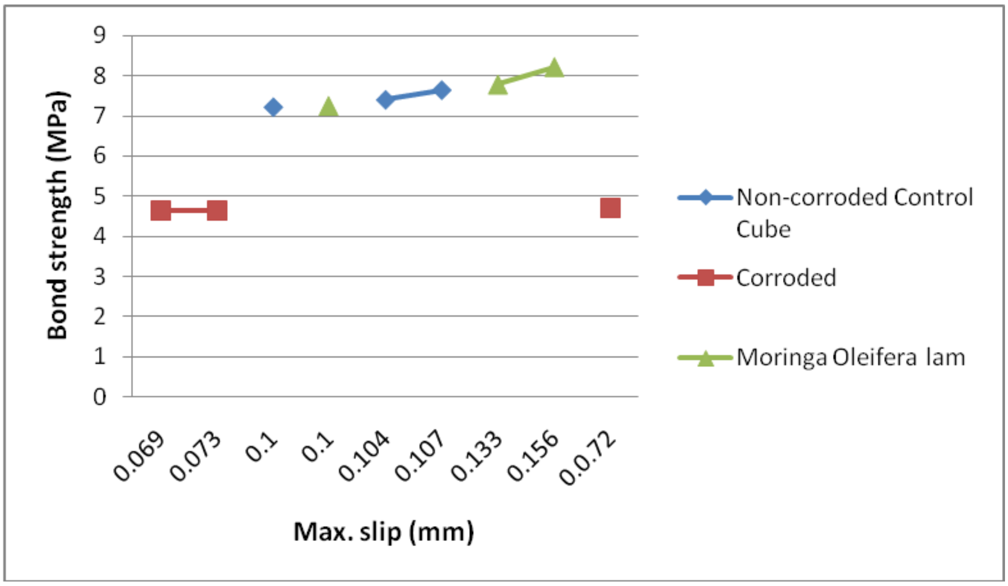

Figure 3.4: Average Results of Pull-out Bond Strength Test (τu) (MPa)
(Bond Strength versus Maximum Slip)

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CONCLUSIONS

Investigated results obtained have the following conclusions:

[1] Results of pull out bond strength of failure bond load, bond strength and maximum slip indicated decreased in percentages of corroded cube members while and increased in both non-corroded and coated respectively.

[2] Entire results showed that moringa oleifera lam resins / exudates of trees extract exhibited good potential in bonding.

[3] Bond strength reduces linearly with increasing corrosion levels.

[4] Effect of coated thickness has much influence in the pull out as compared to the flexural characteristics, bond strength increased was noticed

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