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Corrosion Effect on Bond Strength of Reinforced Concrete Structures Due to Surface Modification

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ABSTRACT

The research work represented high-salt marine media and the possible use of terminalia tomentosa exudate/resin as a barrier to delay the risk of contributing to the reinforced concrete structure exposed or built within this dynamic coastal region with high salinity. The test results obtained from 36 concrete samples as described in the test procedures, 12 controlled concrete samples were placed in freshwater filling for 360 days, and the second sects of 12 non-coated and 12 coated reinforcing steel with exudates/resin samples were all immersed in a 5% solution containing sodium chloride (NaCl) for 360 days and carefully tested for their effectiveness, with a space of three months to test for 90 days, 180 days, 270 days, and 360 days. The average obtained result and the difference in percentile values of failure bond load, bond strength, and maximum slip in comparison showed lower percentage values in all corroded sample on slow load applications indicating the effect on corrosion attach on uncoated samples while controlled and coated concrete cube samples maintained a closed range of values with higher loads application to failure. The same results lower failed loads were noticed in both bond strength and maximum slip samples indicating signs of corrosion effects whereas quite load closeness recorded in controlled and coated samples. Overall results enumerated characterized the poor performance to failure bond load, reduced bond strength, and low slippage in pull bond test as the effect and the presence of corrosion with the reduction in the mechanical properties and surface modification that affected the bonding and the interaction between concrete and reinforcing steel. Results indication from computed experimental work showed that the effect of corrosion on non-coated concrete cubes led to a decrease in diameter and cross-sectional area and a decrease in weight while the diameter and cross-sectional area in coated concrete cubes samples increased, minute weight increases recorded in coated samples were as the result of varying coating thicknesses.

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

1.0 Introduction

The steel reinforcement bonding process and in the concrete ideal affect the load transfer between steel and concrete. This provides secured grip strength of reinforced steel-reinforced concrete, to build a reliable, resistant material with pressures [1]. The strength of the bond mainly comes from the weak chemical bonding between the reinforcement and the hardened concrete, but this resistance is broken at very low pressures. In the obvious case of reinforcing bars, friction is a huge part of the force. The adhesive rotation that tightens the steel bars, and under the extra pressure of the binding depends largely on the binding, or joint tension, between the ribs, rolled over the bar and the surrounding concrete. At this stage, the reinforcing bar produces cracking forces that tend to separate the surrounding concrete. A load of failure can be limited by the resistance provided by these explosive forces with concrete cover and reinforcement. The connection between reinforcement and concrete consists of three different mechanisms: chemical adhesion, friction and mechanical locking [2].

(i) Chemical Adhesion: Adhesion is a chemical bond that forms at the contact surface between steel reinforcement and the surrounding concrete. It can be broken down at very low loads, allowing it to slide between reinforcing steel and concrete.

(ii) Friction: friction, especially between the surface of the steel rail and the concrete. Friction plays an important role between the concrete and the deformed rail (ribs).

(iii) Mechanical interlocking: This shear joint becomes more important as the relative displacement in the composite mechanism increases. The power transmission mechanism is mainly based on mechanical locking between steel reinforcement and concrete. The mechanisms of chemical adhesion and friction are most important with smooth rods. In the case of deformed bars, the mechanical locking of steel reinforcement in concrete is the main mechanism that determines the behavior of the adhesive strength during shear ([3]; [4]).

[5] investigated the strength of the bond between the diameter of the concrete and reinforcement due to the diminishing effect of reinforcing hardened steel from the coastal area of The individual bond strength load is 50.989% versus 96.83% versus -33.74% and the maximum slip percentile average value is 44.55% against the control at -30.82%. Comparative results showed that the values of the depleted samples decreased while the samples were coated with exudates/resins. Overall results showed high values of pull-out bond strength under control and coated exudates/resin for corrugated specimens.

[6[evaluated the effect of corrosion on the bond between steel and concrete interface of exudates /resins reinforcement coated with ficus glumosa. The experimental models were subjected to tensile and pullout bond strength, and the results obtained indicated that the failure load, bond strength, and maximum slip values of the coating failure load, bond strength, and maximum slip those obtained by the control and coating members. Overall the results showed good bonding characteristics and effectiveness in the use of ficus glumosa resins/exudates as protective materials against corrosion.

[7] Explored the core causes of reduced service life, integrity, and the effectiveness of reinforced concrete structures in the marine environment of saline. The results obtained in the comparison show that the failure bond load, bond strength, and maximum slip decreased respectively. The

overall results showed a lower percentage and a higher percentage of corroded members. This justifies the effect of corrosion on the strength of the reduced and coated members.

[8] Investigated the effect of resin/exudates on corrosion prevention for reinforcement in reinforced concrete cubes. Reinforcing steel was coated with varying thickness using dacryodes edulis resin paste: 150um, 250um, and 300um. Reinforced concrete cubes were exposed to corrosive weather for 60 days after 28 days of curing. The obtained results indicated that the failure bond load, bond strength, and maximum slip of reinforced cubes coated with resins were recorded higher than those of corroded.

[9] Evaluated the pull-out bond strength of concrete cube members coated with different applied thicknesses with symphonia globulifera Linn trees exudates/resin, embedded in concrete cubes and exposed to a corrosive environment, with the ability to accelerate corrosion by 60 days. The results obtained showed the presence of corrosion in the uncoated members. Pullout bond strength test results of failure bond load, bond strength, and maximum slip were evaluated and values of corroded members are lower compared to coated members.

[10] Investigated the effect of reinforcement corrosion on the pressure exerted on the pull-out bond separation of control, corroded and resins/exudates paste-coated steel bar, ficus glue, of 150um, 250um and 300um thick from three tree extract of Symphonia globulifera Linn. Uncoated and coated members were embedded in concrete cubes and exposed to the laboratory in a severe/corrosive environment and examined the effects after the initial 30-day curing and 90-day fast-medium acceleration process. Overall results showed that the coating values increased as compared to the corroded specimens, resulting in adhesion properties from the resins/exudates to strengthen the reinforcement.

[11] Studied focused on the relative bond variation of uncoated and coated steel members with three resins tree extracts from dacryodes edulis UBE, moringa oleifera lam and mangifera indica paste of thicknesses 150um, 250um, and 300um, embedded in concrete, and pooled in corrosive media for 60 days. Pullout bond strength results of failure load, bond strength, and maximum slip were examined. Overall results showed lower values in corroded specimens compared to coated specimens, coated members showed higher binding characteristics from dacryodes edulis, moringa oleifera lam and magnifera indica, and the coating acts as a resistance and protective layer against corrosion effects.

[12] studied that the presence of chloride and carbonation contamination in marine zones of the Niger Delta in Nigeria are the primary reasons for poor bonding between steel reinforcement and concrete, leading to premature deterioration in reinforced concrete structures in rough weather. Reinforcing steel bars of 150µm, 300µm, and 450µm thickness were coated and embedded in concrete cubes, cured in a fast corrosive medium, and investigated pull-out bond strength parameters against non-coated ones. Relatively, the results of the corroded specimens decreased while control and cola accuminata exudates/resins increased in steel bar coated samples. Overall results show that natural exudates/resins should be explored as inhibitors for the corrosion effects of steel reinforcement in concrete construction in areas where chloride is expected.

[13] examined the characteristics of bond strength between steel and reinforced concrete structures using corroded and khaya senegalensis inhibited reinforcing steel members, embedded in concrete members, and exposed to corrosive media. The results of the failure bond loads showed a difference of -43.62% and 77.37% and 79.67% for corrosive and coated exudates/resin members, respectively. The reduced average percentage bond strength load ranges from 57.06% to 36.33% and 106.57% in corroded and coated samples. The cohesive strength of corroded and coated specimens showed a greater affinity for coated compared to corroded specimens.

[14] investigated the effect of exudates/adhesives on the corrosion attack on bond strength between steel and concrete. The non-coated and exudates/adhesives were inserted into the concrete cubes and submerged for 178 days for corrosion acceleration assessment. Obtained results showed that the values of the corrosion samples were reduced, but the increase in corrosion whereas exudates / adhesive coating members was indicative of the ability of acacia Senegal exudates/adhesives in reinforcing steel coatings. Overall results showed high values of pull-out bond strength and low failure load in the control and coated over the corroded samples.

[15] Evaluated experimentally the bond strength behavior of non-corroded, corroded, and exudates/resins coated samples using cube dimensions of 150 mm x 150 mm x150 mm, embedded with single reinforcing steel and 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 inhibitors. Exudates/resins coated specimens showed higher resistance to bond strength properties, and higher flexural failure less compared to corroded types.

[16] investigated the effect of corrosion inhibitors on reinforced steel coated and embedded in concrete members and underwent rapid corrosion accelerated process to determine experimentally steel failure bond strength for 150 days. Overall results showed high values of control pull-out bond strength and the exudates/adhesive coated members as against corroded samples.

[17] explored the impact of olibanum exudates/resins in reinforcing steel corrosion in coastal zones under the influence of saltwater on concrete structures. The non-coated and exudates / resin-coated steel were embedded in concrete cubes and pooled in a corrosive medium to evaluate the effects of corrosion. Tests have shown that the values of non-coated samples have deteriorated due to the reduced corrosion attack. Experimental results show that reduced samples have lower bond strength and higher failure bond load and lower maximum slip, while exudates/resins coated samples have lower test samples and higher percentage values compared to corrosive samples.

2.0 Test Program

The application of exudates/resin pastes extracted from plant trunks on steel reinforcement was studied; varying thicknesses were introduced to reinforcing steel of different coating thickness, which then was embedded into concrete cubes.

The corrosion acceleration process was introduced into the environment as the corrosive medium of sodium chloride (NaCl) to determine the potential use of the exudate/resin materials in the control of the changes and effects commonly encountered by reinforcing steel in concrete structures in the coastal marine regions. The test sample refers to the degree of severe acidity, which is termed to be the level of sea salt concentration in the marine environment in reinforced concrete structures. The embedded reinforcement steel is completely submerged and samples for the corrosion acceleration process are maintained in the pooling tank. These models are designed with 36 reinforced concrete cubes of dimensions 150 mm × 150 mm x 150 mm, all restricted, unattached, and coated specimens for the extruded bond test are centrally embedded 12 mm in diameter and immersed in 360 sodium chloride. The days when the initial cube was cured were 28 days. Acid-corrosive media solutions were changed monthly and concrete samples were reviewed for high performance and changes.

2.1 Materials and Methods for Testing

2.1.1 Aggregates

Both (fine and coarse) were purchased. Both met the requirements of [18];

2.1.2 Cement

Portland lime cement grade 42.5 is the most common type of cement in the Nigerian market. It was used for all concrete mixes in this test. It meets cement requirements [19]

2.1.3 Water

The water samples were clean and free from contaminants. Freshwater was obtained from Bori, Civil Engineering Laboratory, Kenule Beeson Saro-Wiwa Polytechnic. Water met [20] Requirements

2.1.4 Structural Steel Reinforcement

Reinforcements are obtained directly from the market at Port Harcourt, [21]

2.1.5 Corrosion Inhibitors (Resins / Exudates) Terminalia tomentosa

The gum exudate / resins were obtained from the tree barks in Amachara Village, in Mpu District, Aninri Local Government Area of Enugu State

2.2 Test Procedures

Corrosion acceleration was tested on high-yielding steel (reinforcement) with a diameter of 12 mm and a length of 650 mm. Coated with 150µm, 300µm, 450µm, and 600µm before corrosion testing. The test cubes were 150 mm x 150 mm x 150 mm and cast into a metal mold and removed after 72 hours. Samples were treated at room temperature in tanks 28 days before the initial treatment period, after which a rapid accelerated corrosion test and a test regime allowed 360 days monthly routine monitoring. Cubes for corrosion-acceleration samples were taken at 90-day, 180-day, 270-day, and 360-day intervals of approximately 3 months, and explored for failure bond loads, bond strength, maximum slip, cross-sectional area reduction/increase, and weight loss/steel reinforcement.

2.3 Accelerated Corrosion Set-Up and Test Method

In real and natural phenomena, the manifestation of corrosion effects on reinforcement embedded in concrete members is very slow and can take many years to achieve; But the laboratory-accelerated process will take less time to accelerate marine media. To test the surface and mechanical properties of modifiers and effects, test both non-coating and exudate/resin coated specimens and immerse them in 5% NaCl solution for 360 days.

2.4 Pull out-Bond Strength Test

The tensile-bond strength test of concrete cubes was carried out on a total of 36 samples with control, non-coated, and coated members in each of the 12 specimens, and subjected to a 50 kN universal test machine according to [22]. Total numbers of 36 cubes measuring 150 mm × 150 mm × 150 mm embedded in the center of a concrete cube with a diameter of 12 mm.

2.5 Tensile Strength of Reinforcement Bars

To determine the yield and tensile strength of the bar, 12 mm diameter restricted, unattached, and coated steel reinforcement was tested under pressure at the Universal Test Machine (UTM) and subjected to direct pressure until the failure load was recorded. To ensure stability, the remaining cut pieces were used in subsequent bond testing and failure bond loads, bond strength, maximum slip, reduction/increase of cross-section area, and weight loss/steel reinforcement.

3.1 Experimental Results and Discussion

The main assumption in reinforced concrete structures is that there is a perfect bond between the reinforcement and the surrounding concrete to deal with the difficulties caused by corrosion attacks. Full relationships do not exist and this further undermines the effectiveness of the relationship due to the initial deterioration of this assumption, the effects of which are not fully understood. Reinforced concrete structures deteriorate during their lifetime. This is especially evident in structures immersed in uneven surfaces that lead to the corrosion of reinforcing steel. Concrete protection, improved concrete structures, and additional concrete coverings increase concrete protection from reinforcement. Based on this new method, the introduction of exudate/resin extracts has been introduced to enhance the bonding properties between concrete and steel and thus act as anti-corrosion agents to prevent the corrosion-reinforcing effect of metal exposed to media distribution.

The test data as presented in Tables 3.1, 3.2, and 3.3, summarized in Tables 3.4 and 3.5 were the results obtained from 36 concrete samples as described in the test procedures, 12 controlled concrete samples were placed in freshwater filling (BS 3148) requirements for 360 days, and the second sects of 12 non-coated and 12 coated reinforcing steel with exudates/resin samples were all immersed in a 5% solution containing sodium chloride (NaCl) for 360 days and carefully tested for their effectiveness, with a space of three months to test for 90 days, 180 days, 270 days, and 360 days. Indeed, the manifestation of corrosion is a long-term process that takes decades to fully function, but the introduction of sodium chloride causes the appearance of corrosion in the short term. The exploration work represented high-salt marine media and the possible use of terminalia tomentosa exudate/resin as a barrier to decay and the risk of contributing to the reinforced concrete structure exposed or built within this dynamic coastal region with high salinity.

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

Sample Numbers	TTC	TTC1	TTC2	TTC3	TTC4	TTC5	TTC6	TTC7	TTC8	TTC9	TTC10	TTC11
	Time Interval after 28 days curing											
Sampling and Durations	**Samples 1 (28 days)**			**Samples 2 (28 Days)**			**Samples 3 (28 Days)**			**Samples 4 (28 Days)**		
Failure Bond Loads (kN)	28.160	26.070	26.634	27.231	28.046	27.747	28.270	28.088	28.152	29.963	29.088	29.289
Bond strength (MPa)	9.262	10.155	8.652	9.583	9.956	10.879	10.972	10.302	10.337	11.042	10.354	10.900
Max. slip (mm)	0.105	0.108	0.109	0.118	0.109	0.112	0.111	0.101	0.107	0.108	0.109	0.100
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)	11.984	11.994	11.984	11.984	11.984	11.994	11.983	11.995	11.994	11.995	11.993	11.985
Rebar Diameter - at 28 Days Nominal(mm)	11.984	11.994	11.984	11.984	11.984	11.994	11.983	11.995	11.994	11.995	11.993	11.985
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)	0.576	0.576	0.574	0.577	0.577	0.576	0.577	0.576	0.577	0.577	0.575	0.583
Rebar Weights- at 28 Days Nominal(Kg)	0.576	0.576	0.574	0.577	0.577	0.576	0.577	0.576	0.577	0.577	0.575	0.583
Weight Loss /Gain of Steel (Kg)	0.000	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)	17.276	16.588	16.878	16.321	15.569	16.436	16.015	16.323	16.021	17.256	16.135	16.869
Bond strength (MPa)	7.861	7.871	7.636	7.858	7.624	7.597	7.395	8.084	7.059	7.547	7.395	7.707
Max. slip (mm)	0.079	0.082	0.083	0.092	0.082	0.086	0.085	0.075	0.081	0.082	0.083	0.074
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)	11.995	11.991	11.984	11.984	11.994	11.985	11.984	11.991	11.983	11.994	11.984	11.985
Rebar Diameter- After Corrosion(mm)	11.948	11.944	11.938	11.937	11.948	11.938	11.938	11.944	11.937	11.948	11.938	11.938
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047

Rebar Weights- Before Test(Kg)	0.578	0.576	0.574	0.577	0.578	0.577	0.577	0.576	0.583	0.575	0.575	0.578
Rebar Weights- After Corrosion(Kg)	0.539	0.536	0.534	0.537	0.539	0.537	0.537	0.536	0.543	0.535	0.535	0.539
Weight Loss /Gain of Steel (Kg)	0.040	0.039	0.040	0.046	0.040	0.040	0.039	0.040	0.035	0.041	0.040	0.038

Table 3.3: Results of Pull-out Bond Strength Test (τu) (MPa) of Terminalia tomentosa Exudate / Resin (Steel Bar Coated Specimen)

Sampling 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)	31.965	29.876	30.440	31.036	31.851	31.552	32.076	31.893	31.958	33.769	32.893	33.095
Bond strength (MPa)	13.068	13.960	12.458	13.388	13.761	14.684	14.778	14.108	14.142	14.848	14.159	14.706
Max. slip (mm)	0.118	0.121	0.122	0.131	0.121	0.125	0.124	0.114	0.120	0.121	0.122	0.113
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)	11.984	11.994	11.994	11.984	11.984	11.984	11.994	11.993	11.983	11.994	11.993	11.991
Rebar Diameter- After Corrosion(mm)	12.042	12.053	12.053	12.042	12.042	12.042	12.053	12.052	12.042	12.053	12.052	12.025
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.035
Rebar Weights- Before Test(Kg)	0.576	0.577	0.574	0.577	0.577	0.576	0.577	0.576	0.575	0.583	0.575	0.575
Rebar Weights- After Corrosion(Kg)	0.634	0.635	0.632	0.635	0.635	0.634	0.635	0.634	0.633	0.641	0.633	0.633
Weight Loss /Gain of Steel (Kg)	0.059	0.058	0.058	0.059	0.052	0.059	0.058	0.057	0.057	0.641	0.057	0.058

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)	26.955	26.645	27.304	27.674	16.914	16.596	16.256	16.108	30.760	30.451	31.109	31.480
Bond strength (MPa)	9.356	9.463	9.397	10.139	7.789	7.788	7.706	7.693	13.162	13.269	13.202	13.945
Max. slip (mm)	0.107	0.112	0.112	0.113	0.081	0.085	0.086	0.087	0.120	0.125	0.125	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)	11.987	11.987	11.984	11.987	11.990	11.986	11.987	11.987	11.991	11.991	11.987	11.984
Rebar Diameter- After	11.987	11.987	11.984	11.987	11.943	11.940	11.941	11.941	12.049	12.049	12.046	12.042

Corrosion(mm)												
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.047	0.047	0.047	0.047	0.059	0.059	0.059	0.059
Rebar Weights- Before Test(Kg)	0.575	0.576	0.576	0.576	0.576	0.576	0.576	0.577	0.576	0.576	0.576	0.577
Rebar Weights- After Corrosion(Kg)	0.575	0.576	0.576	0.576	0.536	0.536	0.537	0.538	0.634	0.634	0.634	0.635
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.039	0.042	0.042	0.042	0.059	0.058	0.056	0.057

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)	59.364	60.555	67.963	71.802	- 45.014	- 45.500	- 47.746	- 48.830	81.863	83.486	91.373	95.427
Bond strength (MPa)	20.119	21.507	21.943	31.793	- 40.819	- 41.304	- 41.632	- 44.830	68.974	70.369	71.327	81.259
Max. slip (mm)	32.443	30.798	30.750	30.395	- 32.579	- 31.446	- 31.413	- 31.163	48.322	45.871	45.800	45.271
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)	0.028	0.033	0.028	0.031	0.033	0.038	0.031	0.032	0.032	0.038	0.031	0.032
Rebar Diameter- After Corrosion(mm)	0.370	0.400	0.362	0.388	-0.879	-0.910	-0.871	-0.841	0.887	0.918	0.879	0.848
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	- 20.649	- 20.649	- 20.649	- 20.649	26.022	26.022	26.022	26.022
Rebar Weights- Before Test(Kg)	0.112	0.117	0.116	0.115	0.116	0.112	0.116	0.119	0.109	0.113	0.116	0.112
Rebar Weights- After Corrosion(Kg)	7.269	7.416	7.284	7.207	- 15.364	- 15.483	- 15.382	- 15.318	18.153	18.320	18.179	18.089
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	- 32.845	- 28.920	- 25.775	- 26.254	48.909	40.687	34.725	35.601

3.2 Failure load, Bond Strength, and Maximum slip

Bond refers to the interaction between reinforcing steel and the surrounding concrete, which allows tensile stresses from the steel to be transferred to the concrete. This is the mechanism that allows the anchoring of straight reinforcing bars and affects many other important features of structural concrete such as crack control and section stiffness [23]. If the bond between the concrete and the reinforcement is affected by corrosion, the full union will not exist and the performance of the reinforced concrete structure will deteriorate, giving rise to a weak transfer of stress. This effect of corrosion needs to be strengthened with the introduction of inhibitory materials to prevent crises and hazards for structures exposed to the coastal zone with high salinity levels.

The results of the failure bond load, bond strength, and maximum slip carried out on 36 concrete cubes presented in Table 3.1, 3.2, and 3.3 are the overall experimental data, averaged in 3.4 and percentile computed in 3.5 and illustrated in figures 1–6b. The obtained results are for 12 samples of controlled, 12 corroded and 12 coated tested to failures using Instron Universal Testing Machines with 50kN as described in the test procedure.

The minimum and maximum calculated average and percentile derivative results of failure bond load are controlled are 26.645kN and 27.674kN (59.364% and 71.802%), 16.108kN and 16.914kN (-48.83% and -45.014%), coated 30.451kN and 31.48kN (61.73% and 95.728%). Bond strength values for controlled are 9.356MPa and 10.139MPa (20.119% and 31.793%), 7.693MPa and 7.789MPa (-44.83% and -40.819%), coated 13.162MPa and 13.945MPa (68.974% and 81.259%). Maximum slip results are controlled mm and 0.107 mm and 0.113 mm (30.395% and 32.443%), 0.081 mm and 0.087 mm (-32.579% and-31.163%), coated 0.12 mm and 0.126 mm (45.271% and 48.322%) . Comparative results as shown in table 3.5 of percentile differences are controlled 71.802% against corroded -45.014% and the coated 95.728%, the bond strength maximum percentile values differences are 31.793% against corroded -40.819% and coated 81.259% and finally, peak obtained maximum differential values are controlled 32.443% against -31.163% and coated 48.322%.

The average values obtained from Tables 3.1, 3.2, and 3.3 disintegrated from the result presented in Table 3.4, and the difference in percentile values from 3.5, failure bond load, bond strength, and Maximum slip in comparison showed lower percentage values in all corroded sample on slow load applications indicating the effect on corrosion attach on uncoated samples while controlled and coated concrete cube samples maintained a closed range of values with higher loads application to failure. The same results lower failed loads were noticed in both bond strength and maximum slip samples indicating signs of corrosion effects whereas quite load closeness recorded in controlled and coated samples as related in the works of ([11];[10];[14][17]). Overall results enumerated characterized the poor performance to failure bond load, reduced bond strength, and low slippage in pull bond test as the effect and the presence of corrosion with the reduction in the mechanical properties and surface modification that affected the bonding and the interaction between concrete and reinforcing steel.

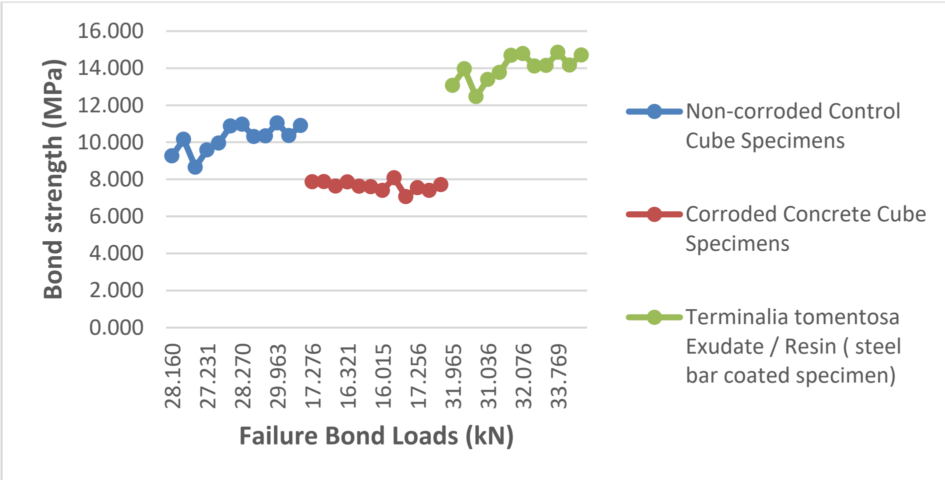

Figure 1. Failure Bond loads versus Bond Strengths

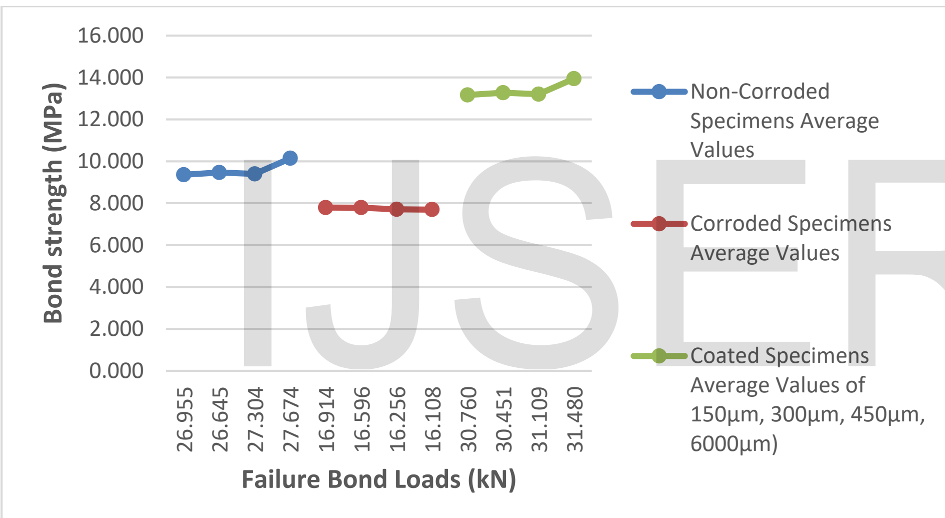

Figure 1a. Average Failure Bond loads versus Bond Strengths

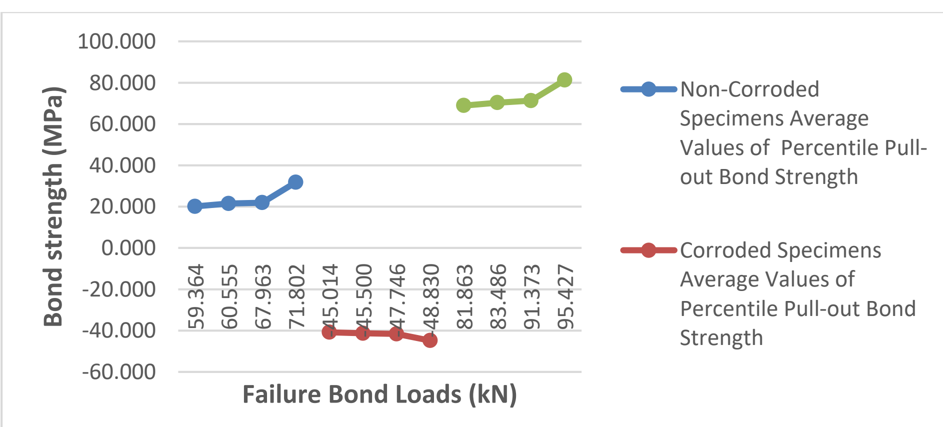

Figure 1b. Average Percentile Failure Bond loads versus Bond Strengths

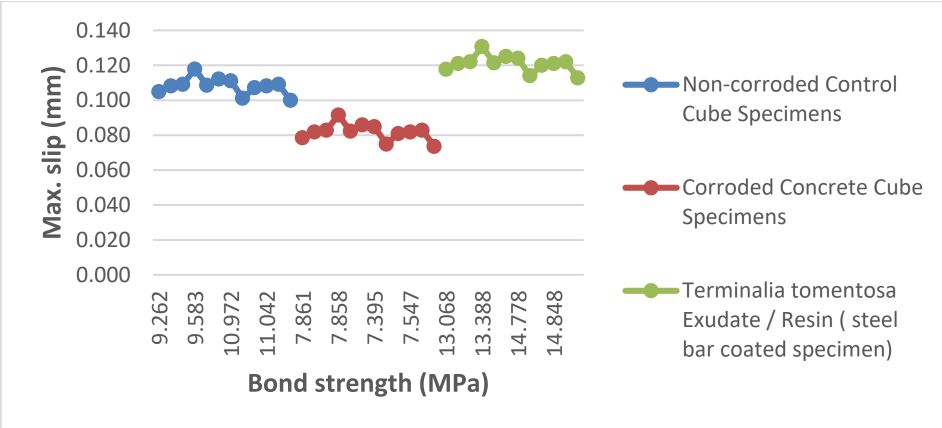

Figure 2. Bond Strengths versus Maximum Slip

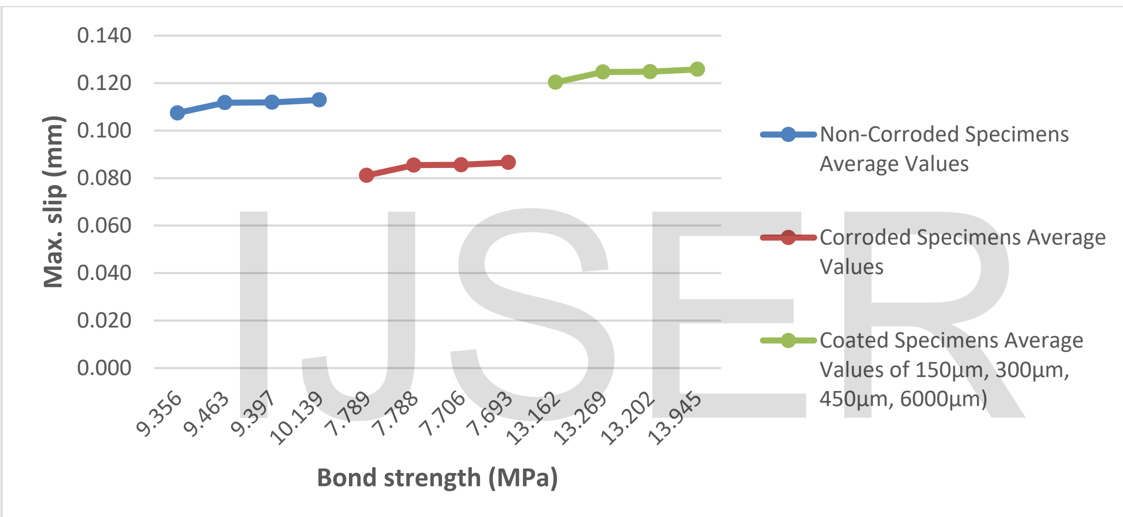

Figure 2a. Average Bond Strengths versus Maximum Slip

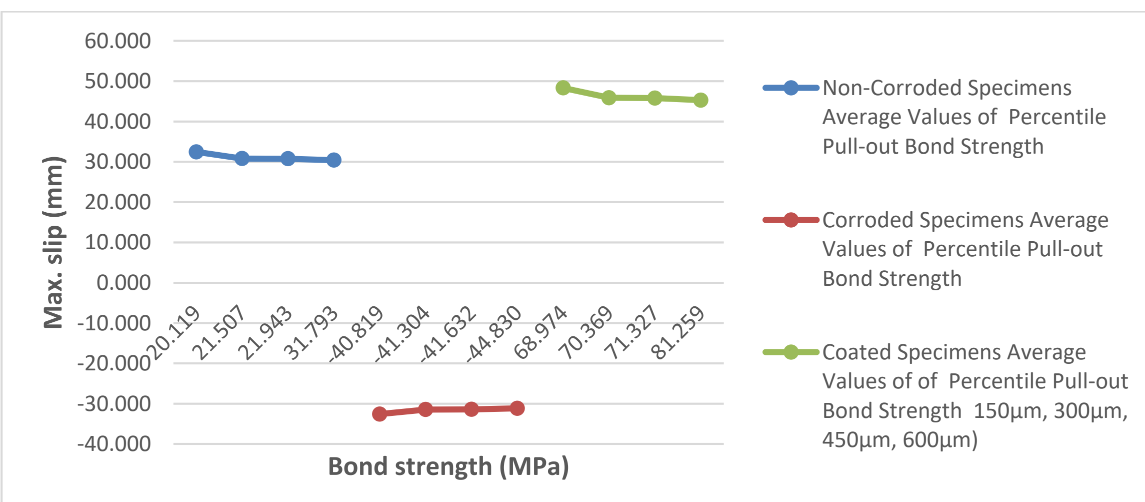

Figure 2b. Average Percentile Bond Strengths versus Maximum Slip

3.3 Mechanical Properties of Reinforcing Bars

When corrosion of reinforcing steel occurs in concrete, there is a possibility of breakage of the concrete section, cracking, reduction in the cross-sectional area of the reinforcing steel, and a decrease in the bond strength between the steel and the surrounding concrete. These problems ultimately affect the integrity and service life of the structure and should be avoided. The bond strength is mainly derived from the weak chemical bond between steel and hardened cement, but this strength is dissipated under a small pressure. In smooth steel bars, friction is an important part of strength. Reinforcing steel bars with ribs under increased sliding connections mainly depends on the bearing or mechanical interlocking between the ribs on the surface and the surrounding concrete. This research pioneered the application of exudates/resin to exacerbate the slippery problem faced by smooth reinforcing steel.

The data presented in Table 3.1, 3.2, and 3.3 and summarized in Table 3.4 and further summarized in 3.5, are controlled, non-coated, and coated samples under the condition of failure in Instron Universal Testing Machine on a 50kN load and accessed their mechanical properties, and behavioral performance under freshwater and corrosive media immersion and describe in the test procedures for 360 days on an interval and routine checks for 90 days, 180 days, 270 days and 360 days respectively.

The data from tables 3.1, 3.2, and 3.3 are summarized in tables 3. 4 and 3.5 into average and percentile the minimum and maximum values and graphically represented in figures 3-6b.

The steel bars with a nominal diameter of all specimens are 100%, and the minimum and maximum diameters of the steel bars measured prior to testing are within the range of 11.94 mm and 11.94 mm (0.024% and 0.033%). The diameter of rebar uncoated specimens (corroded) after corrosion test are 11.94mm and 11.943mm (-0.91% and -0.841%), after coated are 12.042mm and 12.049mm (0.848% and 0.918%). The cross-sectional area results for uncoated (corroded) are 0.047 mm and 0.047 mm (-20.649% and -20.649%), 0.059 mm and 0.059 mm (26.022% and 26.022%) for coated.

The rebar weight results before testing for all samples are 0.575 kg and 0.576 kg (0.112% and 0.117%), after the corrosion test the weights are 0.536 kg and 0.538 kg (-15.483% and -15.318%), coated 0.634 kg and 0.635 kg (18.089% and 18.32%), and steel weight loss / gain 0.039 kg and 0.042 kg (-32.845% and -25.775%) and coated values are 0.056 kg and 0.059 kg (34.725% and 48.909%).

From the results obtained and presented in the figures, the effect of corrosion on the uncoated and coated reinforcing steel is calculated, in figures 3 and 6b on the diameter of the rebar, it can be seen that the maximum value of the uncoated diameter is - 0.841 %. For the cross-sectional area of coated samples increased by 0.918%, the maximum reduction value of corroded is -20.649% and coated increased by 26.022%. For the weight loss and gain, corroded samples reduced (loss) by -25.775%, and coated samples increase by 48.909%. Results indication from computed experimental work showed that the effect of corrosion on non-coated concrete cubes led to a decrease in diameter and cross-sectional area and a decrease in weight while the diameter and cross-sectional area in coated concrete cubes samples increased, minute weight increases recorded in coated samples were as the result of varying coating thicknesses as related to ([11];[10]; [14][17]). Overall results concluded that the exudate/resin served as an inhibitory and resistive material to corrosion attacks.

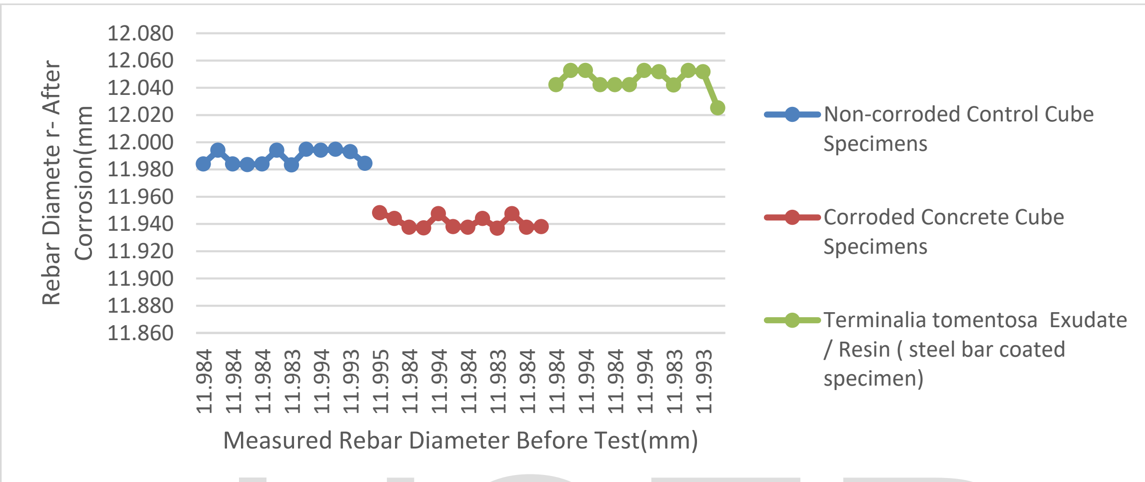

Figure 3. Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

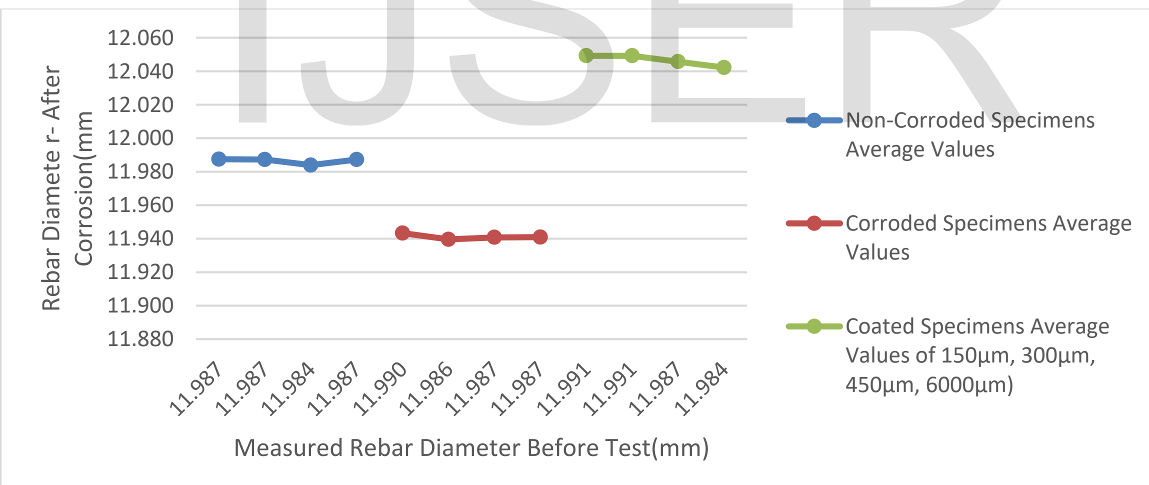

Figure 3a. Average Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion

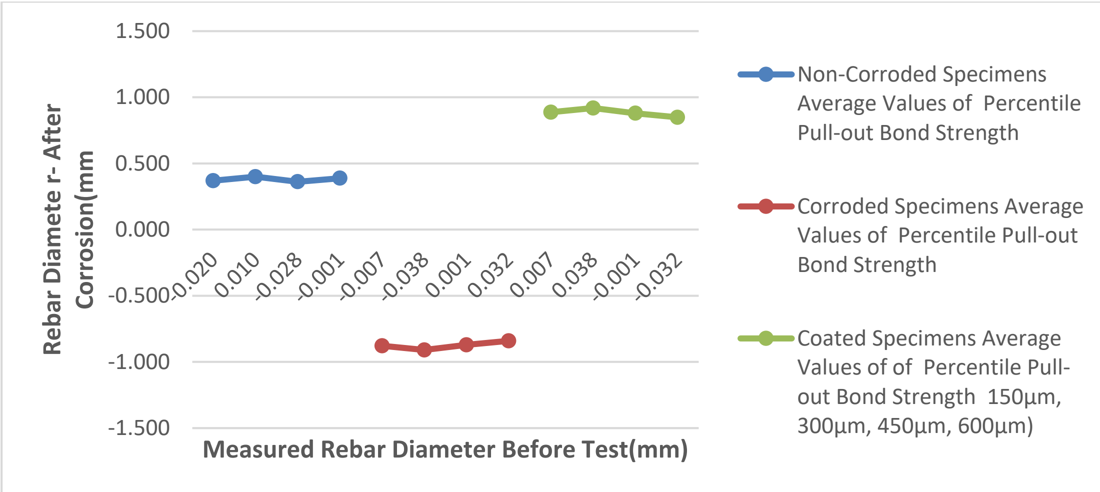

Figure 3b. Average Percentile Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion

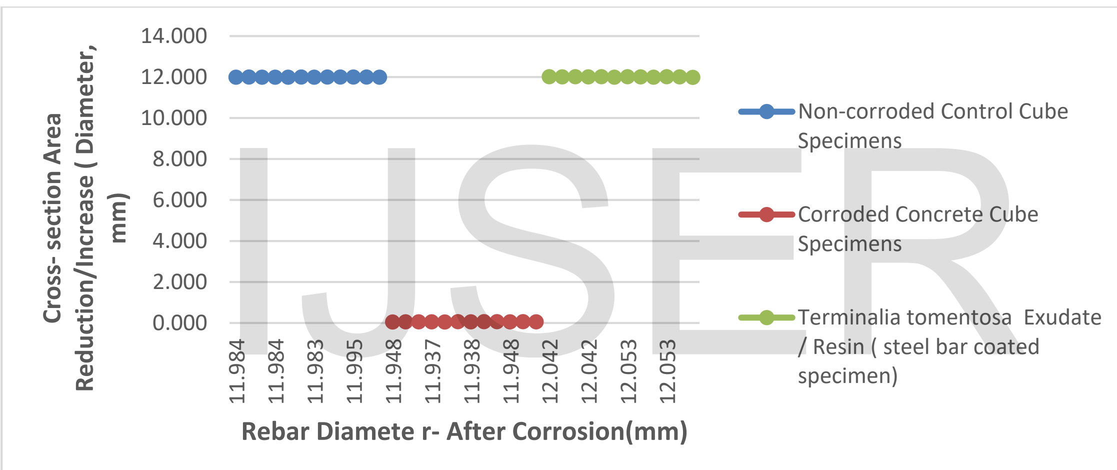

Figure 4. Rebar Diameter- After Corrosion versus Cross - Sectional Area Reduction/Increase

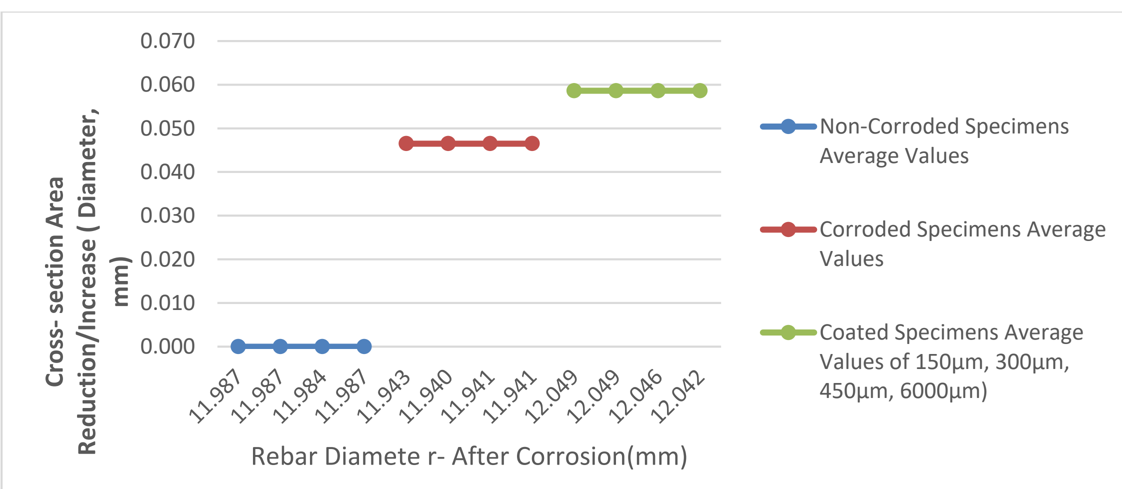

Figure 4a. Average Rebar Diameter- after Corrosion versus Cross – Sectional Area

Reduction/Increase

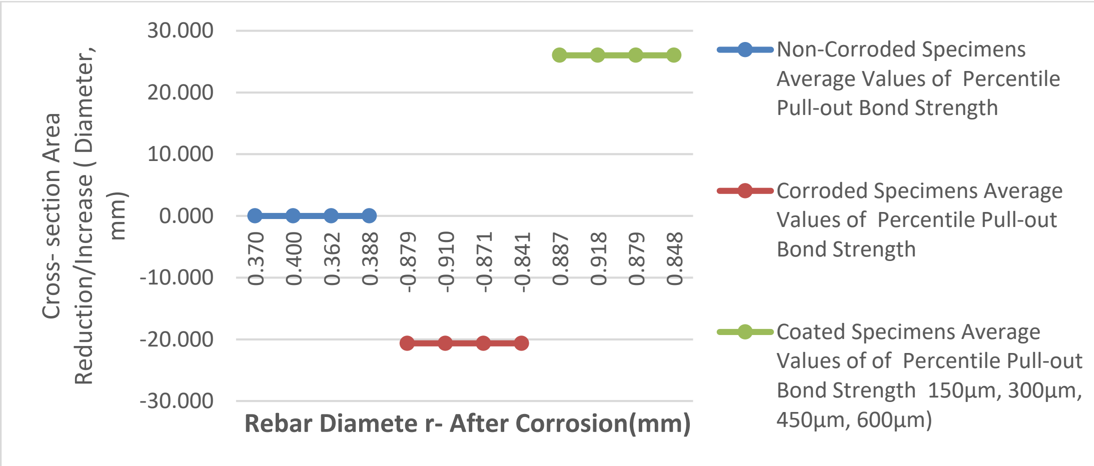

Figure 4b. Average percentile Rebar Diameter- after Corrosion versus Cross - sectional Area Reduction/Increase

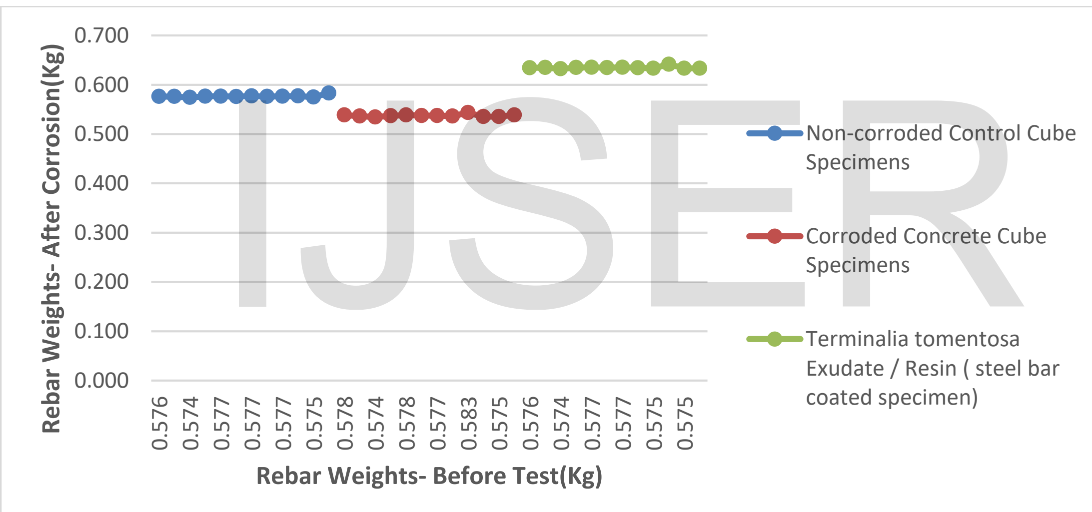

Figure 5. Rebar Weights- before Test versus Rebar Weights- after Corrosion

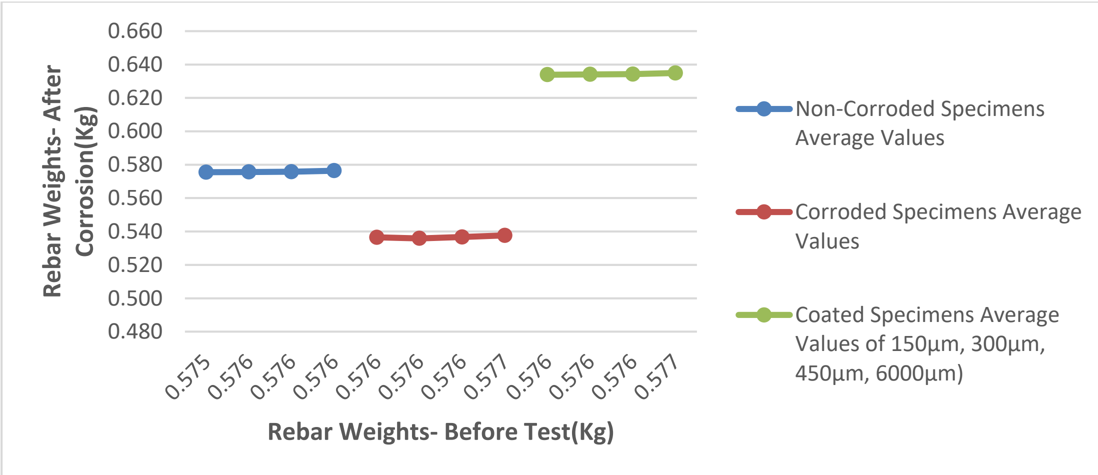

Figure 5a. Average Rebar Weights- before Test versus Rebar Weights- after Corrosion

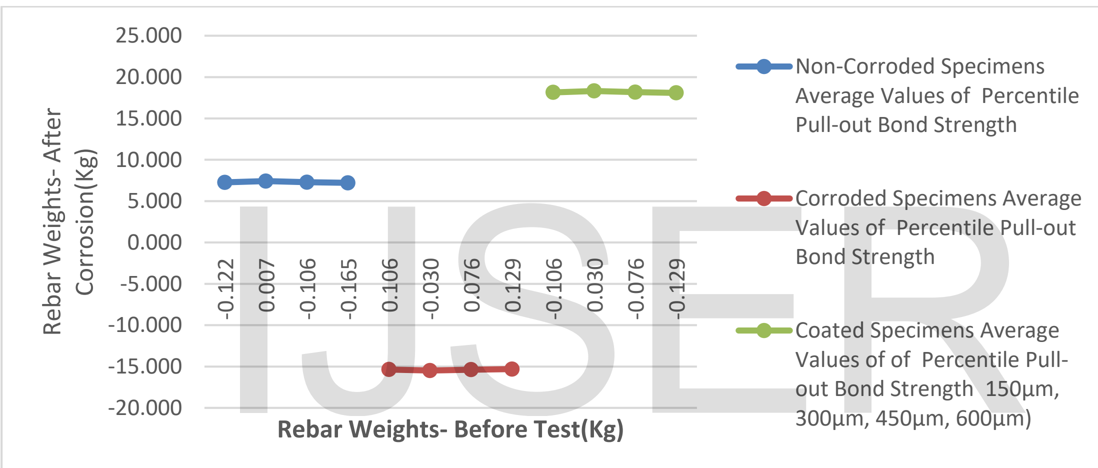

Figure 5b. Average Percentile Rebar Weights- before Test versus Rebar Weights- after Corrosion

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

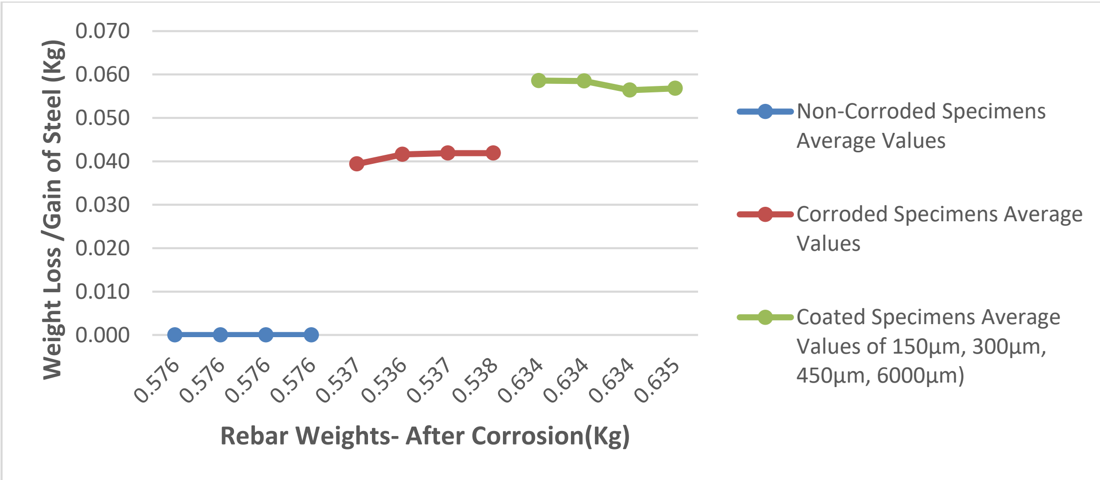

Figure 6a. Average Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

Figure 6a. 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 1 - 6 for 12 controlled samples pooled in a freshwater tank for 360 days whereas second sects of 25 concrete cubes of 12 uncoated samples and 12 coated samples immersed in 5% aqueous sodium chloride (NaCl) solution for 360 days as described in the test procedures in 3.1 - 3.3 and summarized in tables 3.4 - 3.5 and figures 1 - 6b for average and percentage values of failure bond loads, bond strength and maximum slip, reduction/increase of rebar cross-sectional area, the diameter of reinforcement before/after corrosion, weight loss/weight gain. The results obtained for comparison showed that the failure bond load for controlled and coated samples maintained a narrow range of values, whereas the corroded samples for failure bond load, bond strength, and maximum slip possessed lower strength failure resulting from the effect of corrosion. Regarding the mechanical properties of reinforcing steel, the effect of corrosion on reinforcing steel shows a decrease in the cross-sectional area of the rebar diameter compared to the nominal diameter before testing, weight reduction is also observed.

The overall results are characterized by poor bond loading performance, reduced bond strength, and low slip in the bond tensile test as an effect and the presence of corrosion with reduced mechanical properties and surface modifications affected bonding and interactions between concrete and reinforcing steel ([11];[10]; [14][17]). 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 concluded as follows:

i. The exudate/resin has an inhibitory effect against corrosion, 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 slightest damage to the connection, the maximum connection strength and slip is recorded in the corroded elements.
v. The coating and control samples recorded higher values for bond load and bond strength.
vi. Weight loss and area reduction were recorded mainly in the corroded layers and in controlled samples

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