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Evaluation on Effects of Rebar Mechanical Properties from Chloride-Induced Corrosion Bond Strength Degradation

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Abstract

The experimental work explored the effectiveness and the potential application of euphorbia tirucalli exudate/resin extract as anti-corrosion agents on the bond strength of reinforced concrete structure exposed to high salinity zones. The experimental tests was performed on 36 concrete cubes divided into; 12 controlled concrete samples placed in freshwater for 360 days, 12 corroded samples, and 12 coated with exudates/resin as described in experimental procedures and immersed in 5% sodium chloride (NaCl) aqueous solution for 360 days and assessed their effectiveness by testing their performances and surface modifications at 3-months routine tests of 90 days, 180 days, 270 days and 360 days. The comparison results obtained from the maximum load of the connection at the time of failure of the controller were 110.003% compared to the corrosion value of -46.253% and covering 103.936%). The results show decreased corrosion values, lower failure loads compared to the controlled and coated samples with a closed range of values and a higher breaking load. For adhesion strength, the ratio of the maximum value of the controlled sample was 85.953% versus the corroded one -38.204% and covered 85.598%. The results showed lower adhesive break strength in the corroded samples at lower values compared to the controlled and coated samples with increased values and higher traction damage loads. The maximum ratio value of maximum slip was checked with 56.807% compared to -

39.527% and closed with 108.847%. From the values obtained, the corroded samples showed the lower application of damage loads, lower values compared to the controlled and coated samples with higher damage loads and increased slip values. The diameter of the reinforcement above can be seen that the diameter of the reinforcement without layers with a maximum value (decreased) of -0.629% and the layer increases by 0.6823%, for the corroded cross-sectional area has a maximum value of decrease (-11.259% and the layer increases 12.687 %%, weight loss and corrosion gain of -14.877% decreased (-11.259%). The cross-sectional area decreases and the weight decreases, while the closed concrete cubes have diameter and cross-section - the cross-sectional area increases, and the weight increases.

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

INTRODUCTION

An important factor and problem associated with the failure of structures in the marine environment is the steel reinforcement corrosion embedded in concrete structures. Bond strength is the maximum bond developed by friction between reinforcement and concrete, which can easily be considered as shear stress on the surface of the bar (Cairns and Abdullah, 1996), interlocking mechanism along with reinforced bar interfaces with the surrounding concrete.

The corrosion effect of steel reinforcement on structural behavior is considered a major concern today, with many experimental studies (Almussalam et al., 1996; Bingöl and Gül (2009) reported that the residual bond strength increases when the temperature is from 50 ˚C to 150 ˚C due to the increased in residual compressive strength). The effect of bar size on bond strength depends on the degree of constraint in their tests, the bond strength was found to decrease with increasing the bar size for samples with a low degree of restraint and separation failures, but this effect was negligible for samples with a high degree of restraint and pull-out failures. Turk and Yildirim (2003) reported that the bond strength of a reinforcing bar with a diameter of 10 mm is greater than that indicated by a steel reinforcement with a larger diameter.

Charles et al. (2018) Accessed the effect of resins on coated reinforcing steel embedded in concrete and pooled in corrosive media. Experimental samples were subjected to tensile and pull-out bond strength, and the results obtained were satisfactory as against corroded samples failure load, bond strength, and maximum slip values. Generally, the results showed good bonding characteristics and effectiveness in the use of ficus glumosa resins/exudates as protective materials against corrosion. The obtained results indicated the presence of corrosion potential on the members of the uncoated concrete cube.

Charles et al. (2018) investigated the fundamental reasons for the reduction in service life, integrity, and capacity of reinforced concrete structures in the marine environment of saline origin. The results obtained on the comparison show that the failure bond load, the bond strength, and the maximum slip values decrease resulting from corrosion attacks on the reinforcing steel. Generally, the results obtained showed a lower percentage in control and coated and whereas a greater percentage of corroded members. This justifies the effect of corrosion on the strength capacity of corroded and coated members.

Otunyo and Kennedy (2018) studied alternative curbing of corrosion effect on reinforcing steel embedded in concrete structures and exposed to corrosive media for 60 days after 28 days of curing. The obtained results indicated that the failure bond load, bond strength, and resin coating were higher by the maximum slip of reinforced cubes and higher than those obtained of corroded members. Similar results were obtained for the maximum slip (resin coating and control steel members) steel reinforcement with higher values of maximum slip compared to the corroded cubes.

Charles et al. (2018) have investigated that steel reinforcement corrosion in concrete is one of the major factors contributing to the failure of separation between steel and concrete, and the use of resin / exudate was introduced to curb this trend. The study showed that symphonia globulifera linn extract of 150µm, 250µm and 350µm of different applied thicknesses, embedded in concrete and exposed to a corrosive environment, to determine the failure load at pull out bond strength and maximum slip of embedded reinforcing steel of uncoated and coated members. Obtained results indicated that values of corroded members are lower compared to coated members. The results show that resins/exudates enhanced the strength of reinforcement and act as a protective coat against corrosion.

Charles et al. (2018) evaluated the effect of pressure produced by the adhesion of steel bar coated with 150µm, 250µm, and 350µm from three different resins/exudates and non-coated reinforcing steel embedded in concrete members and pooled in corrosive media for 60 days. The results obtained indicated the strength of corrosion in the non-adhesive concrete members. Full results have shown that wrap rates increase compared to corroded types, leading to a decrease in adhesive properties.

Charles et al. (2018) investigated the bond strength exhibited by reinforcement embedded in concrete that is controlled by corrosion effects. The study was performed on steel bars coated with varying thicknesses of inhibitor exudate pastes with 60 days of exposure to sodium chloride for laboratory corrosion media. Computed results showed lower values in the corroded samples compared to the coated specimens, the coated members showed high bonding characteristics variation from resins/exudates and served as resistance and protective membranes against the effect of corrosion.

Gede et al. (2019) investigated the strength of the bond between concrete and reinforcement diameter reduction due to the diminishing effect of reinforcing steel from the coastal area. The application of Artocarpus altilis is reinforced with a coating thickness of 150µm, 300µm, and 450µm, immersed in a concrete cube, ponded in sodium chloride, and control and coating exudates/resin member. Comparative results show that the values of the corroded samples decreased and the exudates/resins coated samples increased while in control. Overall results showed higher values of pull-out bond strength under control and coated exudates/resin for corroded specimens.

Charles et al. (2019) evaluated experimentally the bond strength behavior of non-corroded, corroded, and exudates/resins coated samples of 150 mm x 150 mm x150 mm cubes, immersed in a very high aggressive media for 150 days. Computed results have shown that corroded samples are weak during the separation test with a large load failure of low bond strength and low failure load. Exudate/resins inhibited members showed high protective properties against corrosion effects, which act as an inhibitor. Exudates/resins coated specimens showed higher resistance to bond strength properties, and higher flexural failure less compared to corroded types.

Terence et al. (2019) explored the effectiveness of reinforced steel coated inhibitors in rapid process testing of embedded steel foil bond strength over 150 days. Overall the results showed high values of control pull-out bond strength and exudates/adhesive coating members over for corroded specimens.

Toscanini et al. (2019) experimented with the utility of naturally inorganic corrosion inhibitors extract coated with 150μm, 300μm, and 450μm thickness and reinforced to concrete cubes, cured in rapid corrosive media for 150 days, and evaluated the strength-parameters of pull-bonding against non-coating are investigated. In comparison, the results of the corroded models decreased when the controlled and cola aluminum exudates/resins increased in the steel bar coated specimens. Overall results showed that natural exudates/resins should be investigated as inhibitors for corrosion effects in steel reinforcement in concrete construction in areas where chloride is expected.

Charles et al. (2019) studied the use of acacia senegal exudates/resins as paste materials in reinforcing steel with a thickness of 150μm, 300μm, and 450μm. Investigated samples of coated and non-coated embedded in concrete cubes and immersed in sodium chloride for 178 days. In comparison, the values of non-coating samples are reduced due to the corrosion attack on the steel reinforcing mechanical properties, but the increased strength of the non-corrosive and exudates/resin coated members, which indicates the ability of acacia senegal to be used as exudates/resins steel reinforcing coating operations. Overall results showed high values of pull-out-out bond strength and low failure load in the control and coated over the corroded samples.

MATERIALS AND METHODS FOR EXPERINMENT

The study involved the coating of exudates/resin paste extruded from plant trunks, known as corrosion inhibitor on reinforcing steel. The purpose of this experiment was to determine the potential of using eco-friendly and abundantly available materials by strengthening the steel embedded in concrete structures and immersing it in sodium chloride (NaCl) solutions. The test specimens show the level of sea salt concentration of the marine environment on concrete structures reflecting the acute acidic level. The embedded reinforcement steel is completely submerged in water and the samples are maintained in the pooling tank for the corrosion acceleration process. A 36 number of specimens of dimensions 150 mm x 150 mm x 150 mm of reinforced concrete cubes were prepared with 12 mm diameter reinforcement, embedded in the center for pullout bond testing for all controlled, uncoated, and coated samples and immersed in sodium chloride for 1 - 360 days after the initial 28 days of treatment of cubes. Acidic media samples were changed monthly and samples were inspected for high-efficiency performance.

Materials and methods for testing

Aggregates
Aggregates (fine and coarse) were purchased. Both met the requirements of BS882;

Cement
Portland Lime Cement Grade 42.5 is the most common type of cement on the Nigerian market. It was used for all concrete mixes in this test. Meets Cement Requirements (BS EN 196-6)

Water
The water samples were clean and free of impurities. Freshwater was gotten from Civil Engineering Department, Rivers State Polytechnic, Bori. Water met the requirements of (BS 3148).

Structural Steel Reinforcement
Reinforcements are obtained directly from the market at Port Harcourt, (BS4449: 2005 + A3)

Corrosion Inhibitors (Resins / Exudates) Euphorbia tirucalli
The exudates / latex has a caustic milky white sap that was obtained from the freshy stems that oozes out on breaking. It was obtained from Bori Town, Khana Local Government of Rivers State

Test Procedures

Corrosion acceleration was tested on high-yielding steel (reinforcement) with a diameter of 12 mm and a length of 650 mm. Layered with 150µm, 300µm, 450µm, and 600µm coatings before corrosion testing. The test cubes were cast with a 150 mm x 150 mm x 150 mm metal mold and removed after 72 hours. The samples were treated at room temperature in the tank for 28 days prior to the initial treatment period, followed by a test procedure allowing rapid acceleration corrosion testing and regular monthly monitoring of the procedure for 360 days. Cubes for corrosion-acceleration samples were randomly picked at 90-days, 180-days, 270-days, and 360 days with intervals of 3 months, and failure bond loads, bond strength, maximum slip, decrease/increase in cross-sectional area, and weight loss/steel reinforcement.

Accelerated Corrosion Set and Testing Method

In real and natural phenomena, the expression of corrosion effects on reinforcement embedded in concrete members is very slow and may take many years to achieve; But the laboratory accelerated process will take less and less time in the accelerating media representing the saltwater of the ocean area. To test the surface and mechanical properties of the modifications and effects and to test both co-coated and exudate/resin coated samples, immersed in 5% NaCl solution for 360 days.

Pull-out Bond Strength Test

The tensile-bond strength test of the concrete cube was taken on a total of 36 samples from each of the 12 samples with controlled, non-coated and coated members, and tested on the Universal Testing Machine of load 50 kN according to BSEN12390.2. A total designed specimens of 36 cubes of size 150 mm × 150 mm × 150 mm, with embedded reinforcement in the center of the cubes with a single 12 mm diameter bar.

Tensile strength of reinforcement bars

To determine the yield and tensile strength of the bar, a reinforced, non-coated, and reinforced steel strip with a diameter of 12 mm was tested under stress in a Universal Test Machine (UTM) and subjected to direct stress until failure failed. To ensure stability, the remaining cut pieces were used in subsequent bonding testing.

RESULTS AND DISCUSSION

Reinforced concrete structures exposed to severe weather of high salinity deterioration resulted in the effect of corrosion strong products which occupied larger or greater volume than the original steel in that resulted to increasing pressures on the surrounding concrete. External manifestations of corrosion include staining, cracks, and spalling of concrete. The increase in deformed reinforcing bars (ribs) and slip bonds depends largely on the bearings or mechanical interlocks between the concrete around the ribs on the bar surface. The harmful effects of corrosion attacks have caused many buildings to be repaired as to meet designed life span. The interaction between the concrete and the reinforcing steel is expected to be perfectly cordial to enable the exhibition of high bonding in the surrounding concrete structures.

The experimental data presented in Tables 3.1, 3.2 and 3.3, summarized in tables 3.4 and 3.5 were tests rests performed on 36 concrete cubes and subdivided into; 12 controlled concrete samples placed in freshwater for 360 days, 12 corroded samples and 12 coated with exudates / resin as described in experimental procedures and immersed in 5% sodium chloride (NaCl) aqueous solution for 360 days and accessed their effectiveness by testing their performances and surface modifications at 3-months routine tests of 90 days, 180 days, 270 days and 360 days. Indeed, the manifestation of corrosion is a long-term process that takes decades for full indications, but the artificial introduction of sodium chloride causes the manifestation and appearance of corrosion in a short time. The experimental work represents a suitable high-altitude marine environment and the potential application of euphorbia tirucalli exudate / resin extract as anti-corrosion and anti-corrosion agents for reinforced concrete structure exposed or built within high salinity zones.

Table 3.1: Results of Pull-out Bond Strength Test (τu) (MPa) of Non-corroded Control Cube Specimens

Sample Numbers	ETC	ETC1	ETC2	ETC3	ETC4	ETC5	ETC6	ETC7	ETC8	ETC9	ETC10	ETC11
	Time Interval after 28 days curing											
Samplin g and Durations	**Samples 1 (28 days)**			**Samples 2 (28 Days)**			**Samples 3 (28 Days)**			**Samples 4 (28 Days)**		

Failure Bond Loads (kN)	31.620	29.531	30.095	30.691	31.506	31.207	31.730	31.548	31.613	33.424	32.548	32.749
Bond strength (MPa)	12.548	13.440	11.938	12.868	13.241	14.164	14.258	13.587	13.622	14.328	13.639	14.186
Max. slip (mm)	0.109	0.111	0.101	0.106	0.105	0.104	0.117	0.121	0.129	0.127	0.131	0.129
Nominal Rebar Diameter	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
Measured Rebar Diameter Before Test(mm)	12.001	11.992	12.002	12.001	11.992	12.011	12.002	11.990	12.001	11.998	11.992	12.002
Rebar Diamete r- at 28 Days Nominal(mm)	12.001	11.992	12.002	12.001	11.992	12.011	12.002	11.990	12.001	11.998	11.992	12.002
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rebar Weights- Before Test(Kg)	0.588	0.588	0.586	0.589	0.589	0.589	0.589	0.588	0.590	0.587	0.587	0.595
Rebar Weights- at 28 Days Nominal(Kg)	0.588	0.588	0.586	0.589	0.589	0.589	0.589	0.588	0.590	0.587	0.587	0.595
Weight Loss /Gain of Steel (Kg)	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3.2: Results of Pull-out Bond Strength Test (τu) (MPa) of Corroded Concrete Cube Specimens

Sampling and Durations	**Samples 1 (90 days)**			**Samples 2 (180 Days)**			**Samples 3 (270 Days)**			**Samples 4 (360 Days)**		
Failure Bond Loads (kN)	16.218	15.530	15.820	15.263	14.511	15.378	14.957	15.265	14.963	16.198	15.077	15.811
Bond strength (MPa)	7.867	7.878	7.642	7.864	7.631	7.603	7.402	8.090	7.065	7.554	7.401	7.714
Max. slip (mm)	0.082	0.085	0.086	0.095	0.085	0.089	0.088	0.078	0.084	0.085	0.086	0.077
Nominal Rebar Diameter	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
Measured Rebar Diameter Before Test(mm)	11.993	11.984	11.994	11.993	11.984	12.003	11.994	11.982	11.993	11.990	11.984	11.994
Rebar Diameter- After Corrosion(mm)	11.944	11.935	11.945	11.944	11.935	11.954	11.945	11.933	11.944	11.941	11.935	11.945
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049
Rebar Weights- Before Test(Kg)	0.590	0.590	0.588	0.590	0.590	0.591	0.591	0.590	0.592	0.589	0.589	0.597
Rebar Weights- After Corrosion(Kg)	0.532	0.530	0.532	0.532	0.533	0.533	0.532	0.534	0.531	0.531	0.539	0.531
Weight Loss /Gain of Steel (Kg)	0.058	0.060	0.056	0.058	0.058	0.058	0.059	0.056	0.062	0.058	0.050	0.066

Table 3.3: Results of Pull-out Bond Strength Test (τu) (MPa) of Euphorbia tirucalli Exudate / Resin (steel bar coated specimen)

Samplin g and Durations	**Samples 1 (90 days)**			**Samples 2 (180 Days)**			**Samples 3 (270 Days)**			**Samples 4 (360 Days)**		
Sample	**150μm (Exudate/Resin) coated**			**300μm (Exudate/Resin) coated**			**450μm (Exudate/Resin) coated**			**600μm (Exudate/Resin) coated**		
Failure Bond Loads (kN)	30.706	28.617	29.181	29.777	30.592	30.293	30.817	30.634	30.699	32.510	31.634	31.836
Bond strength (MPa)	12.521	13.413	11.911	12.841	13.214	14.137	14.231	13.561	13.595	14.301	13.612	14.159
Max. slip (mm)	0.152	0.154	0.144	0.149	0.148	0.147	0.160	0.164	0.172	0.170	0.174	0.172
Nominal Rebar Diameter	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
Measured Rebar Diameter Before Test(mm)	11.963	11.954	11.964	11.963	11.954	11.973	11.964	11.952	11.963	11.960	11.954	11.964
Rebar Diameter- After Corrosion(mm)	12.018	12.009	12.019	12.018	12.009	12.028	12.019	12.008	12.018	12.015	12.009	12.019
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
Rebar Weights- Before Test(Kg)	0.590	0.590	0.588	0.590	0.590	0.591	0.591	0.590	0.592	0.589	0.589	0.597
Rebar Weights- After Corrosion(Kg)	0.660	0.661	0.659	0.661	0.661	0.662	0.662	0.661	0.663	0.659	0.660	0.668
Weight Loss /Gain of Steel (Kg)	0.072	0.064	0.069	0.071	0.070	0.070	0.662	0.661	0.663	0.659	0.660	0.668

Table 3.4: Results of Average Pull-out Bond Strength Test (τu) (MPa) of Control, Corroded and Exudate/ Resin Coated Steel Bar

Sample	Non-Corroded Specimens Average Values				Corroded Specimens Average Values				Coated Specimens Average Values of 150μm, 300μm, 450μm, 6000μm)			
Failure load (KN)	30.415	31.135	31.630	32.907	15.856	15.050	15.062	15.696	29.501	30.221	30.716	31.993
Bond strength (MPa)	12.642	13.424	13.822	14.051	7.796	7.699	7.519	7.556	12.615	13.398	13.796	14.024
Max. slip (mm)	0.107	0.105	0.122	0.129	0.084	0.090	0.083	0.082	0.150	0.148	0.165	0.172
Nominal Rebar Diameter	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
Measured Rebar Diameter Before Test(mm)	11.998	12.001	11.998	11.997	11.990	11.993	11.989	11.989	11.960	11.963	11.959	11.959
Rebar Diameter- After Corrosion(mm)	11.998	12.001	11.998	11.997	11.941	11.944	11.940	11.940	12.015	12.018	12.015	12.014
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.049	0.049	0.049	0.049	0.055	0.055	0.055	0.055
Rebar Weights- Before Test(Kg)	0.587	0.589	0.589	0.590	0.589	0.591	0.591	0.592	0.589	0.590	0.591	0.591
Rebar Weights- After Corrosion(Kg)	0.587	0.589	0.589	0.590	0.531	0.532	0.532	0.533	0.660	0.661	0.662	0.662
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.058	0.058	0.059	0.058	0.068	0.070	0.662	0.662

Table 3.5: Results of Average Percentile Pull-out Bond Strength Test (τu) (MPa) of Control, Corroded and Exudate/ Resin Coated Steel Bar

	Non-corroded Control Cube				**Corroded Cube Specimens**				**Exudate / Resin steel bar coated specimens**			
Failure load (KN)	91.821	106.871	110.003	109.658	-46.253	-50.199	-50.965	-50.941	86.058	100.799	103.936	103.836
Bond strength (MPa)	62.166	74.356	83.832	85.953	-38.204	-42.531	-45.497	-46.120	61.822	74.008	83.475	85.598
Max. slip (mm)	47.558	47.460	47.295	56.807	-44.002	-39.527	-49.715	-52.118	78.577	65.364	98.866	108.847
Nominal Rebar Diameter	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Measured Rebar Diameter Before Test(mm)	0.268	0.268	0.268	0.268	0.251	0.251	0.251	0.251	0.250	0.250	0.250	0.250
Rebar Diameter- After Corrosion(mm)	0.683	0.647	0.638	0.688	-0.679	-0.629	-0.679	-0.649	0.623	0.623	0.673	0.6823
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	-11.259	-11.259	-11.259	-11.259	12.687	12.687	12.687	12.687
Rebar Weights- Before Test(Kg)	0.311	0.312	0.311	0.311	0.028	0.028	0.028	0.028	0.028	0.033	0.028	0.028
Rebar Weights- After Corrosion(Kg)	10.606	10.583	10.751	10.569	-19.517	-19.480	-19.596	-19.455	24.250	24.193	24.372	24.155
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	-14.877	-17.232	-19.078	-19.209	17.477	20.820	20.763	37.536

Failure load, Bond Strength, and Maximum slip

Corrosion research has not produced carbon steel either another type of reinforcement that will not be affected when used in reinforced concrete structures and consideration is given to the use of non-ferrous reinforcement for structures exposed to chlorides. The problem of non-replaced carbon to corrosion has given room for research works on coating materials to serve as inhibitors to corrosion. This work introduced the application of euphorbia tirucalli exudates /resins as a possible remedy to the scourge of corrosion damage to reinforcing steel embedded in concrete and exposed to the coastal marine environment of severe condition.

Results of failure bond load, bond strength, and maximum slip conducted on 36 concrete cubes as given in Tables 3.1, 3.2, and 3.3 and summarized into average and percentile values in tables 3.4- 3.5 and projected graphically in figures and 1 - 6b. Test results were obtained for 12 controlled, 12 corroded, and 12 coated samples that were tested for failure using Instron Universal Testing Machines with 50kN pressure load as described. The minimum and maximum calculated average and percentile results of the failure bond load are 30.415kN and 32.907kN representing 91.821% and 110.003%, corroded samples are 15.05kN and 15.856kN representing-46.253% and -50.965%, whereas coated samples are 29.501kN and 31.993kN representing 86.058% and 103.936%.

The computed minimum and maximum bond strength values are controlled 12.642MPa and 14.051MPa with percentile values of 62.166% and 85.953%, corroded samples are 7.519MPa and 7.796MPa with representative percentile values of -46.12% and -38.204%), while coated samples are 12.615MPa and 14.024MPa having percentile values of 61.822% and 85.598%.

The maximum slip computed values are controlled by 0.105 mm and 0.129 mm and percentile values of 47.46% and 56.807%, corroded samples are 0.082 mm and 0.09 mm representing percentile values of -52.118% and -39.527%), and coated samples are 0.148 mm and 0.172 mm with percentile values of 65.364% and 108.847%).

The obtained comparative results of maximum failure bond load for controlled is 110.003% against the values of corroded -46.253% and coated 103.936%). Results showed value reduction in corroded, lower failure load as compared to controlled and coated samples with a closed range of values and higher failure load. For the bond strength, the comparison of the maximum values of the controlled sample is 85.953% as against corroded -38.204% and coated 85.598%. Results showed lower failure bond strength in corroded samples with value decreased as compared to controlled and coated samples with increased values and higher failure load to pullout.

The maximum comparative values from maximum slip are controlled 56.807% against-39.527% and coated 108.847%. From the obtained values, corroded samples exhibited lower failure load application, decrease values as compared to controlled and coated samples with higher failure load, and increased slippage values. The result showed signs of the impact of corrosion on failed bond load, bond strength, and maximum slip (Terence et al., 2019; Toscanini et al., 2019; Gede et al. Corrosion manifestation reduced the performance of the corroded material thereby reducing the mechanical properties of the surface change affecting the bonding and the contact between the concrete and the reinforcing steel.

Figure 1: Failure Bond loads versus Bond Strengths

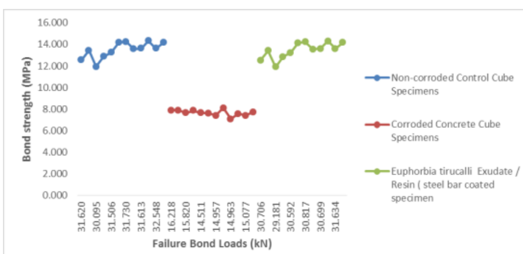


Figure 1a: Average Failure Bond loads versus Bond Strengths

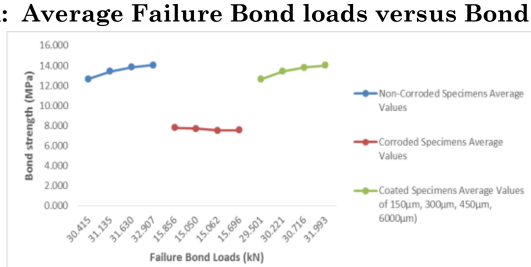


Figure 1b: Average Percentile Failure Bond loads versus Bond Strengths

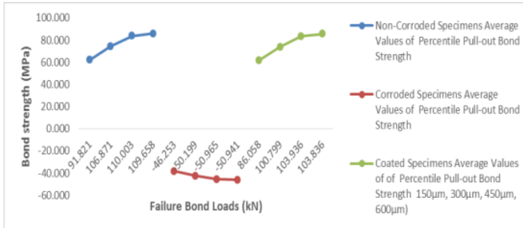


Figure 2: Bond Strengths versus Maximum Slip

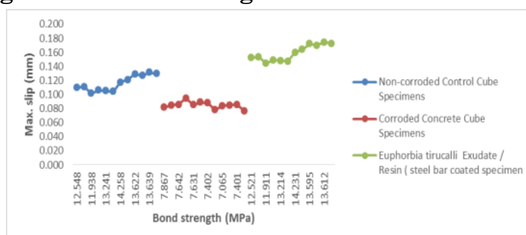


Figure 2a: Average Bond Strengths versus Maximum Slip

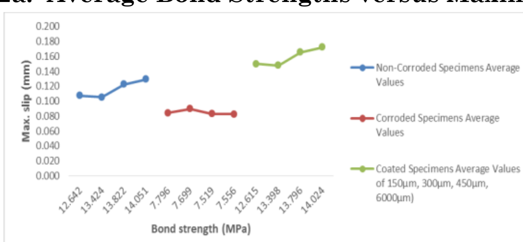
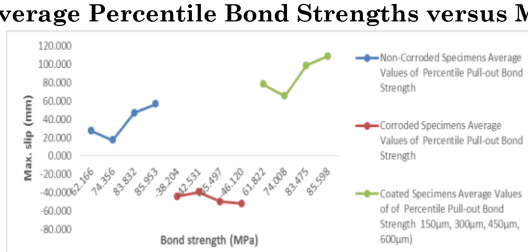


Figure 2b: Average Percentile Bond Strengths versus Maximum Slip



Mechanical Properties of Reinforcing Bars

Bonding plays a key role in the relationship between concrete and reinforcing steel, it ensures that there is little or no slippery steel bar associated with concrete and pressure transfer methods for steel-concrete (Hadi 2008). Bond resistance is formed by chemical adhesion, friction, and mechanical bonding between the bar and the concrete around it. To avoid the adhesion of solid concrete and construction firms, oil is widely used in construction these days. This experimental method may affect the bonding between the concrete and the steel due to contamination of the steel strips with oil before applying the concrete. The strength of a metal binder is studied by many authors. Moetaz and EL-Hawry (1999) studied the strong composition of reinforced concrete by looking at multiple suction tests. The decrease in bond strength in steel and concrete bars under the influence of rotating loads is measured by Cao and Chung (2001). The effect of different levels of corrosion of steel strips on concrete bonding strength has been investigated by Fang et al (2004) and Fang et al (2006). This research introduced the application of exudates/resins to increase the slippage problem caused by simple reinforcing steel.

The data presented in Table 3.1, 3.2, and 3.3 and summarized in table 3.4 of average values and further in 3.5 of percentile values, investigated the mechanical and behavioral characteristics of surface modifications of reinforcing steel leading to corrosion effect of corrosion accelerated process of controlled, uncoated, and coated concrete cube members subject to failure conditions using Instron Universal Testing machine of 50kN pressure load after 360 days periodic assessment, monitoring, and test conducted at 90 days, 180 days, 270 days and 360 days under immersion in fresh water for controlled samples and corrosive media for non-coated and coated samples.

Obtained results are summarized in the minimum and maximum values as stated in Tables 3.4 and 3.5 and graphically represented in figures 3-6b.

The steel bars of the Nominal diameter steel bars of all samples are 100%, and the minimum and maximum diameters of the steel bars measured before the tests are within the range of 11.997mm and 12.00mm. The diameter of the rebar uncoated samples (corroded) after corrosion test are 11.94mm and 11.944mm (-0.629% and -0.679%), after coated are 12.014mm and 12.0180.623mm (0.623% and 0.6823%).

The results of cross - sectional area for uncoated (corroded) are 0.049mm and 0.049mm (-11.259% and -11.259%), for coated are 0.055mm and 0.055mm (12.687% and 12.687%).

The result for rebar weight before the test for all samples is 0.587Kg and 0.59Kg (0.311% and 0.312%), weight after corrosion test for corroded are for 0.531Kg and 0.533Kg (-19.596% and -19.455%), coated are 0.66Kg and 0.662Kg (24.155% and 24.372%), and weight loss /gain of steel are corroded 0.058Kg and 0.059Kg (-19.209% and -14.877%) and coated values are 0.068Kg and 0.662Kg (17.477% and 37.536%).

From the results obtained and presented in the figures, the effect of corrosion on uncoated and coated reinforcing steel are enumerated, in figures 3 and 6b on the diameter of rebar, it can be seen that the diameter of uncoated decreased by the maximum value of (-0.629% and coated increased by 0.6823%, for the cross-sectional area, corroded has maximum reduction value of -11.259% and coated increased by 12.687%, weight loss and gain are corroded -14.877% decreased (loss) and coated 37.536% increase (gain). According to the analysis of the experimental work, the indication is that the corrosion effect of the uncoated concrete cube causes diameter and cross - the sectional area decreases and the weight decreases while the coated concrete cube has diameter and cross - the sectional area increases and the weight increases. Furthermore, the increase in volume and diameter resulted in varying coated thicknesses which also contributed to the minute increase in the unit weight of reinforcing steel. The effect of exudate /resin showed the potency in its use as an inhibitory material in curbing down the effect of corrosion of reinforced concrete structures within the high salinity areas.

Figure 3: Measured (Rebar Diameter before Test vs Rebar Diameter-after Corrosion)

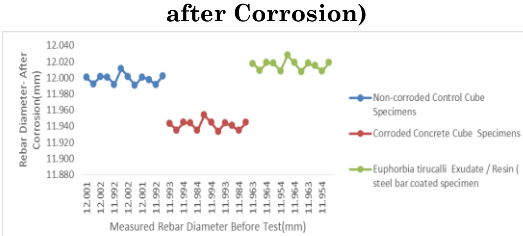


Figure 3a: Average Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

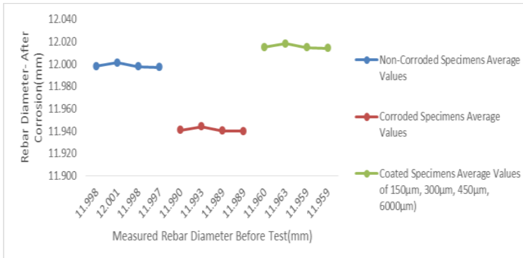


Figure 3b: Average Percentile Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

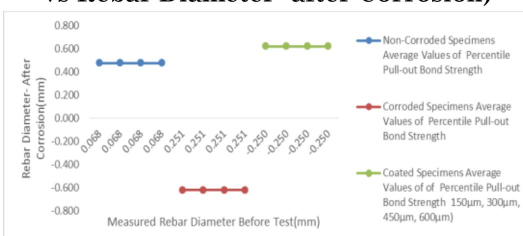


Figure 4: Rebar Diameter- After Corrosion versus Cross - Sectional Area Reduction/Increase

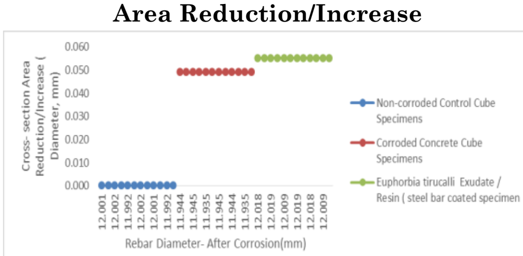


Figure 4a: Average Rebar Diameter- after Corrosion versus Cross – Sectional Area Reduction/Increase

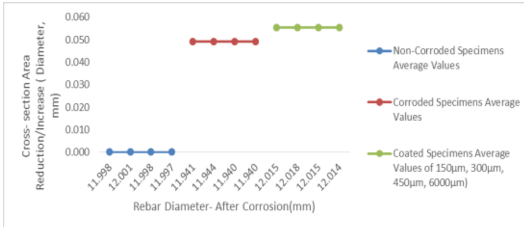


Figure 4b: Average percentile Rebar Diameter- after Corrosion versus Cross - sectional Area Reduction/Increase

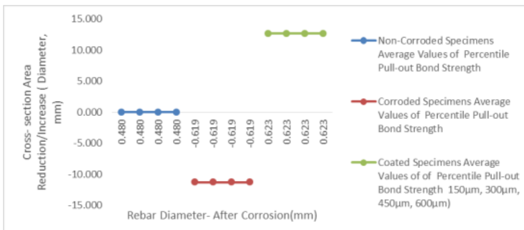


Figure 5. Rebar Weights- before Test versus Rebar Weights- after Corrosion

Figure 5a: Average Rebar Weights- before Test versus Rebar Weights- after Corrosion

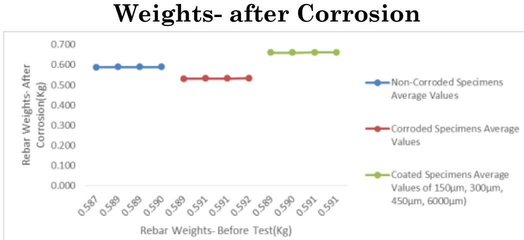


Figure 5b: Average Percentile Rebar Weights- before Test versus Rebar Weights- after Corrosion

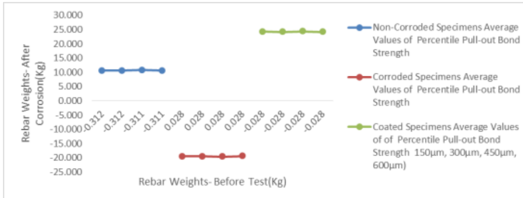


Figure 6: Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

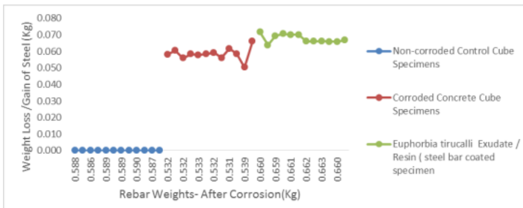


Figure 6a: Average Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

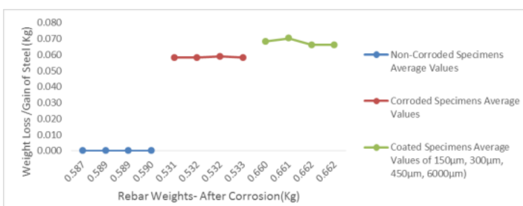
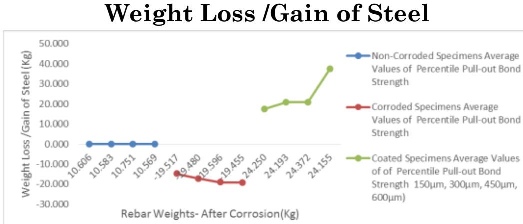


Figure 6b: Average percentile Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel



Comparison of Control, Corroded, and Coated Concrete Cube Members

Comparatively, from the data in tables 3.1, 3.2 and 3.3 and in figures 3, 4,5 and 6 for 12 controlled samples pooled in a freshwater tank for 360 days, 12 uncoated and 12 coated pooled in 5% sodium chloride (NaCl) aqueous solutions for 360 days ad described in 3.1 – 3.3 and summarized into tables 3.4 – 3.5 and figures 3a,3b,4a,4b,5a,5b, 6a and 6b for average and percentile values for failure bond loads, bond strength and maximum slip , cross – sectional reduction / increase, diameter of rebar before /after corrosion, weight loss/gain.

The comparison results obtained from the maximum load of the connection at the time of failure of the controller were 110.003% compared to the corrosion value of -46.253% and covering 103.936%). The results show decreased corrosion values, lower breaking loads compared to the controlled and coated samples with a closed range of values and a higher breaking load. For adhesion strength, the ratio of the maximum value of the controlled sample was 85.953% versus the corroded one -38.204% and covered 85.598%.

The results showed lower adhesive break strength in the corroded samples at lower values compared to the controlled and coated samples with increased values and higher traction damage loads.

The maximum ratio value of maximum slip was checked with 56.807% compared to -39.527% and closed with 108.847%.

From the values obtained, the corroded samples showed lower application of damage loads, lower values compared to the controlled and coated samples with higher damage loads and increased slip values. The results showed signs of a corrosion effect on failed bonds, maximum adhesion and slip strength. The occurrence of corrosion reduces the properties of the material being corroded, thereby reducing the mechanical properties of surface changes that affect the bonding and contact between the concrete and reinforcement.

The results obtained and shown in the figure show the corrosion effect of the uncoated and coated reinforcing steel. In Figures 3 and 6b the diameter of the reinforcement above can be seen that the diameter of the reinforcement without layers with a maximum value (decreased) of -0.629% and the layer increases by 0.6823%, for the corroded cross-sectional area has a maximum value of decrease (-11.259% and the layer increases 12,687 %%, weight loss and corrosion gain of -14,877% decreased (-11,259%) loss and coating increased by 37.536% (After analyzing experimental work, the indication is that the corrosion effect of uncoated concrete cubes causes transverse diameter and stresses. - the cross-sectional area decreases and the weight decreases, while the closed concrete cubes have diameter and cross-section - the cross-sectional area increases and the weight increases. The effect of exudate / resin shows the effectiveness of its use as an inhibitor to limit the effect of corrosion on reinforced concrete structures in areas with high salinity .

CONCLUSION

In the experiment, the results obtained were plotted as follows:

i. The exudate / resin has a corrosion inhibitory effect, as it is watertight resistant to corrosion penetration and attack.
ii. The interaction between concrete and steel in the coated component is greater than that of the corroded sampleT
iii. he bonding properties in coated and controlled components are greater than in those that are corroded
iv. The slightest damage to the connection, the maximum connection strength and slip is registered in the corroded elements
v. The coverage and control patterns show higher bond load values and bond strength.
vi. Weight loss and area reduction were recorded mainly in the corroded layers

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