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Chloride Corrosion of Steel Weight Loss Mechanism on Bond-Slip Strength Measurement

Charles Kennedy[1], Ugo Kingsley[2], Overo Kenneth Ejukonemu[3]

[3]Faculty of Engineering, Department of Civil Engineering, Rivers State University,

[2]School of Applied Sciences, Kenule Beeson Saro-Wiwa Polytechnics, Bori Rivers State, Nigeria

[3]Faculty of Engineering, Department of Civil Engineering, Niger Delta University,Wilberforce Island, Bayelsa State

Author's E-mail: [1]ken_charl@yahoo.co.uk, [2]ugok1960c@gmail.com, [3]kennethovero@gmail.com,

ABSTRACT

This study investigated the bond-slip mechanism of corroded and coated reinforcing steel with the application of gongronema latifolium exudates/resin extract as an inhibitory material in curbing the scourge and menace of corrosion effect on reinforced concrete structure built within severe and harsh region. The results summarized for the difference in percentile values comparatively are the maximum controlled value is 95.427% against corroded -45.014% and coated 91.689%. Results of failure bond load showed lower failure load application on corroded samples as compared to controlled and coated samples with higher load to failure which also showed closed value ranges. Obtained maximum bond strength from controlled samples is 72.719% as against corrode -40.819% and coated 81.259% samples. The comparative results showed the pullout bond strength of corroded failed on lower load applications as compared to controlled and coated samples with both having closed value ranges and failed on higher load application with coated recording the highest. The maximum recorded values of maximum slip of controlled samples are 29.187% against corroded -48.518% and coated 109.636%. In comparison, corroded samples failed at lower load application while controlled and coated failed at higher load application. In Figures 3 to 6b, it can be seen from the diameter of the reinforcement that the diameter of the reinforcement without corroded decreases by a maximum value of -0.872% and the coated increase by 0.88%, for the maximum corroded cross-sectional area the reduction value is -16.626% and the coated increase by 20.042%, weight loss and gain, corroded samples value is - 18.848% which showed decrease value of weight loss while coated value is 20.042% indicating increase increased value of weight gain. Indications from experimental work showed that the effect of corrosion on an uncoated concrete cube causes a decrease in the cross-sectional diameter and cross-sectional area as well as a decrease in weight, while the cube-coated concrete has a cross-sectional diameter and a cross-sectional area increased and weight, due to differences in the thickness of the reinforcing steel layers.

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

1.0 INTRODUCTION

The process of bonding at the steel and concrete interface affects the load transfer between steel and concrete. This allows steel reinforcements in combination with concrete, to create a reliable structural element capable of withstanding the reinforcement and compressive forces (Amleh & Mirza, 1999). Simply and easily, the actual behavior of the bonding stress is the shear stress on the surface of the reinforcing bar. Bond strength originates mainly from weak chemical bonds between steel and hardened cement, but this resistance breaks with very little pressure. Once the slip occurs, friction contributes to bonding. In plain reinforcing steel bars, friction is a major component of strength.

Al-Sulaimani et al. (1990) found from studies of steel reinforcement corrosion and bond strength up to about 1% of the corrosion level, due to the roughness of the reinforcing bar surface at the initial stage. This is in agreement with the experimental results obtained from reinforced concrete elements tests, where the bond strength increased when the degree of corrosion increased by 4% due to radial growth Stress caused by the proliferation of corrosion products (Mangat and Elgarhoff, 1999b).

Chung et al. (2004) experimentally investigated the effects of corrosion on bond strength and developmental length. Different levels of corrosion have been used to reduce reinforcement, and concrete slab models with a steel reinforcement bar have been used to assess the effect of corrosion level on bond stress and corrosion tension member development length. It was concluded that the average bond pressure increases before the corrosion level reaches 2% and began to decrease after the 2% corrosion level.

Charles et al. (2018) experimental models were subjected to tensile and pull-out bond strength test and the results obtained were not degraded by failure load, bond strength, and maximum slip values from coating members at 33.50%, 62.40%, 84.20%, 27.08%, 55.90%, and 47.14%. For corroded cube concrete members, the values are 21.30%, 38.80%, and 32.00% of failure load, bond strength, and maximum slip for those obtained by control and coating members. Entire results showed bonding effects and effectiveness in the application of ficus glumosa resins/exudates as protective membrane against corrosion.

Almusallam et al. (1996) demonstrated that bond strength increases during the pre-cracking phase, but slip decreases at the ultimate bond strength with an increase in corrosion level.

Cabrera (1996), Amleh and Mirza (1999) and Auyeung et al. (2000). Experimental studies have shown that bond strength increased to about 2% at the initial corrosion level. Initially, a strong layer of corrosion around the reinforced steel bar caused the bond strength to increase, resulting in increased bond strength.

Charles et al. (2019) examined the reinforcement of steel at 150µm, 300µm and 450µm thickness as a coating material of acacia senegal exudates/resins paste, embedded in a concrete cube and immersed in sodium chloride and accelerated for 178 days. Results of corroded members showed reduced percentage values against control and coated members' exudates/resins, indicating the potential of acacia senegal exudates/resins in steel reinforcing coating operations.

Charles et al. (2018) investigated the underlying reasons for the reduction in service life, integrity, and strength of reinforced concrete structures in the marine environment of the saline condition. The results obtained on comparison showed that the failure bond load, bond strength, and maximum slip decreased to 21.30%, 38.80%, and 32.00%, respectively, for coating samples are 51.69%, 66.90%. Overall results showed a lower percentage and greater percentage of corroded members. This justifies the effect of corrosion on the strength capacity of corroded and coated members.

Charles et al. (2018) stated that corrosion of steel reinforcement embedded in concrete is one of the main contributing factors for failure to occur between steel and concrete, the use of epoxy, resin/exudates have been introduced to counteract this tendency encountered by reinforced structures formed within the saline zone. The results obtained showed the presence of corrosion in the uncoated members. Values obtained of corroded members are lower compared to coated members. The results showed that resins/exudates increase the strength of reinforcement and act as a protective coat against corrosion.

Otunyo and Kennedy (2018) studied the utilization of resin/exudates in curbing the corrosion effect of reinforcing steel in concrete structures. The obtained results indicated that the failure bond strength, bond strength, and maximum slip of the adhesive coated reinforced cubes are high. The higher values of maximum slip (adhesive coated and control steel members) were compared to those of the reinforced cubes of steel reinforcement. For corroded members, the maximum slip, failure bond load, bond strength, and adhesive coated reinforcements were low.

Charles et al. (2018) investigated the effect of corroded and coated reinforcement on the pullout bond separation of control, corroded and resin/exudates paste coated steel bar. The obtained results showed the corrosion potential on the members of the uncoated concrete cube. 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 against corrosion.

Charles et al. (2019) assessed the characteristics of coated and non-coated reinforcing steel embedded in concrete members and exposed to a harsh environment. Collective results show that corroded models exhibited weak maximum slip during split separation testing and high failure load with lower bond strength. Non-corroded and exudates/resins coated models have high bond strength and low failure load. Exudates/resin designs show high protective properties against corrosion effects, thereby acting as inhibitors. Exudates/resins coated models exhibited high-performance resistance properties for bond strength and maximum slip with minimal failure compared to corroded models.

Toscanini et al. (2019) examined the use of environmentally harmless corrosion inhibitors of natural resource exudates/resins coated to steel bars of 150µm, 300µm, and 450µm thickness, embedded to concrete cubes, cured in a fast corrosive medium, and the pull-out bond strength parameters are examined against the non-coated. Comparatively, the results of the corroded specimens decreased against control and cola acuminate exudates/resins coated members increased. The overall results show that natural exudates/resins should be investigated as inhibitors for the corrosion effects of steel reinforcement in concrete construction in the following places.

Charles et al. (2019) investigated the effect of olibanum exudates/resins in reinforcing steel corrosion in coastal zones under the influence of saltwater on concrete structures. Non-coated and exudates / resin-coated steel were embedded in concrete cubes and pooled in a corrosive medium to assess corrosion effects. Tests have shown that non-coated specimens have decreased values and deteriorated due to corrosion attacks. Test results showed that corroded samples have lower bond strength and higher failure bond load and lower maximum slip, while exudates/resins coated samples have lower test samples, with higher percentage values compared to corroded samples.

Gede et al. (2019) investigated the strength of the bond between concrete and reinforcement elasticity due to the reduction of steel reinforcement over the presence of saltwater. The introduction of extracts from Artocarpus altilis exudates/resins to boost reinforcing steel with a coating thickness of 150µm, 300µm, and 450µm. An investigative assessment on non-coated and coated reinforcing steel samples were embedded in concrete and saturated with sodium chloride for 150 days. Comparable results showed that the values of the applied load decreased of non-coating (corrosion) and increased in the coating samples. Overall results showed high values of strength from the controlled and the coating samples over the corroded samples due to the reduction of fiber and diameter from the corrosion effect.

2.0 MATERIALS AND METHODS

In this study, the coating of exudates/resin paste of the sap of plant trunks called inhibitors are directly on the reinforcing steel. Study, aimed at determining the effectiveness of the use of environmentally friendly and widely available materials in controlling the negative impact of corrosion attacks of reinforcing steel embedded in concrete structures and exposed to the marine environment of highly harsh nature with the introduction of sodium chloride (NaCl) solutions as corrosion accelerated media. Experimental specimens reflect severe acid levels that indicate the level of sea salt concentration in the marine environment in reinforced concrete structures. The embedded reinforcement steel is completely submerged in water and the samples for the corrosion acceleration process are maintained in the pooling tank. These specimens are designed with 36 reinforced concrete cubes of dimensions 150 mm × 150 mm x 150 mm, with a diameter of 12 mm for all controlled, non-coated, and coated samples embedded centrally for pullout bond testing and immersed in sodium chloride for 360 days duration after the initial 28 days of curing the cubes. Acid media samples were changed monthly and samples were reviewed for high performance.

2.1 Materials and methods for testing

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

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. Meets Cement Requirements (BS EN 196-6)

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) requirements

2.1.4 Structural steel reinforcement
Reinforcements are obtained directly from the market at Port Harcourt, (BS4449: 2005 + A3)

2.1.5 Corrosion Inhibitors (Resins / Exudates) Gongronema latifolium
The exudates were obtained from the stem and yields milky gummy exudates. They are abundantly seen in the Southern part of Nigeria. They are obtained from Chokocho Town in Etche Local Government of Rivers 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. Glue with 150µm, 300µm, 450µm, and 600µm coatings before corrosion testing. The test cubes were cast with 150 mm x 150 mm x 150 mm metal mold and removed after 72 h. Samples were treated at room temperature in tanks 28 days prior to the initial treatment period, followed by a rapid acceleration corrosion test and a test method that allowed routine monthly monitoring of a process for 360 days. Cubes for corrosion-acceleration samples were taken randomly at 90-day, 180-day, 270-day, and 360-day intervals of 3 months, and failure bond loads, binding strength, maximum slip, reduction/increase in cross-sectional area, and weight loss/steel reinforcement.

2.3 Accelerated Corrosion Setting and Testing 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 the marine marine marine media. Immersed for 360 days in 5% NaCl solution to test the surface and mechanical properties of the changes and effects and to test both non-coating and exudate/resin coated samples.

2.4 Pull-Out Bond Strength Test
The tensile-bond strength test of concrete cubes was carried out on a total of 36 samples in each of the 12 samples with controlled, non-coated, and coated members, and subjected to a 50 kN Universal Testing Machine according to BSEN12390. 2. Total numbers of 36 cubes of 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 strength of the bar, a 12 mm diameter reinforced, uncoated, and reinforced steel strip 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.

3.1 EXPERIMENTAL RESULTS AND DISCUSSIONS
The interaction between concrete and reinforcing steel is expected to be cordially perfect to enable the exhibition of maximum bonding in the surroundings concrete structures. The increase in deformed (rib) reinforcing bars and slip bonds mainly depends on the bearings or mechanical interlocks between the concrete around the ribs on the surface of the bar. The damaging effect from the attack by corrosion has rendered many structures unserviceable and designed life span shortened.
Experimental data presented in tables 3.2.3.2 and 3.3, summarized into tables 3.4 and 3.5 are test conducted on 36 concrete cubes samples of 12 controlled placed in freshwater for 360 days, 12 uncoated and 12 exudates/resin coated samples all embedded with reinforcing steel and immersed in 5% sodium chloride (NaCl) aqueous solution for 360 days and evaluated their performances with examinations, monitoring, checking and testing intervals of 3

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months at 90 days, 180 days, 270 days and 360 days. Indeed, the manifestation of corrosion is a long-term process which takes decades for full functionality, but the artificially introduction of sodium chloride triggers the manifestation and occurrence of corrosion with lesser time. The experimental work represented the ideal coastal marine region of high salinity and the potential application for of gongronema latifolium exudates / resin extract as inhibitory material in curbing the scourge and menace of corrosion effect on reinforced concrete structure exposed or built within such severe and harsh region.

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

	Non-corroded Control Cube Specimens											
Sample Numbers	GLC	GLC1	GLC2	GLC3	GLC4	GLC5	GLC6	GLC7	GLC8	GLC9	GLC10	GLC11
	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)	31.363	29.274	29.838	30.434	31.249	30.950	31.474	31.291	31.356	33.167	32.291	32.493
Bond strength (MPa)	12.411	13.303	11.801	12.731	13.104	14.027	14.121	13.451	13.485	14.191	13.502	14.049
Max. slip (mm)	0.109	0.110	0.101	0.105	0.104	0.103	0.116	0.120	0.128	0.126	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)	11.958	11.950	11.959	11.958	11.949	11.968	11.959	11.948	11.958	11.955	11.949	11.959
Rebar Diamete r- at 28 Days Nominal(mm)	11.958	11.950	11.959	11.958	11.949	11.968	11.959	11.948	11.958	11.955	11.949	11.959
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)	0.589	0.590	0.588	0.590	0.590	0.591	0.591	0.590	0.592	0.588	0.589	0.597
Rebar Weights- at 28 Days Nominal(Kg)	0.589	0.590	0.588	0.590	0.590	0.591	0.591	0.590	0.592	0.588	0.589	0.597
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

Samplin g 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)	0.080	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)	11.958	11.950	11.959	11.958	11.949	11.968	11.959	11.948	11.958	11.955	11.949	11.959
Rebar Diamete r- After Corrosion(mm)	11.910	11.902	11.911	11.911	11.901	11.921	11.911	11.900	11.911	11.908	11.901	11.910
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.050
Rebar Weights- Before Test(Kg)	0.590	0.590	0.588	0.591	0.590	0.597	0.591	0.589	0.590	0.590	0.589	0.592
Rebar Weights- After Corrosion(Kg)	0.534	0.534	0.532	0.534	0.534	0.535	0.535	0.534	0.536	0.533	0.533	0.541
Weight Loss /Gain of	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056

Steel (Kg)												

Table 3.3: Results of Pull-out Bond Strength Test (τu) (MPa) of Gongronema latifolium 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)	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)	0.175	0.176	0.167	0.172	0.171	0.170	0.183	0.187	0.195	0.192	0.197	0.195
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)	11.958	11.950	11.959	11.958	11.949	11.968	11.959	11.948	11.958	11.955	11.949	11.959
Rebar Diameter- After Corrosion(mm)	12.015	12.007	12.016	12.016	12.006	12.026	12.016	12.005	12.015	12.012	12.006	12.016
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
Rebar Weights- Before Test(Kg)	0.589	0.589	0.587	0.590	0.590	0.590	0.590	0.589	0.592	0.588	0.588	0.596
Rebar Weights- After Corrosion(Kg)	0.658	0.658	0.656	0.659	0.659	0.659	0.659	0.658	0.660	0.657	0.657	0.665
Weight Loss /Gain of Steel (Kg)	0.070	0.069	0.069	0.069	0.070	0.067	0.069	0.068	0.070	0.657	0.067	0.069

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)	30.158	29.849	30.507	30.878	16.914	16.596	16.256	16.108	30.760	30.451	31.109	31.480
Bond strength (MPa)	12.505	12.612	12.545	13.288	7.789	7.788	7.706	7.693	13.162	13.269	13.202	13.945
Max. slip (mm)	0.106	0.105	0.103	0.104	0.082	0.087	0.087	0.088	0.173	0.172	0.170	0.171
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)	11.956	11.956	11.955	11.959	11.956	11.956	11.955	11.959	11.956	11.956	11.955	11.959
Rebar Diamete r- After Corrosion(mm)	11.956	11.956	11.955	11.959	11.908	11.908	11.908	11.911	12.013	12.013	12.013	12.016
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.048	0.048	0.048	0.048	0.057	0.057	0.057	0.057
Rebar Weights- Before Test(Kg)	0.589	0.589	0.589	0.590	0.589	0.589	0.589	0.592	0.589	0.589	0.589	0.590
Rebar Weights- After Corrosion(Kg)	0.589	0.589	0.589	0.590	0.533	0.533	0.534	0.535	0.657	0.658	0.658	0.659
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.056	0.056	0.056	0.056	0.069	0.069	0.069	0.069

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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)	78.304	79.858	87.670	91.689	-45.014	-45.500	-47.746	-48.830	81.863	83.486	91.373	95.427
Bond strength (MPa)	60.540	61.933	62.801	72.719	-40.819	-41.304	-41.632	-44.830	68.974	70.369	71.327	81.259
Max. slip (mm)	29.187	21.465	19.092	18.798	-52.298	-49.468	-48.824	-48.518	109.636	97.894	95.404	94.242
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)	0.063	0.063	0.068	0.065	0.068	0.066	0.068	0.068	0.061	0.066	0.063	0.067
Rebar Diamete r-After Corrosion(mm)	0.400	0.400	0.400	0.400	-0.872	-0.872	-0.872	-0.872	0.880	0.880	0.880	0.879
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	-16.626	-16.646	-16.766	-16.696	20.042	20.042	20.042	20.042
Rebar Weights-Before Test(Kg)	0.057	0.046	0.059	0.0390	0.036	0.065	0.068	0.411	0.056	0.064	0.068	0.409
Rebar Weights-After Corrosion(Kg)	10.418	10.414	10.412	10.392	-18.886	-18.880	-18.877	-18.848	23.283	23.275	23.269	23.226
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	-19.348	-19.165	-19.759	-19.247	23.989	23.709	24.625	23.834

3.2 Failure load, Bond Strength, and Maximum slip

Pullout and traction failure occur when the reinforcement straps are tightly closed and the insertion or length of the splice is insufficient to improve the yield and hardness of the steel. This failure is reflected in the series of cracks in the shear plane that connect the peaks to the reinforcement. The failure example suggests that the resistance to gravity is controlled by the amount of concrete in the shear, and that friction and adhesion materials are more important than splitting failure. To ensure adequate bonding between concrete and reinforcing and curb the effect of corrosion, the introduction of coating materials of inorganic origin of eco-friendly were used to ascertain the performance of reinforced concrete structures exposed to the severe coastal environment. The results of the pullout test of failure bond 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 summarized averagely in 3.4, percentile in 3.5 and presented graphically in figures 1 - 6b. The results obtained of 12 controlled, 12 corroded and 12 coated samples tested for failure using Instron Universal Testing Machines at 50kN as described in the test procedure were are thus below;

The minimum and maximum calculated average and percentiles values obtained from the failure bond load of controlled concrete cube samples are 29.849kN and 30.878kN, representing (78.304% and 91.689%), the corroded samples are 16.108kN and 16.914kN, representing (-48.83% and -45.014%), the coated samples are 30.451kN and 31.48kN, representing (81.863% and 95.427%).

The Bond strength values for controlled are 12.505MPa and 13.288MPa representing (60.54% and 72.719%), the corroded sample is 7.693MPa and 7.789MPa representing (-44.83% and -40.819%), and the coated sample values are 13.162MPa and 13.945MPa, representing (68.974% and 81.259%).
The Maximum slip results are controlled 0.103 mm and 0.106 mm presenting (18.798% and 29.187%), the corroded samples are 0.082 mm and 0.088 mm with percentile representation (-52.298% and -48.518%), and the coated are 0.17 mm and 0.173 mm representing (94.242% and 109.636%).

The results are shown in tables 3.1, 3.2, and 3.3 which are derived into 3.4 and summarized to 3.5, for the difference in percentage values. Comparatively, the maximum controlled value is 95.427% against corroded -45.014% and coated 91.689%. Results of failure bond load showed lower failure load application on corroded samples as compared to controlled and coated samples with higher load to failure which also showed closed value ranges.

Obtained maximum bond strength from controlled samples is 72.719% as against corrode -40.819% and coated 81.259% samples. The comparative results showed the pullout bond strength of corroded failed on lower load applications as compared to controlled and coated samples with both having closed value ranges and failed on higher load application with coated recording the highest.

The maximum recorded values of maximum slip of controlled samples are 29.187% against corroded -48.518% and coated 109.636%. In comparison, corroded samples failed at lower load application while controlled and coated failed at higher load application as related to (Almusallam et al., 1996; Chung et al., 2004; Al-Sulaimani et al., 1990; Otunyo and Kennedy, 2018; Charles et al., 2018; Toscanini et al., 2019; Terence et al., 2019). Overall results showed the effect of corrosion on reinforcing steel that has led to lower load failure applications with a great surface modification that has led to ribs been consumed and converted to a smooth surface. The effect has led to low effective performance of adhesion and proper interaction between concrete and steel.

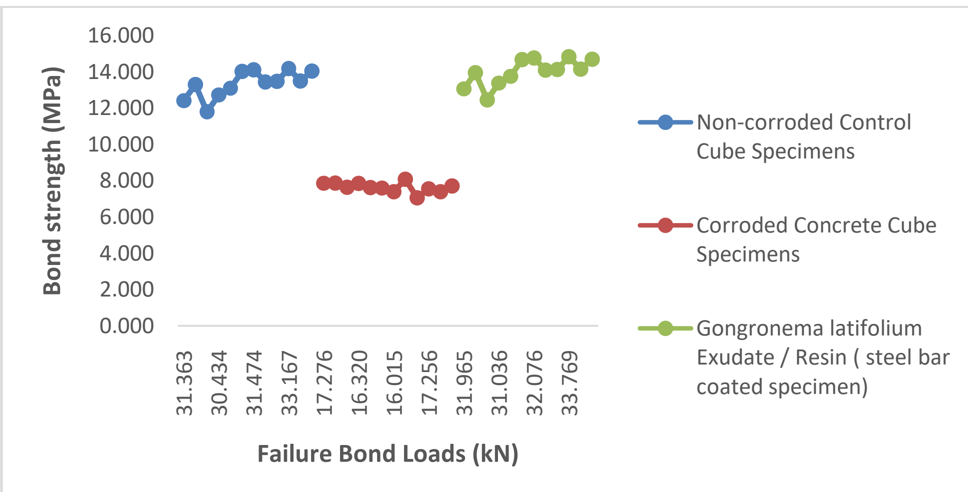

Figure 1: Failure Bond loads versus Bond Strengths

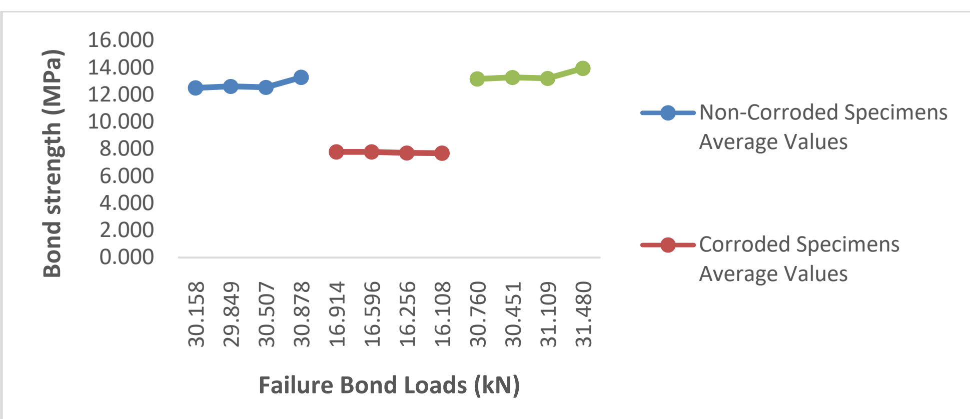

Figure 1a: Average Failure Bond loads versus Bond Strengths

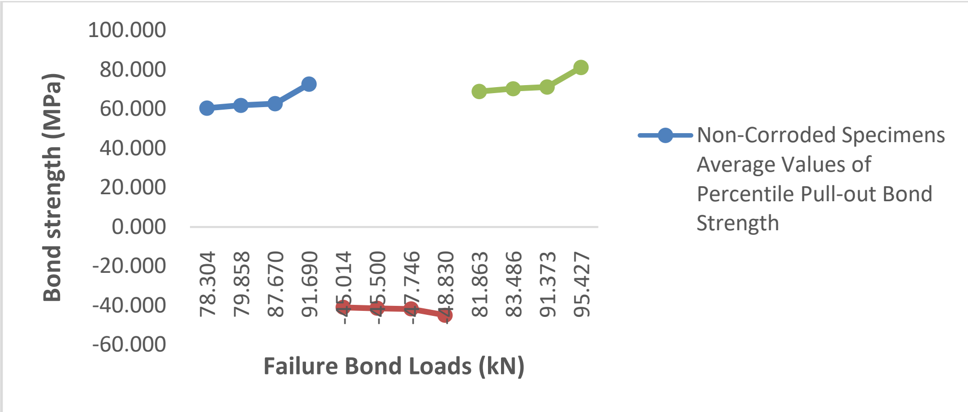

Figure 1b: Average Percentile Failure Bond loads versus Bond Strengths

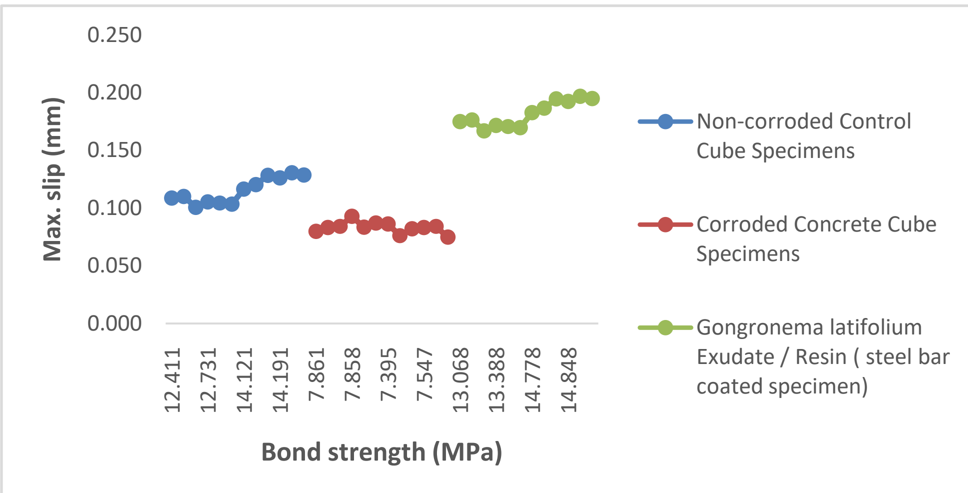

Figure 2: Bond Strengths versus Maximum Slip

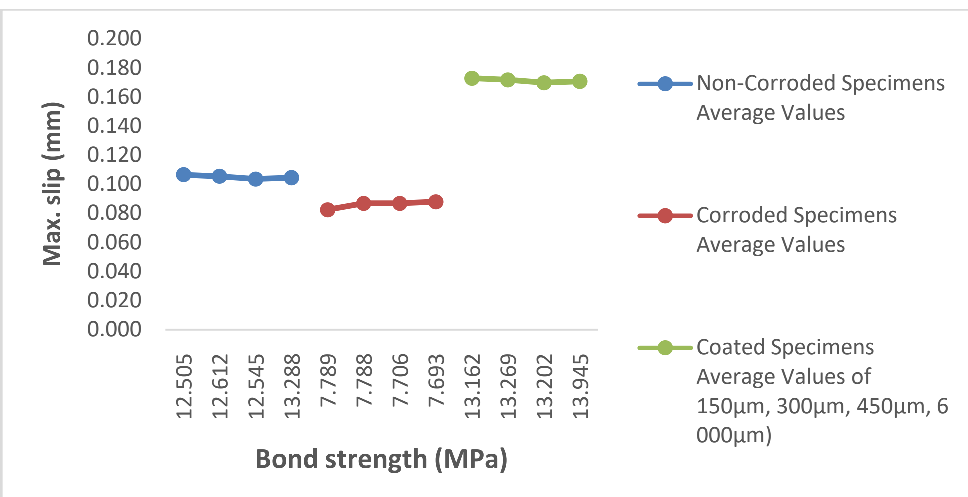

Figure 2a: Average Bond Strengths versus Maximum Slip

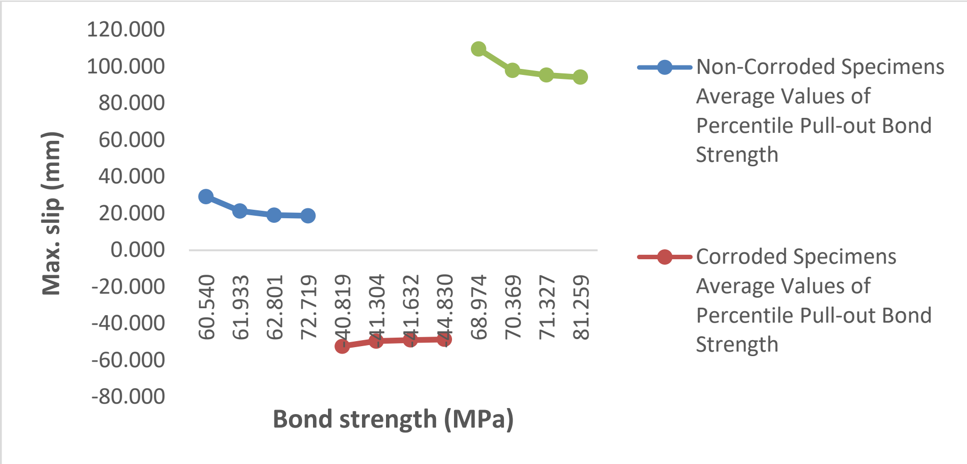

Figure 2b: Average Percentile Bond Strengths versus Maximum Slip

3.3 Mechanical Properties of Reinforcing Bars

The main concern is the use of coating materials for reinforcing in structural concrete is their effect on the bond between concrete and reinforcement. The strength of the adhesive is mainly due to the weak chemical bond between the steel and the hardened cement, but this strength is destroyed at low pressure. Immediately after slipping, friction aids in binding. The ability of steel to transfer forces to the concrete by a binding action is important for the short and long-term performance of concrete structures.

With a fine/smooth or low rib steel bar, friction is an important part of strength, and the use of exudates/ resin aid in fixing these phenomena. Reinforcement of steel bars with ribs with raised shear joints relies mainly on bearing or mechanical locking between the ribs and the surrounding concrete on the surface. This study introduces the use of exudates/resins to increase the slip problem in plain / low rib / weak rib reinforcing steel.
The data presented in tables 3.1, 3.2, and 3.3 and averaged in table 3.4 and summarized in 3.5 accounts for the behavioral mechanical properties of the controlled, uncoated (corroded), and coated concrete cubes exposed to both freshwater for controlled and induced in corrosion accelerated process for 360 days as described in experimental procedures and pressured with 50KN to failure using Instron Universal Testing to access the periodic performance of samples at 3-month intervals as shown in tables 3.1- 3.5 and plotted in figures 1-6b. The yield of the controlled samples is a value of 100%, as it is pooled in a suitable freshwater tank (BS 3148).

The nominal diameter of the steel bars of all samples is 100% and the minimum and maximum diameters of steel bars measured before the test were 11.955 mm and 11.595 mm. The diameter of the uncoated (corroded) reinforcement sample after the corrosion test was 11.908 mm and 11.911 mm representing -0.872% and -0.872%, after coating 12.013 mm and 12.016 mm and representing 0.879% and 0.88%. The results for uncoated (corroded) cross-sectional areas were 0.048 mm and 0.048 mm representing -16.766% and -16.626%, for the coating sample were 0.057 mm and 0.057 mm representing 20.042% and 20.042%.

The results of the weight of reinforcement before testing for all samples were 0.589 kg and 0.59 kg and these represents values of 0.039% and 0.059%, the weight after the corrosion test for the corroded samples were 0.533Kg and 0.535 kg representing -18,886% and -18.848%) and coating samples were 0.657 kg and 0.659 kg representing 23.226% and 23.283%) and decreased weight / weight gain of corroded steel 0.056 kg and 0.056 kg representing -19.759% and -19.165%, as well as coating values of 0.069 kg and 0.069kg representing 23.709% and 24.625%).

The results obtained and shown in the figures show the effect of corrosion on uncoated reinforcing steel. In Figures 3 to 6b, it can be seen from the diameter of the reinforcement that the diameter of the reinforcement without corroded decreases by a maximum value of -0.872% and the coated increase by 0.88%, for the maximum corroded cross-sectional area the reduction value is -16.626% and the coated increase by 20.042%, weight loss and gain, corroded samples value is - 18.848% which showed decrease value of weight loss while coated value is 20.042% indicating increase increased value of weight gain.

Indications analyzed from experimental work show that the effect of corrosion on an uncoated concrete cube causes a decrease in the cross-sectional diameter and cross-sectional area as well as a decrease in weight, while the cube-coated concrete has a cross-sectional diameter and a cross-sectional area increased and weight, due to differences in the thickness of the reinforcing steel layers as related to(Cabrera, 1996; Amleh and Mirza, 1999; Auyeung et al., 2000; Gede et al., 2019; Charles et al., 2019).

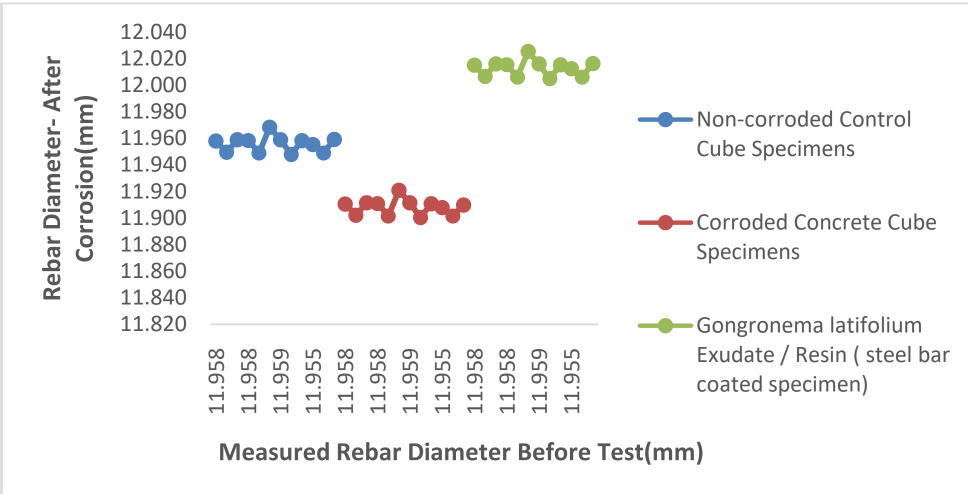

Figure 3: Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

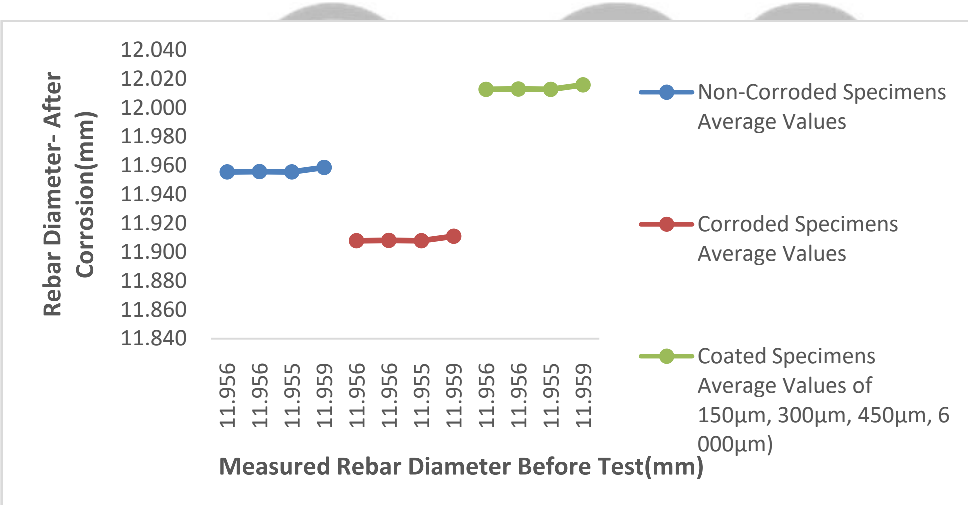

Figure 3a: Average Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

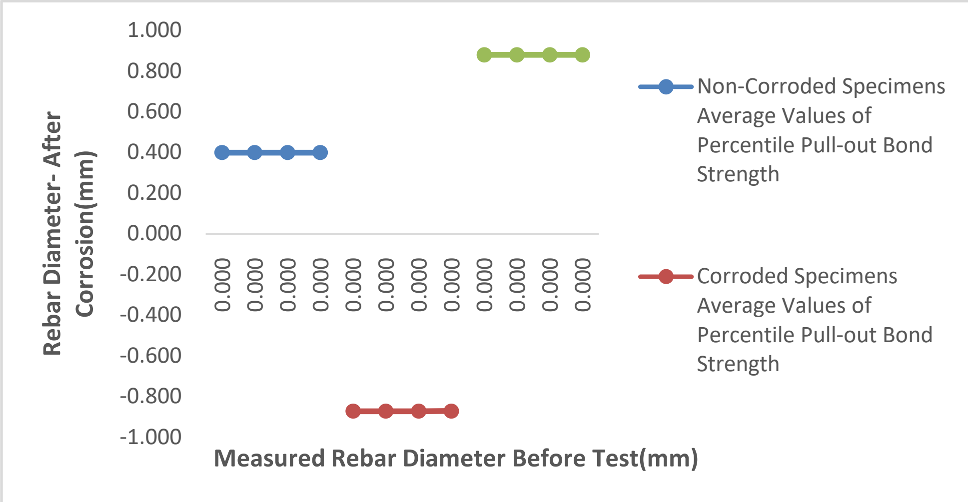

Figure 3b: Average Percentile Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion

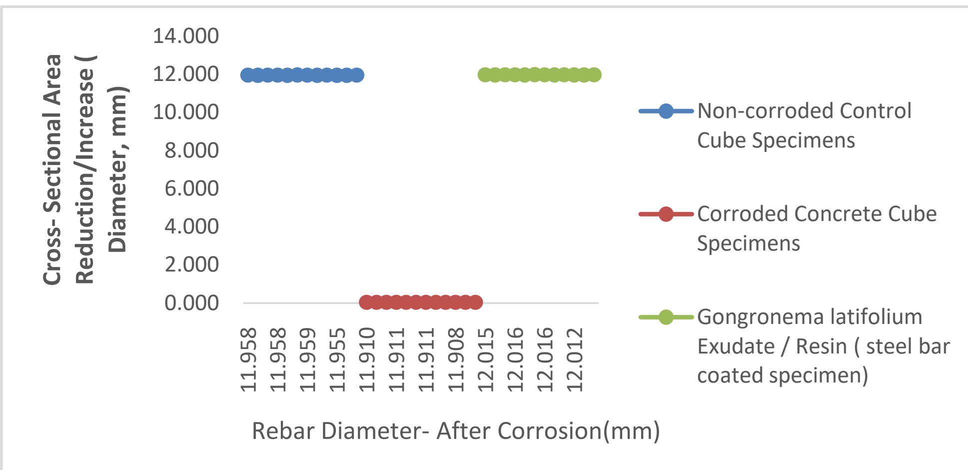

Figure 4: Rebar Diameter- After Corrosion versus Cross - Sectional Area Reduction/Increase

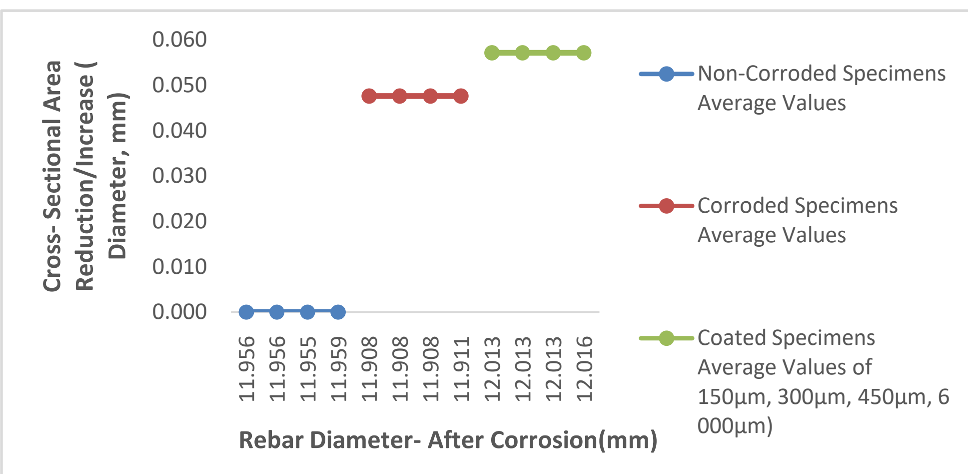

Figure 4a: Average Rebar Diameter- after Corrosion versus Cross – Sectional Area Reduction/Increase

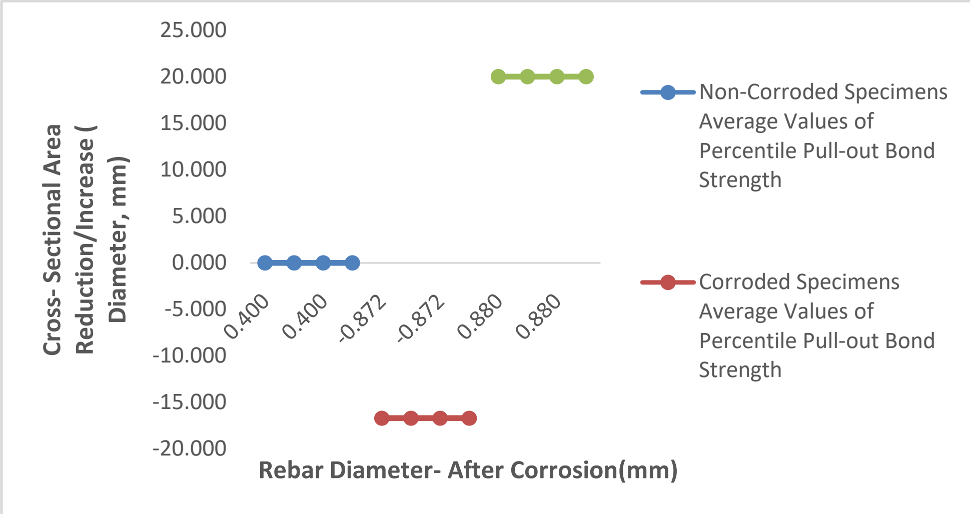

Figure 4b: Average percentile Rebar Diameter- after Corrosion versus Cross - sectional Area Reduction/Increase

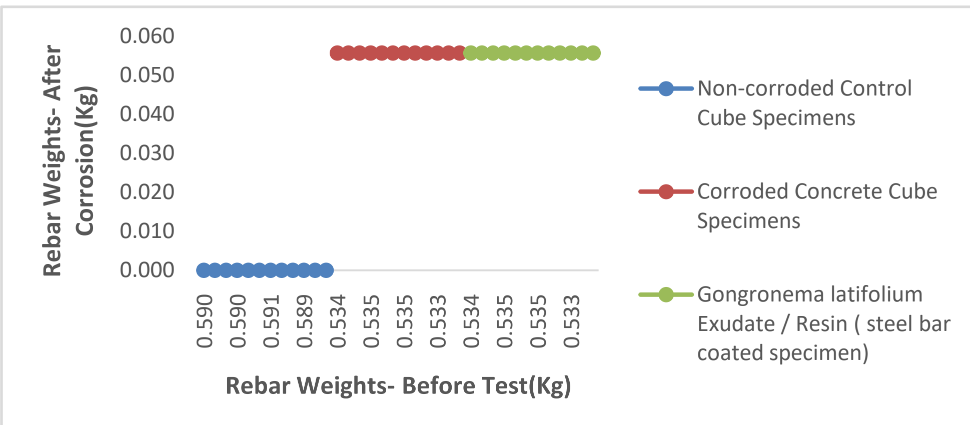

Figure 5: Rebar Weights- before Test versus Rebar Weights- after Corrosion

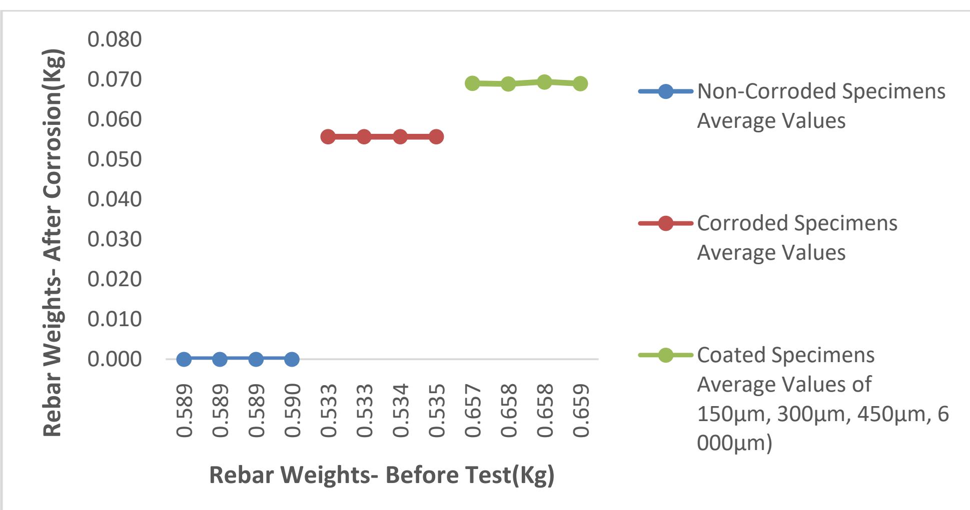

Figure 5a: Average Rebar Weights- before Test versus Rebar Weights- after Corrosion

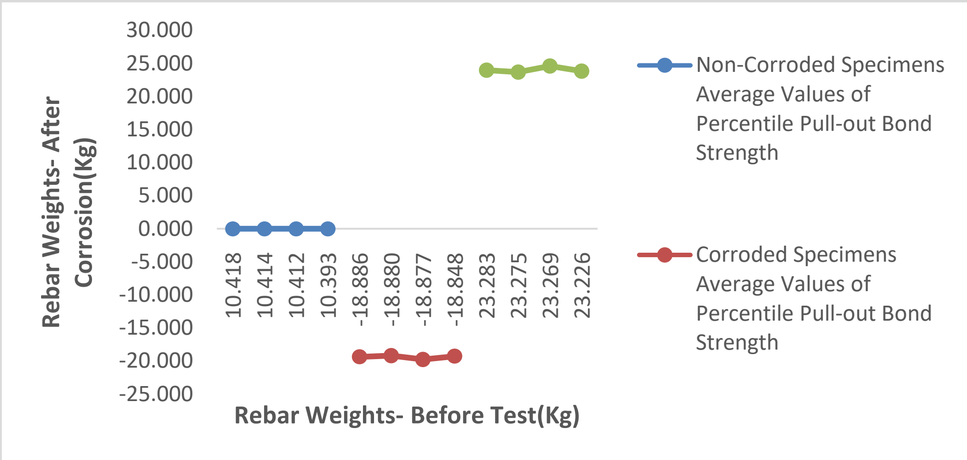

Figure 5b: Average Percentile Rebar Weights- before Test versus Rebar Weights- after Corrosion

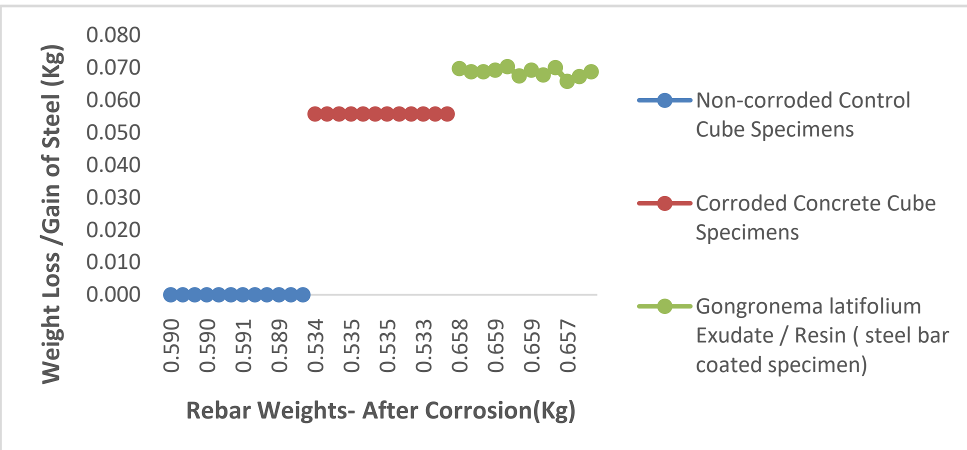

Figure 6: Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

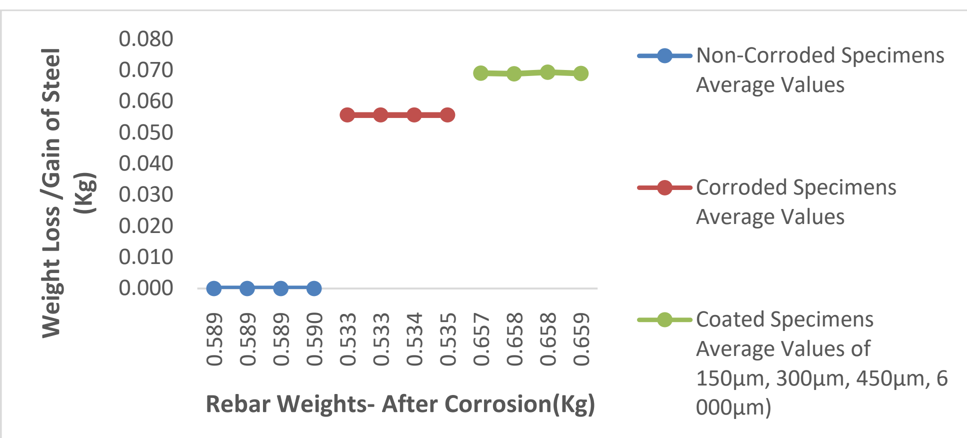

Figure 6a: Average Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

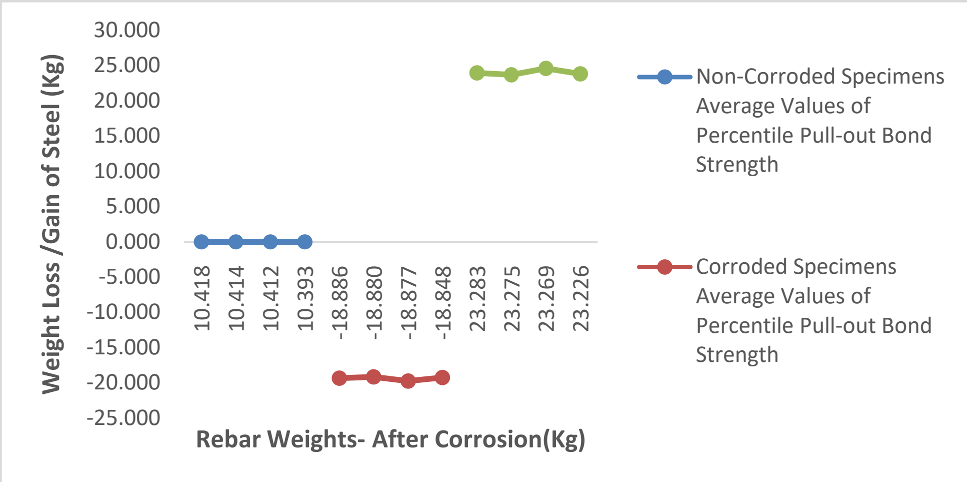

Figure 6b: Average percentile Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

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

By comparison, from the data in Tables 3.1, 3.2, 3.3 and in figures 3, 4,5, and 6 of the 12 controlled samples were placed in a freshwater tank for 360 days, while 12 non-coated(corroded) and 12 coated pooled in 5% sodium chloride (NaCl) aqueous solution for 360-days as described in 3.1 - 3.3 and summarized in tables 3.4 - 3.5 with figures 3a, 3b, 4a, 4b, 5a, 5b, 6a and 6b with average and percentile failures bond loads, bond strength and maximum slip, reduction/increase of cross-section, the weight of rebar before / after corrosion test, weight loss/ gain.

The results obtained by comparison showed that the controlled and coated failure bond load maintains close values, while the corroded members resulted in lower load application, similar factors are present in bond strength and maximum slip. Of the mechanical properties of reinforced steel, the impact of corrosion on reinforced steel revealed a cross-sectional reduction in the diameter of the bar compared to the nominal diameter before the test, the weight loss is observed and the cross-sectional area of the coated members is increased, with an increase in the diameter and weight of the coating material compared to the nominal resilience. The exudate/resin studied showed the potency of the inhibitory properties against corrosion attack and can be concluded that it can be used as an inhibitor for corrosion.

4.0 CONCLUSIONS

In the experiment, the result obtained is drawn as follows:

i. Exudate / resin has a preventive effect on corrosion because its waterproofing resistance to corrosion penetration and attacks.

ii. The contact between the concrete and steel in the coated components is greater than in the embossed specimens

iii. The properties of the bonds in the coated and controlled components are much higher than in the corrugated

iv. Less failed bond load, bond strength and maximum slip were recorded in the twisted member

v. The coating and control model recorded high values of bond load and bond strength.

vi. Weight loss and cross-sectional reduction are mainly recorded in corrugated coatings and controlled models

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