Chloride-Induced Corrosion on Mechanical Interlocking Reduction of Reinforced Concrete Structures

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ABSTRACT

This study entails the coating of extruded exudates/resin paste extracted from plants on reinforcing steel. The experiment aimed at determining the potency of eco-friendly inhibitor substances in curtailing the damaging effect of corrosion attacks on reinforcing steel embedded in concrete structures with varying thickness of the coating and immersed in Sodium Chloride (NaCl) solutions and experimentally examined the surface modifications of steel resulting from the accelerated media. Obtained results of average values and summarized percentile values for differential performance characteristics of controlled, corroded, and coated concrete cube samples. The obtained maximum percentile values of failure bond load are controlled the reference point is 101.194% against corroded 44.812% and coated 100.52%. Results in comparison showed validated values between controlled and coated with higher load failure recorded over corroded with lower load failure application. The comparative results of bond strength showed the closer values range in controlled and coated over corroded samples with lower failure load application while higher failure recorded in controlled and coated samples. Results in comparison showed validated closed values of controlled (reference point) and coated over corroded with lower slippage failure load while higher failure load is controlled and coated samples. It can be seen from the diameter of the reinforcement that the diameter of the reinforcement of corroded decreases by a maximum of -0.585%, and the coated increases by 0.589%, for the maximum corroded cross-sectional area of -6.793% and the coated increases by 8.7%, weight loss and corrosion gain -9.409% decreased (loss) and coated increased by 18.546% (gain). Results of the analyzed experimental work showed that the effect of corrosion on uncoated concrete cubes causes a decrease in the cross-sectional diameter and cross-sectional area as well as a decrease in the body/ unit weight, while the cube-coated concrete has a cross-sectional diameter and a cross-section area and weight minute increased, due to differences in the thickness of the reinforcing steel layer.

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

1.0 Introduction

Corrosion is one of the main reasons for the limited durability of reinforced concrete structures built in the extreme coastal marine area with rear a unique condition with a high concentration of salt. There is general acceptance that steel reinforcement is the primary cause of poor bonding between steel reinforcement and concrete, leading to premature deterioration in reinforced concrete structures. Chloride and carbonation contamination of reinforced concrete structures are the main causes of steel corrosion, leading to a reduction in bar diameter, mechanical properties of steel reinforcement, and tear. Degradation, failures usually occur and can result in expensive sealed reinforced concrete structures. The bar is affected by the geometry, the concrete properties, the presence of force around the bar, as well as the surface conditions of the bar ACI [1].

Charles et al. [2] investigated the effect of corroded and coated reinforcement on the pressure exerted on the pull-out bond separation of control, corroded and resins/exudates paste coated steel bar.

Overall results showed that the coating values increased as compared to corroded specimens, resulting in adhesion properties from the resins/exudates to strengthen the reinforcement and act as a protective coat against corrosion.

Auyeung et al. [3] studied the bond behavior of corroded reinforcement bars and found that when the heavy loss of reinforcement due to corrosion reaches about 2%, concrete cracks along the bar are formed. A low amount of corrosion increases both bond strength and bond stiffness, but the slip is significantly reduced at failure. However, they stated that when the mass loss exceeds 2%, the bond strength will decrease significantly.

Ravindrarajah and Ong [4] investigated the effect of the steel bar diameter and the thickness of the cover on the degree of corrosion of the lightweight steel bars embedded in the concrete. They found that the corrosion intensity had a significant effect on the bar diameter, cover thickness, and sample size.

Charles et al. [5] explored the primary reasons for reducing service life, integrity, and the effectiveness of reinforced concrete structures in the marine environment of saline. The results obtained for comparison showed that the failure bond load, bond strength, and maximum slip decreased in the corroded specimen. The full results showed a lower percentage of corporations and a higher percentage of coated members. This justifies the effect of corrosion on the strength of the corroded members.

Charles et al. [6] stated that the bond strength exhibited by reinforcement embedded in concrete is controlled by corrosion effects. Overall results showed lower values in corroded specimens compared to coated specimens, coated members showed high bonding characteristics from dacryodes edulis, moringa oleifera Lam and magnifera indica, and the coating acts as a resistance and protective layer against corrosion effects.

Charles et al. [7] investigated the effectiveness of resin/exudates in corrosion to prevent reinforcement in reinforced concrete cubes. The results were obtained showed high-throughput (resin-coated and control members) which had higher total initiation rates compared to cubes that corroded.

Toscanini et al. [8] studied the application of environmentally-friendly corrosion inhibitors of exudates/resin from a natural source to reinforcing steel bars with 150μm, 300μm, and 450μm coating thicknesses embedded in concrete cubes, cured in fast corrosive media, and investigated pull-out bond strength parameters against non-coated ones. Relatively, the results of the corroded specimens decreased whereas control and cola accuminata exudates/resins increased in steel bar coated samples. Overall results showed that natural exudates/resins be explored as inhibitors for corrosion effects in steel reinforcement in concrete construction in areas where chloride is expected.

Terence et al. [9] explored the impact of reinforced steel coated inhibitors under a rapid process test of embedded steel failure bond strength for 150 days. The overall results showed high values of the control pull-out-bond strength and the exudates/adhesive coating over the corroded samples.

Charles et al. [10] examined the use of acacia senegal exudates/resins as coat materials in reinforcing steel with a thickness of 150μm, 300μm, and 450μm. Experimental studies investigated coated and non-coated samples embedded in concrete cubes and immersed in sodium chloride and accelerated for 178 days. In comparison, the values of non-coated specimens are reduced due to the presence of corrosion attack on mechanical properties of reinforcing steel, but non-corroded and exudates/resins coated members increased, indicating the potential of acacia senegal exudates/resins in steel reinforcing coating operations. Overall results showed high values of pull-out bond strength and low failure load in the control and coated over corroded specimens.

Charles et al. [11] investigated the impact of olibanum exudates/resins on reinforcing steel corrosion in the coastal zones with the impact of saltwater on concrete structures. Reinforcing steel of non-coated and exudates/resin-coated was embedded in concrete cubes and pooled in corrosive media and assessed corrosion effects. The tests showed that the non-coated samples decreased and deteriorated due to corrosion attacks. The mean percentage bond strength load was 33.13% and coated members 45.66% and 71.84% compared to the control difference. The mean maximum slip values are 0.083 mm and mean 33.87% and 75.30% compared to control and coated -25.30%. The test results show that reduced samples have lower bond strength and higher failure bond load and lower maximum slip, whereas exudates/resins coated samples have lower test specimens, with higher percentage values compared to corroded samples.

Charles et al. [12] Experimental work evaluated the bond strength of non-corroded, corroded, and exudates/resins coated samples of 150 mm x 150 mm x150 mm concrete cubes standard, immersed in a corrosive medium for 150 days. The combined results showed that the corroded samples were weakened during the separation test with a high failure load with low bond strength. Non-corroded and exudates/resin members have a higher bond strength and lower failure load. Exudate/resin designs show high protective properties against the effects of corrosion, acting as inhibitors. The exudates/resins coated specimens show a higher resistance to bond strength properties, and higher flow with less failure compared to the composite members.

Charles et al. [13] Studied reinforcing steel bond strength using corroded and khaya senegalensis exudates/adhesive coated specimens. The results of the failure bond loads showed a difference of -43.62% and 77.37% and 79.67% for the members of the corrosive and coated exudates/resin. The reduced mean percentage bond strength load varies from 57.0631% to 36.331% and 106.576% in the corroded and coated samples. The obtained results clearly showed that the corrosive bond loads were higher for the corroded than for the exudates/adhesive coated members. The binding strength of the corroded and coated specimens showed a higher affinity for coated compared to corroded ones.

2.0 Experimental Program

This study entails the coating of extruded exudates/resin paste extracted from plants on reinforcing steel. The experiment aimed at determining the potency of eco-friendly inhibitor substances in curtailing the damaging effect of corrosion assaults on reinforcing steel embedded in concrete structures with varying thickness of the coating and immersed in Sodium Chloride (NaCl) solutions and experimentally examined the surface modifications of steel resulting from the accelerated media. The test specimens represent the intense acidic degree indicating the sea salt degree of the marine environment on the concrete structures. The embedded reinforcement steel is completely submerged in water and the samples are maintained in the pooling tank for the corrosion acceleration process. The specimens were designed with 36 reinforced concrete cubes of dimensions 150 mm × 150 mm x 150 mm, with a 12 mm diameter reinforcement embedded inside the center for pullout bond test controlled, uncoated, and coated specimens and immersed in sodium chloride. A test period of 1 - 360 days after the preliminary 28 days of curing of the cubes. Acid media samples have been replaced month-to-month and samples were inspected for high-efficiency performance.

2.1 Materials and methods for testing

2.1.1 Aggregates

Aggregates (fine and coarse) were purchased. Both met the requirements of BS882 [14]

2.1.2 Cement

Portland Lime Cement Grade 42.5 is the most common form of cement in the Nigerian marketplace. It changed into used for all concrete mixes in this take a look at. Meets Cement Requirements (BS EN 196-6) [15]

2.1.3 Water

The water samples were clean and free from contaminants. Freshwater was obtained from the Civil Engineering Laboratory, Kenule Beeson Saro-Wiwa Polytechnic, Bori, and Rivers State. Water met (BS 3148) [16] requirements

2.1.4 Structural Steel Reinforcement

Reinforcements are acquired at once from the market at Port Harcourt, (BS4449: 2005 + A3) [17]

2.1.5 Corrosion Inhibitors (Resins / Exudates) Chrysophyllum albidum

The grayish brown and whitish gummy exudates were obtained from the tree bark. They are abundantly seen in the bushes of Ekpeye land in Ahoada West / Ahoada East Local Government of Rivers State

2.2 Test Procedures

Corrosion acceleration turned into examined on high-yielding metallic (reinforcement) with a diameter of 12 mm and a length of 650 mm. Paste with 150µm, 300µm, 450µm, and 600µm coatings earlier than corrosion testing. The concrete cubes have been cast with 150 mm × 150 mm x 150 mm steel mold and dismantled after 72hours. Samples were treated at room temperature in tanks for 28 days before the initial curing, accompanied by a fast acceleration corrosion process for 360 days. The cubes for corrosion-acceleration samples have been taken for 90 days, 180 days, 270 days, and 360 days at 3 months duration, and failure bond loads, bond strength, maximum slip, decrease/increase in cross-sectional area, and weight loss/steel reinforcement.

2.3 Accelerated Corrosion set-up and Testing Method

In real and natural phenomena, the expression of corrosion outcomes on reinforcement embedded in concrete members is very slow and might take a few years to reap; but the laboratory expanded process will take much less and much less time with accelerating media representing the salt water of the sea zones. Checks on surface modifications of reinforced concrete structures were monitored to ascertain the trend of damage for the uncoated and coated members with an accelerated 360 days period n 5% NaCl solution.

2.4 Pull-out Bond Strength Test

The pullout-bond strength concrete cubes were designed for 36 samples and 12 samples and each for controlled, non-coated, and coated members, and subject to a 50kN universal testing machine according to BSEN12390-2. 36 cubes size 150 mm × 150 mm × 150 mm, embedded in the center of a single 12 mm diameter concrete cube.

2.5 Tensile Strength of Reinforcement Bars

To determine the yield and tensile electricity of the bar, the reinforced, non-lined, and strengthened steel strip with a diameter of 12 mm became tested under stress inside the Universal Test Machine (UTM) and subjected to direct strain until failure load is recorded.

3.1 Experimental Results and Discussions

Increased deformation (ribs) of reinforcing bars and bonding mainly depends on the mechanical interlock between the concrete around the ribs on the surface of the rebar. The interaction between concrete and reinforcement is expected to run perfectly to achieve maximum bonding in the surrounding concrete structure. The detrimental effects of corrosive attacks have rendered many buildings unusable and shortened the life of the buildings.

The experimental data shown in tables 3.1,3.2 and 3.3, summarized in tables 3.4 and 3.5, were carried out on 36 samples of concrete cubes from 12 controlled samples placed in freshwater for 360 days, and 24 induced samples of 12 uncoated and 12 coated with exudates/resin, all were embedded with reinforcing steel and immersed in 5% sodium chloride (NaCl) aqueous solution for 360 days and examinations on their performance was assessed through inspection, monitoring, verification, and testing at intervals of 3 months for 90 days, 180 days, 270 days and 360 days. The occurrence of corrosion is a long-term process that can take decades to reach full functionality. However, the artificially introduced sodium chloride causes corrosion to occur in a shorter time. The experimental work represents the ideal marine areas on the coast with high salinity and the possible use of chrysophyllum albidum exudates/resins as a barrier to limit the risk of corrosive effects on reinforced concrete structures in such heavy and rough conditions exposed or constructed areas.

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

Sample Numbers	CAC	CAC1	CAC2	CAC3	CAC4	CAC5	CAC6	CAC7	CAC8	CAC9	CAC10	CAC11
	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)	27.686	25.596	26.160	26.757	27.572	27.273	27.796	27.613	27.678	29.489	28.614	28.815
Bond strength (MPa)	8.899	9.792	8.289	9.220	9.592	10.516	10.609	9.939	9.973	10.679	9.991	10.537
Max. slip (mm)	0.106	0.108	0.098	0.103	0.102	0.101	0.114	0.118	0.126	0.124	0.128	0.126
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	11.991	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	11.991	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)	0.577	0.577	0.575	0.577	0.577	0.578	0.578	0.577	0.579	0.576	0.576	0.584
Rebar Weights- at 28 Days Nominal(Kg)	0.577	0.577	0.575	0.577	0.577	0.578	0.578	0.577	0.579	0.576	0.576	0.584
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

Samplin g and Durations	**Samples 1 (90 days)**			**Samples 2 (180 Days)**			**Samples 3 (270 Days)**			**Samples 4 (360 Days)**		
Failure Bond Loads (kN)	14.922	14.235	14.525	13.967	13.215	14.083	13.662	13.970	13.668	14.903	13.782	14.516
Bond strength (MPa)	6.767	6.777	6.542	6.764	6.531	6.503	6.301	6.990	5.965	6.453	6.301	6.613
Max. slip (mm)	0.080	0.083	0.084	0.093	0.084	0.087	0.086	0.076	0.082	0.083	0.084	0.075
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	11.983	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	11.934	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)	0.580	0.580	0.578	0.580	0.580	0.581	0.581	0.580	0.582	0.579	0.579	0.587
Rebar Weights- After Corrosion(Kg)	0.525	0.523	0.526	0.526	0.526	0.526	0.525	0.527	0.524	0.524	0.532	0.524
Weight Loss /Gain of Steel (Kg)	0.055	0.057	0.052	0.055	0.054	0.055	0.056	0.052	0.058	0.055	0.047	0.062

Table 3.3: Results of Pull-out Bond Strength Test (τu) (MPa) of Chrysophyllum albidum 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)	27.589	25.499	26.063	26.660	27.475	27.176	27.699	27.516	27.581	29.392	28.517	28.718
Bond strength (MPa)	9.644	10.536	9.034	9.964	10.337	11.260	11.354	10.684	10.718	11.424	10.735	11.282
Max. slip (mm)	0.101	0.102	0.093	0.098	0.097	0.096	0.109	0.113	0.121	0.118	0.123	0.121
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)	11.961	11.952	11.962	11.961	11.952	11.971	11.962	11.951	11.961	11.958	11.952	11.962
Rebar Diamete r- After Corrosion(mm)	12.014	12.005	12.015	12.017	12.005	12.023	12.013	12.003	12.015	12.011	12.004	12.015
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.053	0.053	0.053	0.055	0.053	0.052	0.052	0.053	0.054	0.053	0.053	0.053
Rebar Weights- Before Test(Kg)	0.580	0.580	0.578	0.580	0.580	0.581	0.581	0.580	0.582	0.579	0.579	0.587
Rebar Weights- After Corrosion(Kg)	0.643	0.643	0.641	0.643	0.643	0.644	0.644	0.643	0.645	0.642	0.642	0.650
Weight Loss /Gain of Steel (Kg)	0.064	0.056	0.062	0.063	0.062	0.062	0.644	0.643	0.645	0.642	0.642	0.650

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

	Control, Corroded and Resin Steel bar Coated											
Sample	Non-Corroded Specimens Average Values				Corroded Specimens Average Values				Coated Specimens Average Values of 150µm, 300µm, 450µm, 6000µm)			
Failure load (KN)	26.481	27.200	27.696	28.973	14.561	13.755	13.767	14.400	26.384	27.103	27.599	28.876
Bond strength (MPa)	8.993	9.776	10.174	10.402	6.695	6.599	6.419	6.456	9.738	10.521	10.919	11.147
Max. slip (mm)	0.104	0.102	0.119	0.126	0.083	0.088	0.082	0.081	0.099	0.097	0.114	0.121
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	11.990	11.989	11.958	11.961	11.958	11.957
Rebar Diamete r- After Corrosion(mm)	11.998	12.001	11.998	11.997	11.941	11.944	11.941	11.940	12.011	12.015	12.010	12.010
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.049	0.049	0.049	0.049	0.053	0.053	0.053	0.053
Rebar Weights- Before Test(Kg)	0.576	0.577	0.578	0.578	0.579	0.580	0.581	0.581	0.579	0.581	0.581	0.582
Rebar Weights- After Corrosion(Kg)	0.576	0.577	0.578	0.578	0.525	0.526	0.525	0.527	0.642	0.643	0.644	0.644
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.054	0.054	0.055	0.054	0.060	0.062	0.644	0.644

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)	81.864	97.748	101.182	101.194	-44.812	-49.250	-50.119	-50.130	81.197	97.043	100.477	100.520
Bond strength (MPa)	34.319	48.134	58.498	61.126	-31.244	-37.273	-41.211	-42.084	45.443	59.420	70.101	72.663
Max. slip (mm)	25.863	15.700	45.942	55.616	-16.439	-9.003	-28.409	-33.020	19.672	9.893	39.683	49.299
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)	0.066	0.066	0.066	0.066	0.268	0.268	0.268	0.268	-0.268	-0.268	-0.268	-0.268
Rebar Diamete r- After Corrosion(mm)	0.587	0.587	0.587	0.587	-0.581	-0.585	-0.580	-0.581	0.585	0.589	0.583	0.584
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	-7.145	-8.003	-6.793	-6.969	7.695	8.700	7.288	7.492
Rebar Weights- Before Test(Kg)	0.544	0.543	0.542	0.542	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
Rebar Weights- After Corrosion(Kg)	9.778	9.757	9.927	9.745	-18.297	-18.262	-18.381	-18.238	22.394	22.341	22.521	22.306
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	-9.875	-12.687	-9.409	-9.544	10.957	14.530	16.977	18.546

3.2 Failure load, Bond Strength, and Maximum slip

The results of the failure load, bond strength, and maximum slip were carried out on 36 concrete cubes, as shown in table 3.1, 3.2, and 3.3 and 3.4 - 3.5 are summarized and shown graphically in Figures 1 - 6b. The results obtained refer to 12 controlled, 12 corroded and 12 coated samples tested for failure using Instron Universal Testing Machines at 50kN as described in the test procedure.

The minimum and maximum mean values and percentiles calculated from the bond load were examined with 26.481kN and 28.973kN (81.864% and 101.194%), corroded with 13.755kN and 14.561kN (-50.13% and -44.812%), with 26.384kN and 28.876kN (81.197% and 100.52%). The value of bond strength to control was 8.993MPa and 10.402MPa (34.319% and 61.126%), corroded 6.419 MPa and 6.695MPa (-42.084% and -31.244%), covering 9.738MPa and 11.147MPa (45.443% and 72.663%). The maximum slip yield results of controlled are 0.102 mm and 0.126 mm (15.7% and 55.616%), corroded with 0.081 mm and 0.088 mm (-33.02% and -29.003%), with 0.097 mm and 0.121 mm (39.893% and 49.299) %) coated samples.

Obtained results from tables 3.1, 3.2, and 3.3 substituted in tables 3.4 of average values and summarized to tables 3.5 percentile values for differential performance characteristics of controlled, corroded, and coated concrete cube samples. The obtained maximum percentile values of failure bond load are controlled the reference point is 101.194% against corroded 44.812% and coated 100.52%. Results in comparison showed validated values between controlled and coated with higher load failure recorded over corroded with lower load failure application. The maximum values recorded of bond strength are controlled 61.126%, corroded -31.244%, and coated 72.663%. The comparative results of bond strength showed the closer values range in controlled and coated over corroded samples with lower failure load application while higher failure recorded in controlled and coated samples. The maximum slip values recorded are controlled 55.616% against corroded -29.003% and coated 49.299%. Results in comparison showed validated closed values of controlled (reference point) and coated over corroded with lower slippage failure load while higher failure load is controlled and coated samples as confirmed by the studies of (Charles et al. [2], Terence et al. [9], Toscanini et al. [8])

The data presented in tables 3.1 - 3.5 and plotted graphically in figures 1-6b showed clear indications of the effect of corrosion on the failure bond load, bond strength, and maximum slip of reinforced concrete cubes induced in corrosive media as related to the studies of (Auyeung et al., [3]; Ravindrarajah and Ong, [4]; ACI, Charles et al., [7]).

The presence of corrosion reduces the efficiency of the mechanical properties and surface modification thereby removing the ribs, which affect the bond interaction between concrete and reinforcing steel.

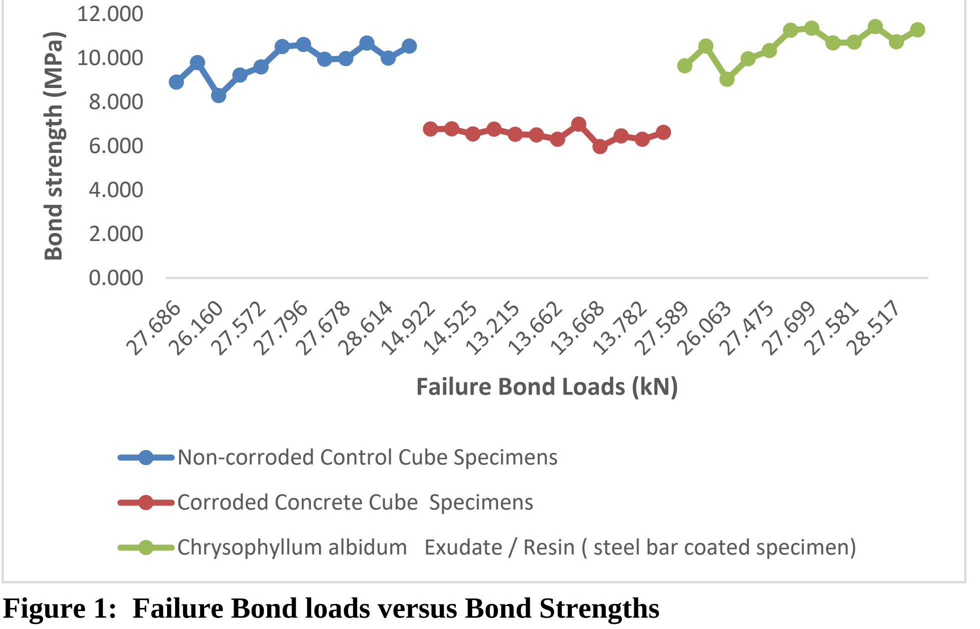

Figure 1: Failure Bond loads versus Bond Strengths

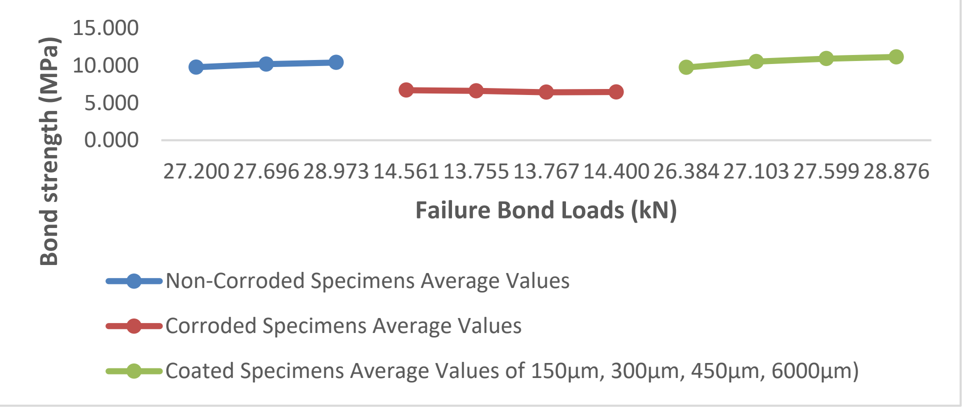

Figure 1a: Average Failure Bond loads versus Bond Strengths

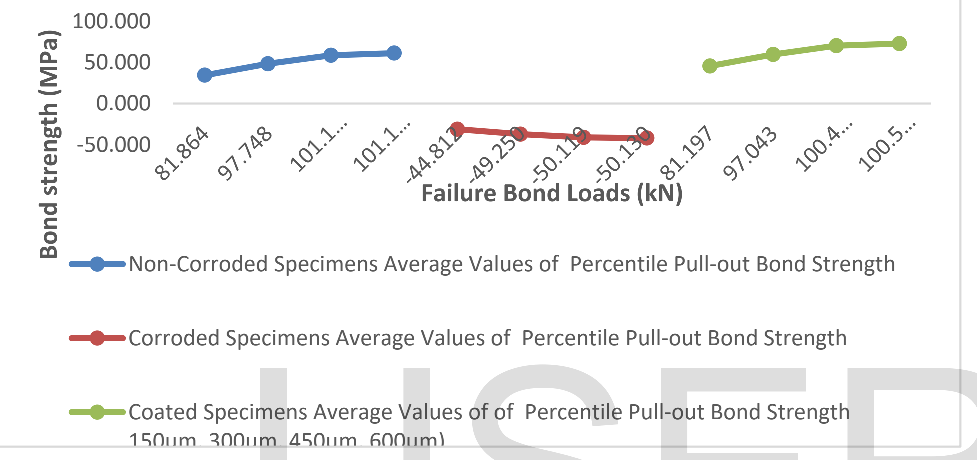

Figure 1b: Average Percentile Failure Bond loads versus Bond Strengths

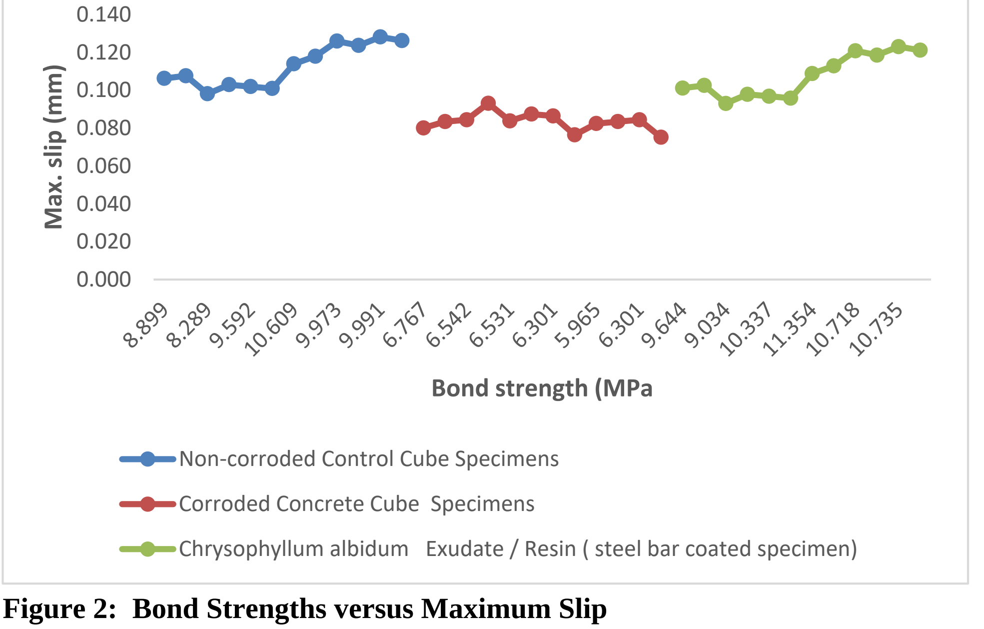

Figure 2: Bond Strengths versus Maximum Slip

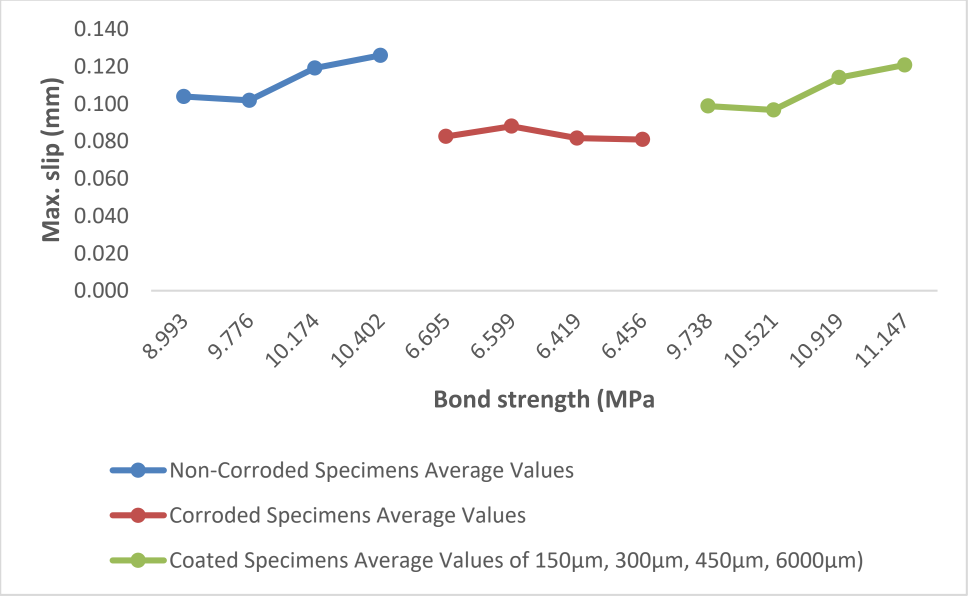

Figure 2a: Average Bond Strengths versus Maximum Slip

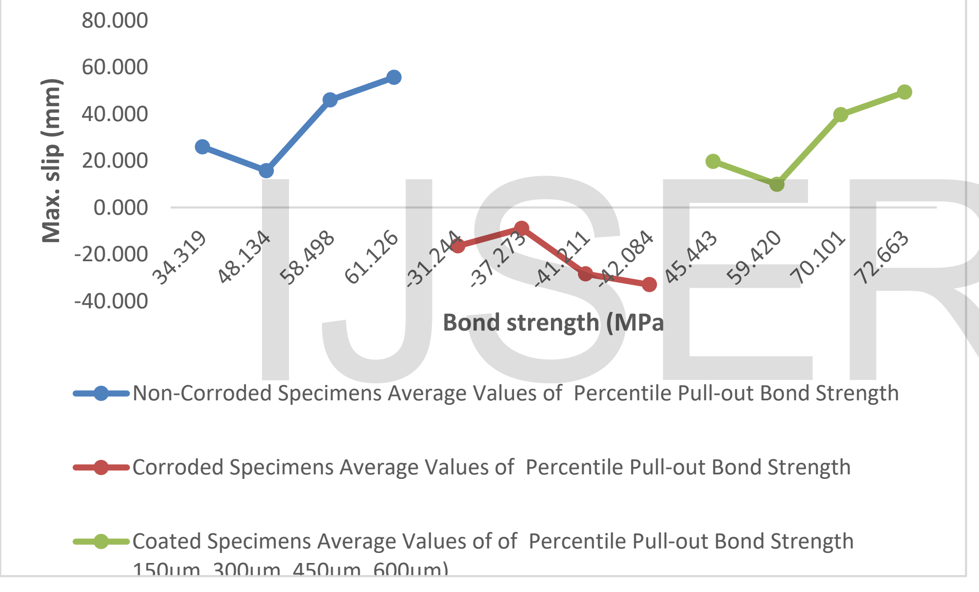

Figure 2b: Average Percentile Bond Strengths versus Maximum Slip

3.3 Mechanical Properties of Reinforcing Bars

The mechanical properties of reinforcing steel embedded in concrete and exposed to highly salinity media are severely affected by corrosion attack resulting in rebar cross-sectional reduction and weight loss thereby causing a low bond between concrete and reinforcing steel. The bond strength is mainly due to the weak chemical bond between the steel and the hardened cement, but this strength is destroyed by low pressure. As soon as slippage occurs, friction aids adhesion. This study introduces the use of chrysophyllum albidum exudates/resins to increase the slip problem in reinforcing steel.

The data presented in tables 3.1, 3.2, and 3.3 and averagely summarized in table 3.4 and substituted in percentile difference in table 3.5, accounting for the behavioral characteristics of mechanical properties of concrete cube samples of the controlled, uncoated (corroded) and coated samples pressured to failure conditions of using Instron Universal Testing Machine after accelerated corrosion of the induced process for 360 days and periodic performance arrangements of samples at 3 months intervals are as shown in the table and plotted in figure 1-6b. The controlled sample yield is a value of 100%, as it is pooled in a suitable freshwater tank (BS 3148 [14])

The summarized results of the minimum and maximum values are obtained from Tables 3.4 and 3.5 are the nominal diameter of the steel bars of all samples was 100%, and the minimum and maximum diameters of steel bars measured before the test were 11.997 mm and 12.00 mm, respectively.

The diameter of the rebar uncoated samples (corroded) after corrosion test are 11.94mm and 11.944mm (-0.58% and - 0.585%), after coated are 12.01mm and 12.015mm (0.583% and 0.589%). The results of cross - sectional area for uncoated (corroded) are 0.049mm and 0.049mm (-8.003% and -6.793%), for coated are 0.053mm and 0.053mm (7.288% and 8.7%). The result for rebar weight before test for all samples are 0.576 Kg and 0.578Kg (0.542% and 0.544%), weight after corrosion test for corroded are for 0.525Kg and 0.527Kg (-18.381% and -18.238%), coated are 0.642Kg and 0.644Kg (22.306% and 22.521%), and weight loss /gain of steel are corroded 0.054Kg and 0.055Kg (-12.687% and -9.409%) and coated values are 0.06Kg and 0.644Kg (10.957% and 18.546%).

The results obtained and presented in the figures showed the effect of corrosion on uncoated and coated reinforcing steel. In figures 3 and 6b, it can be seen from the diameter of the reinforcement that the diameter of the reinforcement of corroded decreases by a maximum of -0.585%, and the coated increases by 0.589%, for the maximum corroded cross-sectional area of -6.793% and the coated increases by 8.7%, weight loss and corrosion gain -9.409% decreased (loss) and coated increased by 18.546% (gain).

Results of the analyzed experimental work showed that the effect of corrosion on uncoated concrete cubes causes a decrease in the cross-sectional diameter and cross-sectional area as well as a decrease in the body/ unit weight, while the cube-coated concrete has a cross-sectional diameter and a cross-section area and weight minute increased, due to differences in the thickness of the reinforcing steel layer as related to the studies of (Charles et al. [2], Terence et al. [9], Toscanini et al. [8])

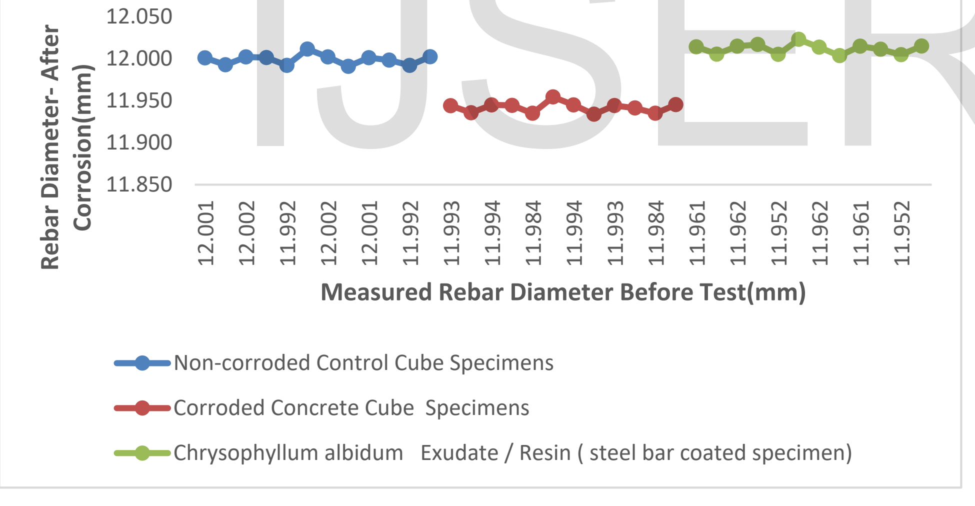

Figure 3: Measured (Rebar Diameter before Test vs Rebar Diameter - after Corrosion)

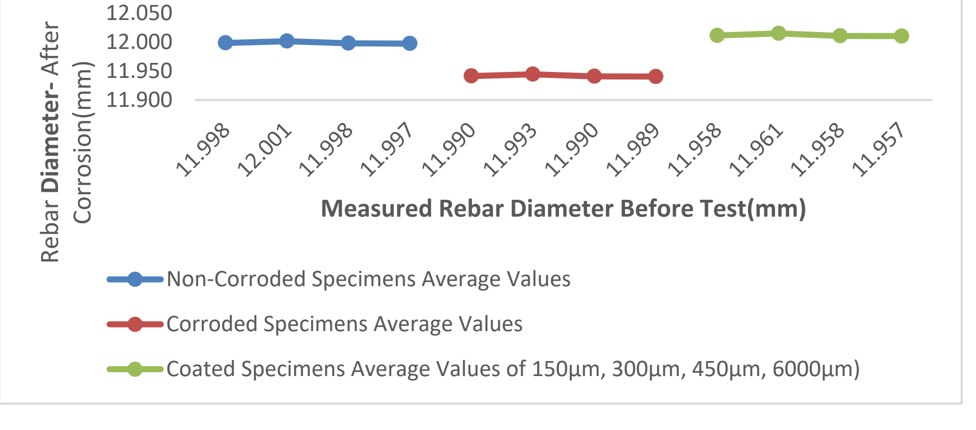

Figure 3a: Average Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

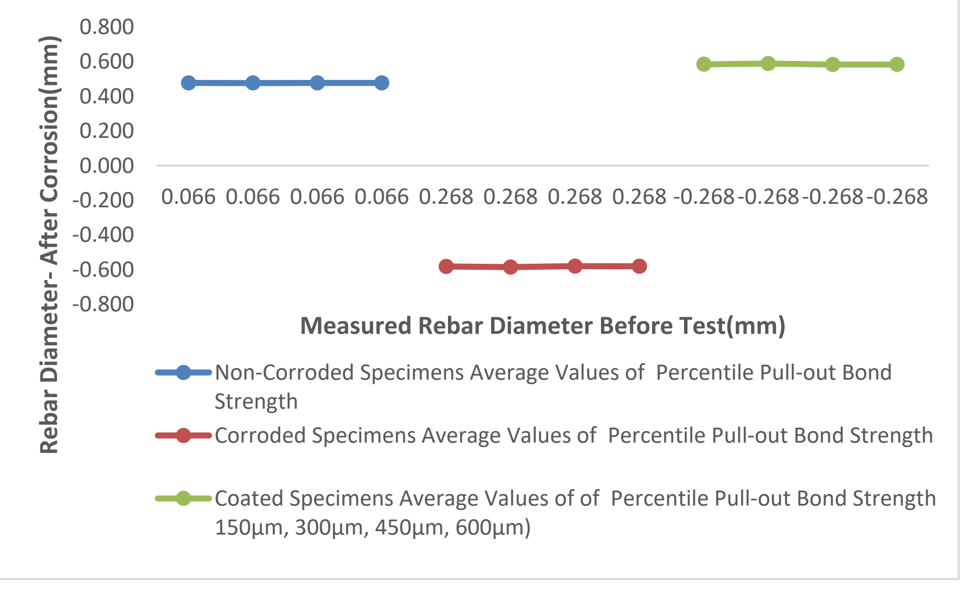

Figure 3b: Average Percentile Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

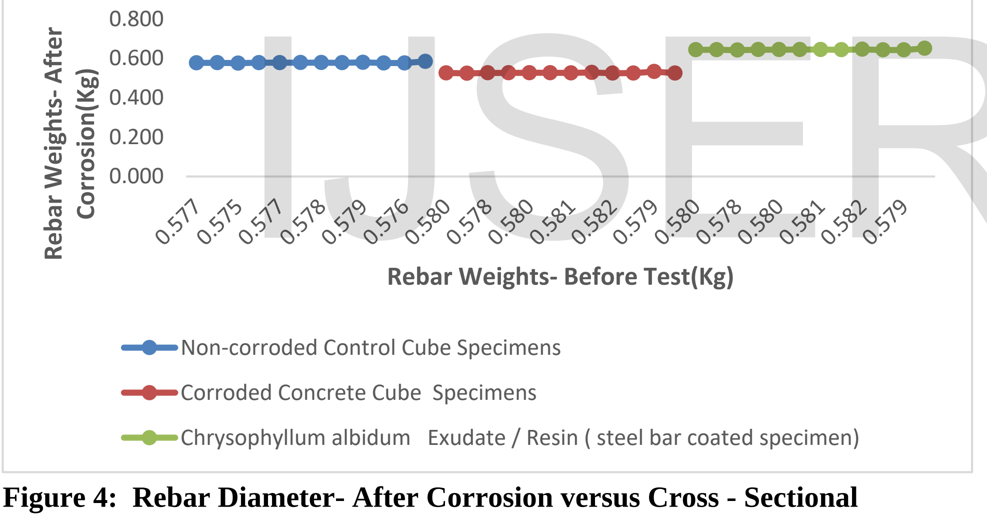

Figure 4: Rebar Diameter- After Corrosion versus Cross - Sectional Area Reduction/Increase

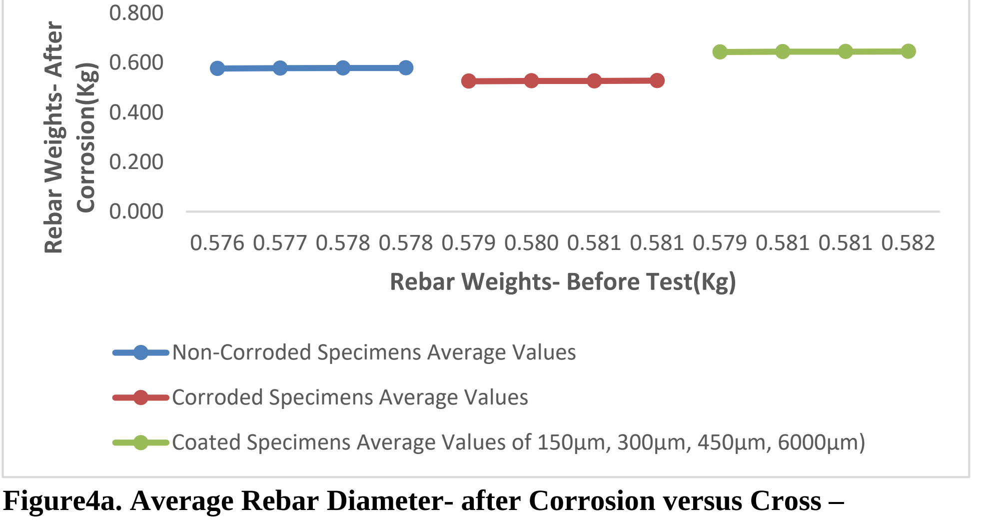

Figure4a. Average Rebar Diameter- after Corrosion versus Cross –

Sectional Area Reduction/Increase

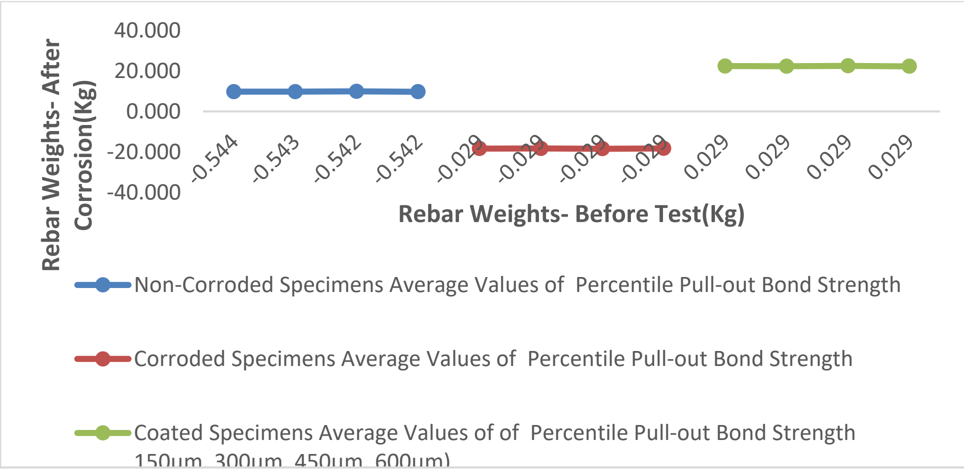

Figure 4b: Average percentile Rebar Diameter- after Corrosion versus Cross –Sectional Area Reduction/Increase

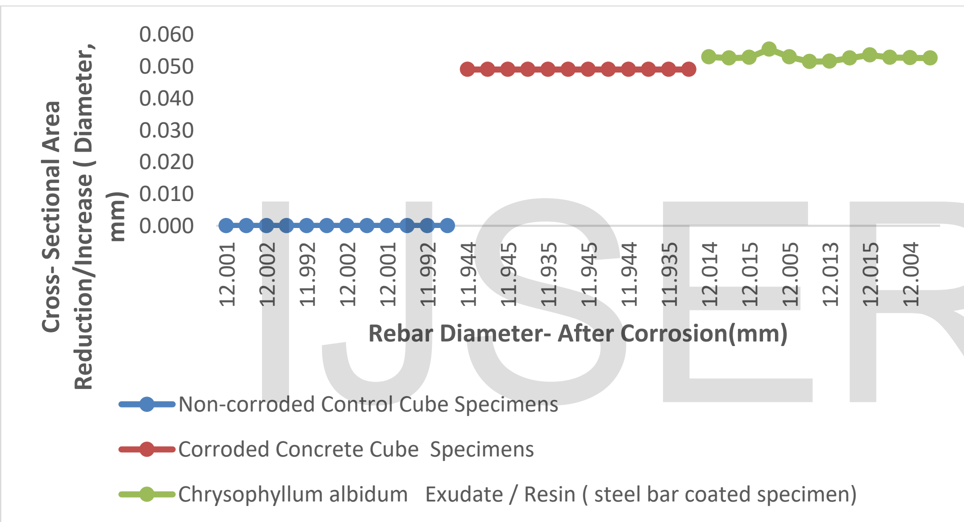

Figure 5: Rebar Weights- before Test versus Rebar Weights- after Corrosion

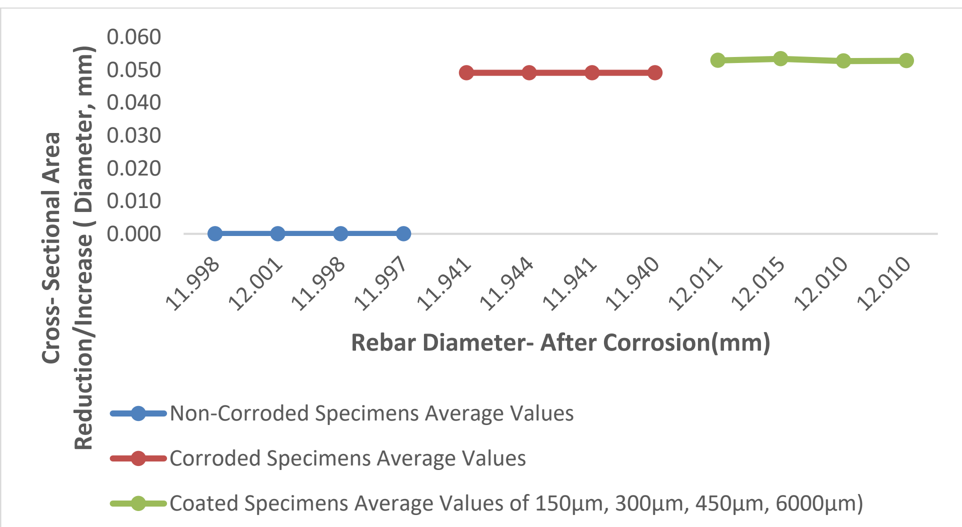

Figure 5a: Average Rebar Weights- before Test versus Rebar Weights - after Corrosion

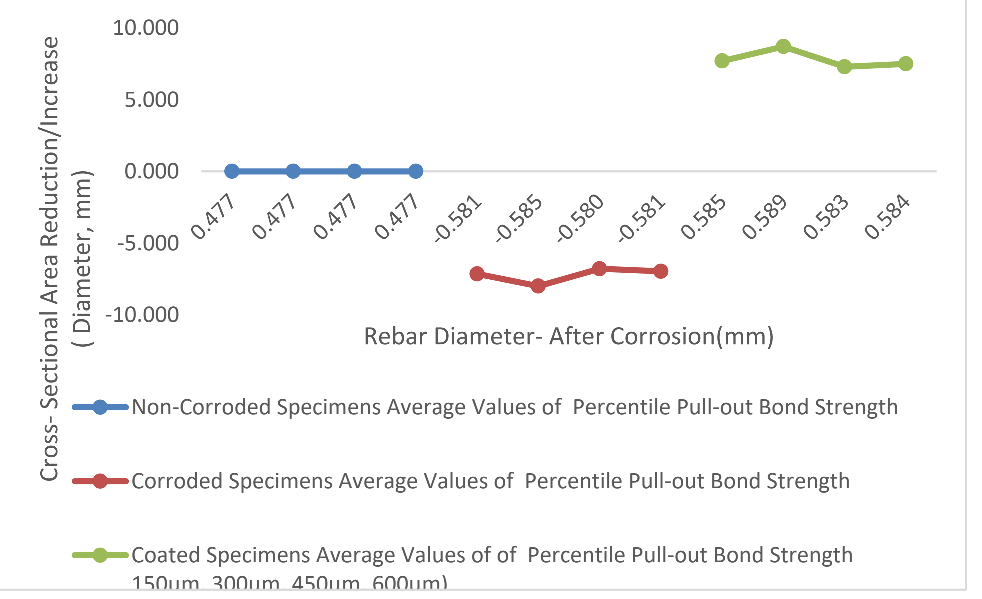

Figure 5b: Average Percentile Rebar Weights- before Test versus Rebar Weights- after Corrosion

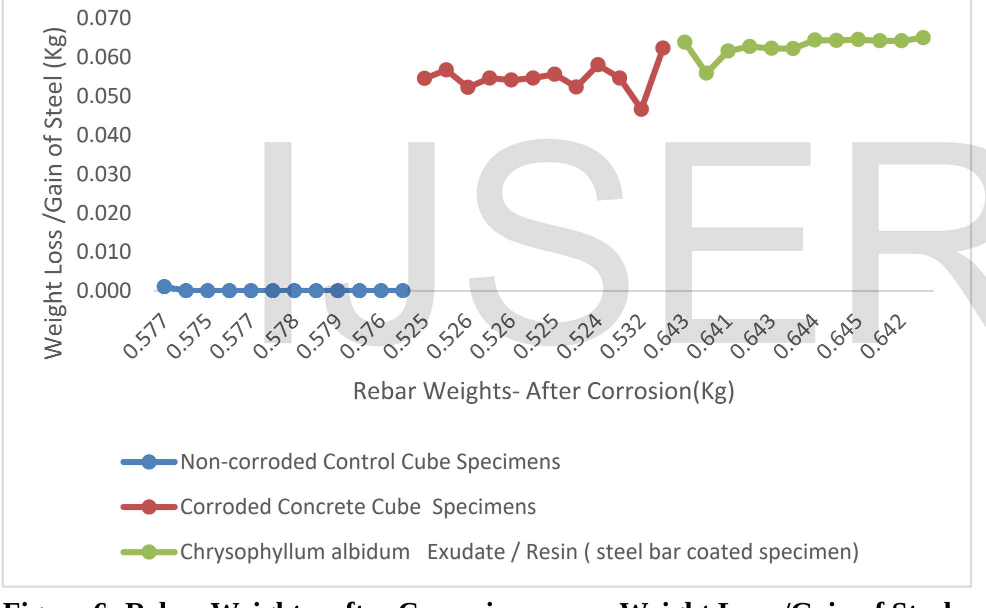

Figure 6: Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

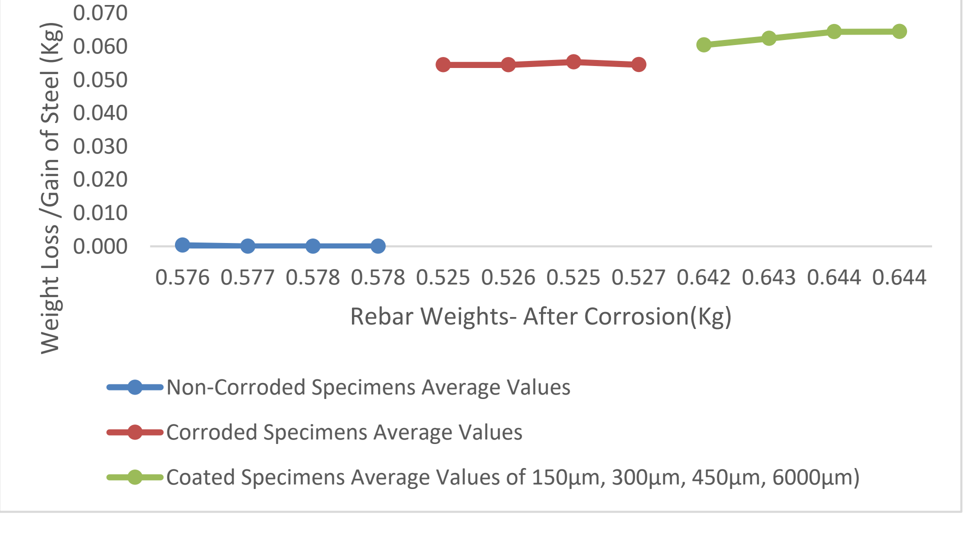

Figure6a. Average Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

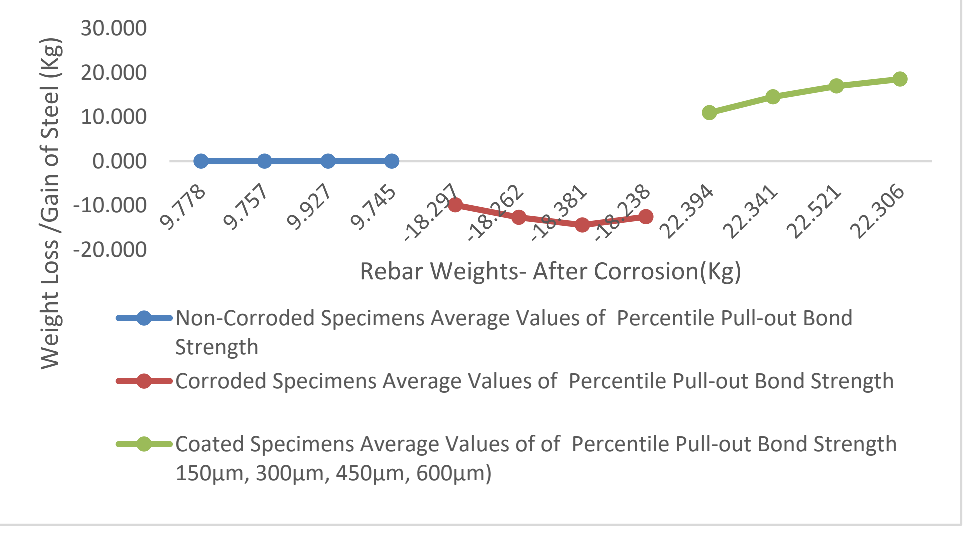

Figure6b. Average percentile Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

3.3 Comparison of Control, Corroded, and Coated Concrete Cube Members

The data in tables 3.1, 3.2, and 3.3 and figures 3, 4.5 and 6 are detailed results for 12 controlled samples immersed in a freshwater tank for 360 days, a second sets of 24 concrete cube samples of 12 uncoated and 12 coated samples in as described in experimental procedures are fully submerged in 5% aqueous sodium chloride (NaCl) solution for 360 days and described in 3.1 - 3.3 and summarized in tables 3.4 - 3.5 and figures 3a, 3b, 4a, 4b, 5a, 5b, 6a and 6b for mean values and percentile of failure bond loads, bond strength and maximum slip, cross-sectional reduction/ increase, the diameter of rebar before /after corrosion, weight loss/gain. Comparatively, the results obtained showed that the failure loads from the controlled and coated samples maintained a closed range of values, whereas the corroded elements produced lower failure loads on stress application, similar factors for bond strength, and maximum slip applied. Regarding the mechanical properties of reinforcing steel, the effect of corrosion on reinforcing steel shows a decrease in the cross-sectional reduction on the diameter of the bar as compared to nominal diameter before the test, weight loss also notices while and coated members possess cross -sectional area increased, diameter increase and weight increase as compared to nominal rebar, these increased resulted from the coating materials varying thicknesses. It can be concluded that the exudate/resin studied has shown effective inhibiting properties against corrosion attack and can be used as a corrosion inhibitor.

4.0 Conclusion

In the experiment, the results obtained were summarized 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 sample
iii. The bonding properties in coated and controlled components are greater than in those that are corroded
iv. The coated and control samples showed higher bond load values and bond strength.

v. Weight loss and area reduction were recorded mainly in the corroded sampled

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