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Reinforcement Bond Strength Interface Behavior of Corroded and Coated in Concrete Members

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Abstract

This study investigated the bond strength between concrete and diameter reduction of reinforcement due to corroded effect of reinforcing steel exposed to harsh weather from the marine coastal region of Niger Delta of Nigeria. The application of artocarpus altilis exudate on reinforcement with coating thickness of 150µm, 300µm and 450µm, immersed in concrete cube and ponded in sodium chloride (NaCl) and accelerated for 150days. Obtained percentile average failure bond load -44.963% against 81.698% and 81.977% control and coated exudates/resin member. Percentile bond strength load is -33.7477% against 50.989% and 96.833% and maximum slip percentile average value is -30.8221% against 44.555% control. Comparative results, obtained values of corroded specimens decreased while control and exudates/resins coated specimens increased. Entire results showed higher values of pullout bond strength in control and exudates/resin coated to corroded specimens. Overall results justify the effectiveness of artocarpus altilis exudates as corrosion inhibitors.

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

INTRODUCTION

A major significant factor and issue of concerned associated to failure of structures within the marine environment is the corrosion of steel reinforcement embedded in concrete structures. The corrosion of steel reinforcement in concrete, spailling, cracking and reduction in cross-sectional area is noticed which in turns causes reduction in the bond strength between the steel and the surrounding concrete. Bond strength is the maximum bond stress developed by friction between reinforcement and concrete, this can easily be regarded as a shear stress over the surface of the bar (Cairns and Abdullah, 1996), the interlocking mechanism along the reinforcing bar interfaces with surrounding concrete.

The effect of the corrosion of steel reinforcement on structural behavior is considered a major issue today, as demonstrated by many experimental studies (Almusallam et al., 1996; Bingöl and Gül (2009) reported that the residual bond strength increased when temperature ranged from 50˚C to 150˚C due to the increase in the residual compressive strength. (2004) have provided experimental evidence that the influence of the bar size on the bond strength depends on the level of confinement. In their tests, the bond strength was found to decrease with increasing bar size for specimens with low levels of confinement and splitting failures, but this effect was negligible for specimens with high levels of confinement and pull-out failures. Turk and Yildirim (2003) reported that the diameter of the steel bar had a very important effect on the bond strength. (1993) reported that the bond strength of a 10mm diameter reinforcing bar was higher than that of large diameter steel reinforcement suggesting that the bond strength decreased with increasing diameter of steel reinforcement

Charles et al. (2018) 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. Results obtained indicated corrosion potential presence on uncoated concrete cube members. 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 control 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.

Charles et al. (2018) 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. This research work experimented on the preventive trend of corrosion using inhibitors of inorganic origin from tree extracts of acardiun occidentale l. resins / exudates. 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 Control 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.

Otunyo and Kennedy (2018) 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 Control 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.

Charles et al. (2018) 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. 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.

Charles et al. (2018) investigated the effect of corroded and inhibited reinforcement on the stress generated on pullout bond splitting of Control, corroded and resins / exudates paste coated steel bar of 150µm, 250µm and 350µm thicknessfrom 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.

Charles et al. (2018) studied 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 thicknessof 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. 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; 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.

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 AND METHODS FOR EXPERINMENT

Aggregates

The fine aggregate and coarse aggregate were purchased. Both met the requirements of BS 882

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 BS EN 196-6

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 BS 3148

Structural Steel Reinforcement

The reinforcements are gotten directly from the market in Port Harcourt. BS 4449:2005+A3

Corrosion Inhibitors (Resins / Exudates) Artocarpus altilis

The study inhibitor (Artocarpus altilis) is of natural tree resin /exudates substance extracts.

EXPERIMENTAL PROCEDURES

Experimental method

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 (Artocarpus altilis exudate), resin pastes with coating thicknessof 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.

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.

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.

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.

Experimental results and discussion

Tables 1, 2 and 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 Artocarpus altilis exudates/ resins steel bar coated specimens paste on reinforcement embedded in concrete cubes member. Table 4 and 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 1 and 2 are the plots of entire failure bond load versus bond strength and bond strength versus maximum slip, while figures 3 and 4 are the plots of average failure bond load versus maximum slip obtained from tables 1, 2 and 3

Control Concrete Cube Members

Average and summed up pullout out bond strength of failure bond load obtained from table 1, 4 and 5 as shown in figures 1 – 4, are 28.125kN, 28.7016kN, 29.0016kN, summed average to 28.6094kN, indicated 81.698% percentile value. Values of bond strength are 8.3MPa, 8.72MPa, 8.72MPa with summed average value of 8.58MPa and percentile difference 50.938%. Maximum slip average values are 0.10166mm, 0.110666mm, and 0.108mm summed average value of 0.1067mm represented 44.5 % percentile values.

Corroded Concrete Cube Members

From table 2, summarized into 4 and 5, as shown in figures 1 – 4 obtained average failure bond load are 15.743333kN, 15.776kN, 15.716kN and summed to 15.745kN represented -44.963% against 81.698% and 81.977% control and coated exudates/resin member. Bond strength load are 5.623kN, 5.803kN, 5.626kN summed to 5.684kN, represented percentile value of -33.7477% against 50.989% and 96.833% and maximum slip average values are 0.0702mm, 0.0775333mm, 0.073867mm, summed to average of 0.073867mm, this represented -30.8221% against 44.555% control. Comparative results, obtained values of corroded specimens decreased while control and exudates/resins coated specimens increased.

Artocarpus altilis exudates Steel Bar Coated Concrete Cube Members

From tables 3, summarized into 4 and 5, as shown in figures 1 – 4, obtained failure bond load average values are 27.74333kN, 29.05667kN, 29.16kN summed to 28.653kN, represented 81.977% against -44.9637% corroded percentile differences, bond strength average values are 10.81MPa, 10.95MPa, 11.80667MPa summed to 11.188MPa, represented 96.833% against -33.747% and maximum slip values are 0.1904mm, 0.198733mm, 0.245067mm summed to 0.2114mm represented 186.1913% against -30.8221% corroded percentile differences. Entire results showed higher values of pullout bond strength in control and exudates/resin coated to corroded specimens.

Table 1: Results of Pull-out Bond Strength Test (τu) (MPa)

S/no		**Control Cube Specimens**								
Concrete Cube	**Sample**	GAC	GBC	GCC	GDC	GEC	GFC	GGC	GHC	GIC
CCS1-1	Failure Bond Loads (kN)	28.865	28.005	27.505	29.715	28.215	29.075	29.215	28.015	28.875
CCS1-2	Bond strength (MPa)	8.43	8.3	8.17	8.83	8.29	9.04	8.83	8.89	8.44
CCS1-3	Max. slip (mm)	0.115	0.1	0.09	0.12	0.103	0.109	0.11	0.095	0.119
CCS1-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 2: Results of Pull-out Bond Strength Test (τu) (MPa)

S/no		**Corroded Cube Specimens**								
Concrete Cube	**Sample**	GAC2	GBC2	GBC2	GDC2	GEC2	GFC2	GGC2	GHC2	GIC2
CCS 2-1	Failure Bond load (KN)	15.32	16.07	15.84	16.3	15.55	15.48	16.07	15.55	15.53
CCS 2-2	Bond strength (MPa)	5.24	5.89	5.74	6.26	5.7	5.45	5.86	5.55	5.47
CCS 2-3	Max. slip (mm)	0.0552	0.0812	0.0742	0.0862	0.0732	0.0732	0.0792	0.0712	0.0712
CCS2-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 3: Results of Pull-out Bond Strength Test (τu) (MPa)

		Artocarpus altilis exudates (steel bar coated specimen)								
S/no		**(150μm) coated**			**(300μm) coated**			**(450μm) coated**		
Concrete Cube	**Sample**	GAC3	GBC3	GBC3	GDC3	GEC3	GFC3	GGC3	GHC3	GIC3
CCS3-1	Failure load (KN)	27.83	27.38	28.02	28.61	29.43	29.13	29.34	29.51	28.63
CCS3-2	Bond strength (MPa)	11.18	11.38	9.87	10.38	11.18	11.29	12.28	11.58	11.56
CCS3-3	Max. slip (mm)	0.2004	0.1904	0.1804	0.1974	0.1904	0.2084	0.2364	0.2504	0.2484
CCS3-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 4: Results of Average Pull-out Bond Strength Test (τu) (MPa)

S/no		**Control Cube**			**Corroded Cube Specimens**			**Exudate steel bar coated specimens**		
Concrete Cube	**Sample**	**Control Specimens Average Values**			**Corroded Specimens Average Values**			**Coated Specimens Average Values of 150μm, 300μm, 450μm)**		
CCS4-1	Failure load (KN)	28.125	29.00166	28.7016	15.74333	15.776667	15.7166	27.74333	29.0566	29.16
CCS4-2	Bond strength (MPa)	8.3011	8.7221	8.7203	5.623333	5.80333	5.62666	10.8156	10.9567	11.8066
CCS4-3	Max. slip (mm)	0.10166	0.11066	0.108	0.0702	0.0775333	0.07386	0.1904	0.19873	0.24506
CCS4-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 5: Results of Average Pull-out Bond Strength Test (τu) (MPa)

		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**		
CCS5-1	Failure load (KN)	28.60944	15.74556	28.65333	181.6985	55.03622	181.9773	81.69854	-44.9638	81.97728
CCS5-2	Bond strength (MPa)	8.58	5.684444	11.18889	150.9382	66.25227	196.8335	50.93823	-33.7477	96.83346
CCS5-3	Max. slip (mm)	0.106778	0.073867	0.2114	144.5548	69.17794	286.1913	44.55475	-30.8221	186.1913
CCS5-4	Bar diameter (mm)	12	12	12	100	100	100	0	0	0

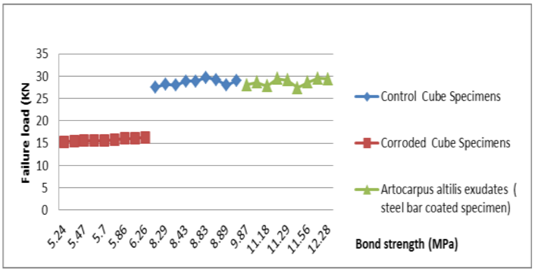

Figure 1: Summary Results of Pull-out Bond Strength Test (τu) (MPa) (Failure loads versus Bond Strengths)

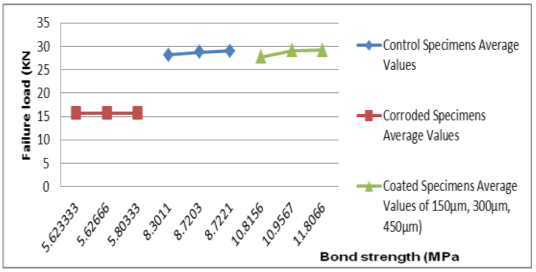

Figure 2: Average Results of Pull-out Bond Strength Test (τu) (MPa) (Failure loads versus Bond Strengths)

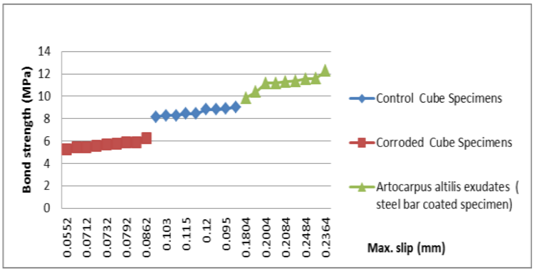

Figure 3: Summary Results of Pull-out Bond Strength Test (τu) (MPa) (Bond Strength versus Maximum Slip)

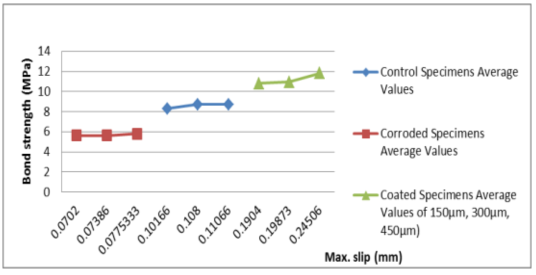

Figure 4: Average Results of Pull-out Bond Strength Test (τu) (MPa) (Bond Strength versus Maximum Slip)

CONCLUSION

Experimental results showed the following conclusions:

i. Lower percentile values were recorded in corroded while control and artocarpus altilis exudates/ resins coated specimens have higher values, especially in coated members.
ii. Results vindicated the negative and positive effects of corrosion on the strength capacity of corroded and coated members.
iii. Summarized results showed higher values of pullout bond strength in control and exudates/ resins coated to corroded specimens
iv. Bond test results showed, bond stresses experienced exudates /resins coated reinforcements are higher compared to the controlled specimens.

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