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Effect of Corrosive Environment on Reinforced Concrete Structures Pullout Bond Strength of Corroded and Resins / Exudates Coated reinforcement

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Abstract

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. This study evaluated the pullout bond strength in concrete cube members of corroded and coated members with Symphonia globulifera linn trees extract of varying applied thickness of 150µm, 250µm and 350µm , embedded in concrete and exposed to corrosive environment , accelerated potential of corrosion for 60days after initial 30days normal cure to assessed the bonding strength of reinforcements. Results obtained showed presence of corrosion in uncoated members. 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.

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

1.0 INTRODUCTION

A major cause of steel reinforcement corrosion is the presence of chlorides from chloride contaminated aggregates and admixtures containing chlorides which are used during construction, or from penetration of chloride ions from sea water or ingress of de-icing salt. Corrosion of steel reinforcement is generally the most important factor that shortens the service life of reinforced concrete structures that are subjected to corrosive environments. It is t noted that tensile force transfer to the concrete is controlled by the bond strength of the reinforcing steel bar. If the bond between steel and concrete is not perfect, the flexural theory for beams reinforced with steel bar cannot be used for flexural capacity beam calculation.

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Otunyo and Kennedy [1] 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. 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

Chung *et al*., [2] studied the effect of corrosion on pullout bond strength and development length. Different level of corrosion 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.

Han-Seung Lee *et al*., [3] evaluated the corrosion of reinforcing steel as function of degree of bond properties between concrete and reinforcement. They evaluated pull out bond test to ascertain the the bond characteristics between concrete and corroded reinforcing steel bar. Pull-out tests were conducted on specimens with and without confinement reinforcement. Experimentally, results were obtained from load versus free end slip behavior was studied and the rigidity of bond for the analysis of Finite Element with corroded reinforcement in reinforced concrete members.

Cairns and Plizzari [4] affirmed that the split from concrete surrounding resulted from bearing action of ribs that generates bursting forces. 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 counter balance the force generated by bond.

Almusallam [5] stated experimentally, that tensile strength of corroded bar does not adversely affect the crosse- sectional area resulting from corrosion but bonding between reinforcement and concrete affect the structural capacity as compared to the loss of tensile strength resulting fron corrosion of reinforcement.

Rodriguez [6] additionally explored the level of various consumption degrees on solid pillars. The outcomes demonstrated that erosion builds avoidances and splits widths at the administration stack, diminishes quality at extreme load and causes an expansion in both the separating and width of transverse splitting because of security crumbling.

Pandian and Mathur [7] set up the utilization of common items as erosion inhibitor for metals in destructive media.

Auyeung *et al.*, [8] considered the bond conduct of consumed fortification bars and found that when the mass loss of the support because of consumption comes to around 2%, solid breaks along the bar. It was watched that a little measure of consumption increments both the bond quality and bond solidness, yet the slip at disappointment diminishes significantly. Notwithstanding, it was additionally watched that when the mass misfortune surpasses 2%, the bond firmness diminishes significantly.

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 [9].

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 [10]

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 [11]

2.1.4 Structural Steel Reinforcement

The reinforcements are gotten directly from the market in Port Harcourt. Met the requirements of [12]

2.1.5 Corrosion Inhibitors (Resins / Exudates) Symphonia globulifera linn

The study inhibitor (Symphonia globulifera linn) is of natural tree resins /exudates 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.

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 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

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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 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 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

Results from figures 3.1 – 3.4 shows the results entire experimental work of pullout bond strength of failure bond load, bond strength and maximum slip obtained from tables 3.1 and average in table 3.2. The plotted failure bond load versus bond strength and bond strength versus maximum slip were experimented values of 27 samples on non-corrode, corroded and resins/ exudates coated steel bar with Symphonia globulifera linn.

Samples A-I of table 3.1 represented derive values that formed the percentages of the experimental work

3.1 Non-Corroded Concrete Cube Members

Table 3.1 shows the entire results experiment while results from table 3.2 are the derive average values of the failure load, bond strength and maximum slip of 27.08%, 55.90% and 47.14%.

3.2 Corroded Concrete Cube Members

From tables 3.1 and 3.2, the average values of ABC from A – I, the pullout bond load (tensile), bond strength and maximum slip values obtained are 21.30%, 36.80%, 32.00% representing decreased characteristics as compared to non- corroded of 27.08%, 55.90% and 47.14% respectively.

3.3 Symphonia globulifera linn Steel Bar Coated Concrete Cube Members

Results obtained from tables 3.1 and 3.2, plotted graphs of figures 3.1 – 3.4 showed the entire and summarized average values from pullout bond strength test of failure bond load, bond strength and maximum slip of non-corroded, corroded and resins/exudates coated concrete cube members as presented tables. The percentages increased and decreased recorded were experimented based on the control samples. Failure bond load, bond strength and maximum slip for coated specimens are 36.47%, 64.00% and 49.30%, for corroded 21.30%, 36.80%, 32.00% respectively. The results showed and increased in coated compared to 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	17.55
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
		Coated spemens								
		(150µm) coated (A, B, C)			**(250µm) coated(D,E, F)**			**(350µm) coated (G,H,I)**		
3		**Symphonia globulifera linn(steel bar coated specimen)**								
CCk 3-1	Failure load (KN)	20.45	21.82	20.90	23.90	24.75	24.20	24.90	26.75	29.30
CCk 3-2	Bond strength (MPa)	6.55	7.15	6.45	7.45	7.95	7.75	8.10	8.35	8.35
CCk 3-3	Max. slip (mm)	0.072	0.088	0.078	0.108	0.132	0.118	0.138	0.145	0.158
CCk 3-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

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

Control, Corroded and Resin Steel bar Coated

S/N0		A	B	C
1A Concrete Cube		**Non-corroded Control Cube**		
CCk1A-1	Failure Bond Loads (kN)	22.09	22.46	22.66
CCk1A-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
2A		**Corroded**		
CCk 2A-1	Failure Bond load (KN)	17.76	17.77	17.74
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-5	Bar diameter (mm)	12	12	12
3A	**Symphonia globulifera linn(steel bar coated specimen)**			
CCk 3A-1	Failure load (KN)	21.05	24.28	26.98
CCk 3A-2	Bond strength (MPa)	6.72	7.72	8.26
CCk 3A-3	Max. slip (mm)	0.079	0.119	0.147
CCk 3A-4	Bar diameter (mm)	12	12	12

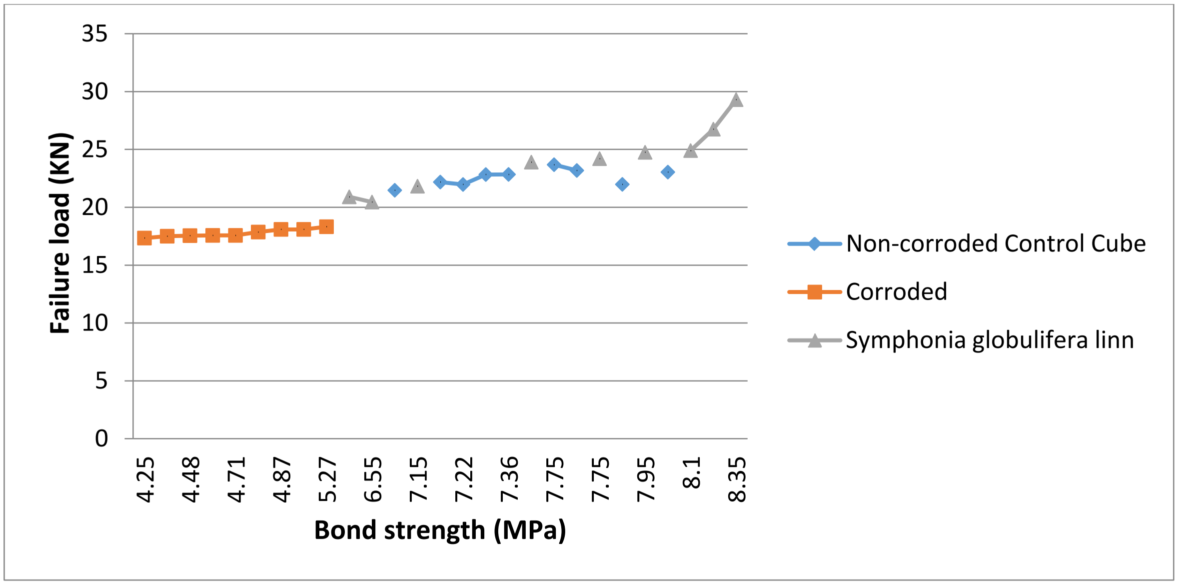

Figure 3.1: Summary Results of Pull-out Bond Strength Test (τu) (MPa) (Failure loads versus Bond Strengths)

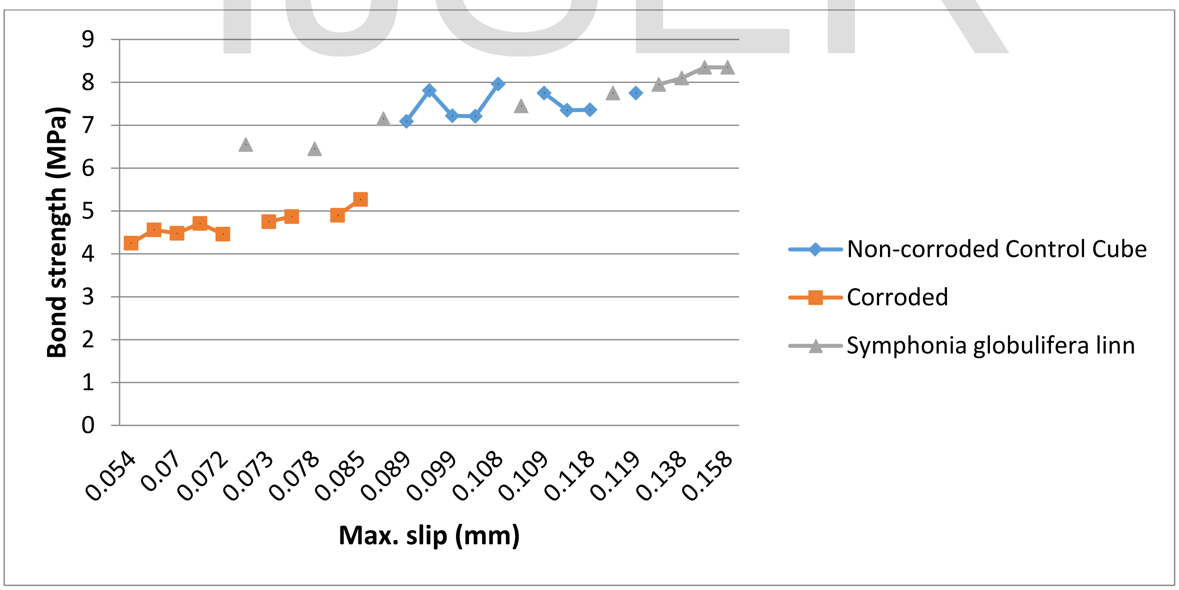

Figure 3.2: Summary Results of Pull-out Bond Strength Test (τu) (MPa) (Bond Strength versus Maximum Slip)

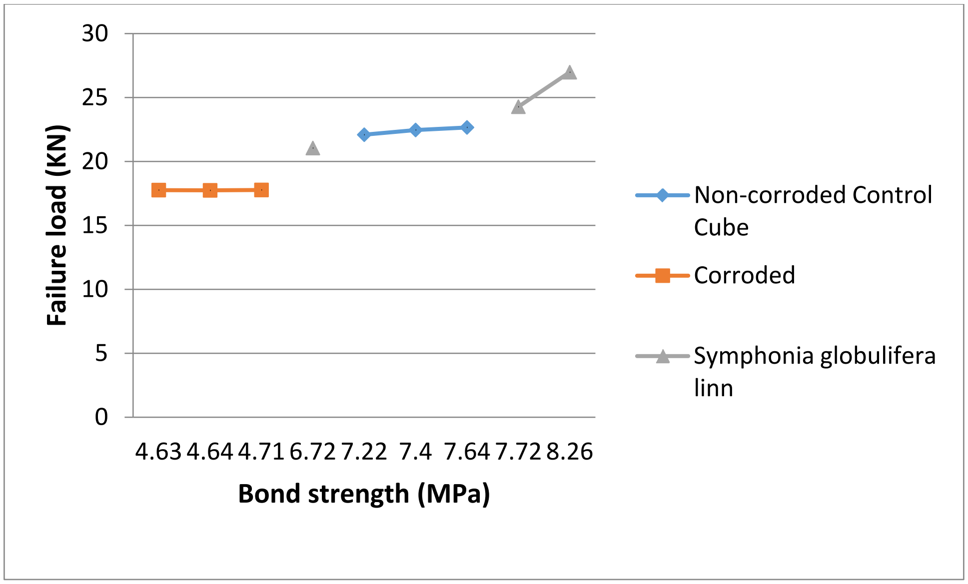

Figure 3.3: Average Results of Pull-out Bond Strength Test (τu) (MPa) (Failure loads versus Bond Strengths)

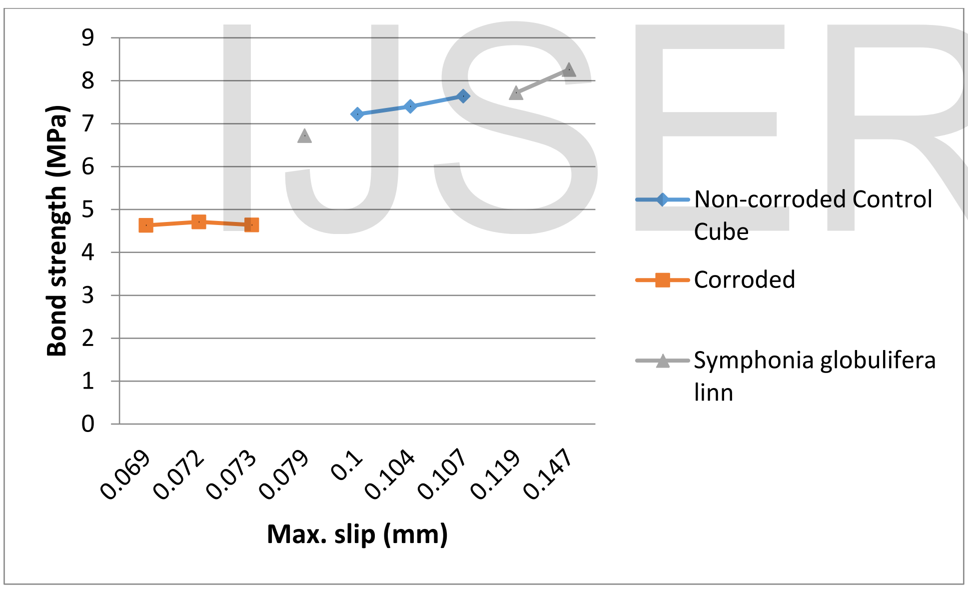

Figure 3.4: Average Results of Pull-out Bond Strength Test (τu) (MPa) (Bond Strength versus Maximum Slip)

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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