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Original Research Article

Behavioral Response of Concrete and Reinforcing Steel Bond Interface of Corrosion Induced Reinforced Concrete Structures

Charles Kennedy[1*], Sylvester Obinna Osuji[2], Ebuka Nwankwo[2]

[1]Department of Civil Engineering, Faculty of Engineering, Rivers State University, Port Harcourt - Rivers State, Nigeria
[2]Department of Civil Engineering, University of Benin, Benin City, Edo State, Nigeria

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***Corresponding author:** Charles Kennedy

Abstract

The research work investigated the potential use of exudates/resin to curb the surface and mechanical properties of the indentation from corrosion attack on reinforcing steel of both non-coating and exudates/resin coated samples after 360 days immersion in 5% NaCl solution. The obtained results maximum percentile failure bond load values of controlled samples are 64.308% against corroded -35.029% and the coated 68.823%. The differential maximum values computed of the average and percentile ranges of failure bond load are controlled (2.492kN and 14.869%) against corroded samples values are (0.806kN and 5.738%), coated are (2.492kN and 14.907%. The differentially potential maximum failure bond loads, as well as comparative values of maximum deflective values over-controlled and coated samples. The peak percentile bond strength values for comparison recorded are controlled 46.996% against corroded and coated -34.33% and 72.41%. The differential computed average and percentile values are controlled 1.409MP and 19.463% against corroded 0.276 MP and 7.669%, coated values are 1.408 MP and 20.134%. From the values obtained, the corroded samples exhibited a pullout bond strength compared to the increased values for the values of the coated samples and the controlled samples with pullout bond strength. The maximum recorded average and percentile values of controlled 86.42% against corroded and coated samples of -27.728% and 80.247% and with differential recorded values of the controlled 0.024mm and 42.379% against corroded values of 0.007mm and 16.793% and coated values 0.024mm and 41.881%. The maximum percentile values obtained for comparison among the investigated samples showed that the corroded exhibited lower slippage and reduced percentile values and low load application to failure, while coated samples exhibited higher slippage, and increased values. The obtained computed results of the nominal reinforcing steel with no traces of corrosion effect is 100%, the comparative results after corrosion and the potential differential values of the tested samples showed percentile values reduction in corroded samples resulting from induced effect from corrosion while the coated samples exhibited a potential increase in volumetric based on varying coating thicknesses. It can be seen that the diameter of uncoated decreased by the maximum value of 0.596% and coated increased by 0.674%, for the cross-sectional area, corroded has maximum reduction value -13.251% and coated increased by and 15.275%, weight loss, and gain are corroded -20.31% decreased (loss) and coated 29.25% increase (gain). Indication as analyzed from the experimental work showed that the effect of corrosion on uncoated concrete cubes caused diameter and cross–sectional area reduction and weight decrease while coated concrete cubes have diameter and cross–sectional area increases and weight gain resulting from the varying thickness coated to reinforcing steel.

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

1.0 INTRODUCTION

The bonding between concrete and steel reinforcement is critical to the strength of reinforced concrete structures. Because concrete is very weak in strength, compared to its strength in compression, steel is used as a reinforcement. The reinforcing steel absorbs the strength of the reinforced concrete structures cracked notice. The relationship between concrete and reinforcing steel length is also important for the composite effect of reinforced concrete structures [1, 2]. It is known that the use of deformation rods can significantly increase the strength of the steel-concrete bond. Three main components determine the strength of the joints between adjacent reinforcing ribs. These components are the shear stress due to adhesion on the surface of the reinforcement, the bearing stress relative to the surface of the reinforcement (mechanical

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interlocking), and the friction between the reinforcement and the concrete in the ribs and the surrounding concrete. The biggest contribution to bonds Strength comes from mechanical interlocking [3]. However, it is the bond between steel and concrete that makes these combined actions possible. The corrosion of steel reinforcement affects this bond strength. The bond strength between steel and concrete can be divided into two parts: The adhesion itself comes from three different sources. The first and second is the strength of the encounter between concrete and steel. Finally, a closed pressure made of concrete on the reinforcing steel. The mechanical feature comes from the back forces. The loss of stress conformity at the depth of reinforcement causes a redistribution of stresses in reinforced concrete elements, which can result in excessive use deviations and changes in load-bearing capacity [4]. One way to evaluate the steel-concrete bond is to test the development of the slip-stress bond, which is usually determined by the classical tensile test [5]. Even if this test is not completely satisfactory due to boundary or load conditions [6] and is replaced by another test arrangement (direct tensile test with connecting tension [7], it is still the most convenient and easiest experiment to perform for an overall assessment of the bonding effect. It has been shown that the important properties of stress shear joints and in particular the maximum joint stresses depend on the material, geometric parameters, or load parameters. The positive effect of rib spacing and height has been demonstrated by [8] and Castel *et al*., [9]. The closure is identified as one of the key parameters affecting the maximum terminal voltage value. This moment is very important for structures with stirrup reinforcement or structures with triaxial stress [10].

Research work investigated the properties of exposed, corroded, and exudates/resin-coated elements exposed to a corrosive environment using 150mm x 150mm x 150mm concrete cubes for 150 days. The combined results showed that the samples corroded during the separation test were weak with high breaking strength at low strength joints and with the higher bond strength and low breaking load. The exudates/resin has high protective properties against the effects of corrosion, which acts as a barrier material. Samples coated with exudates/resin exhibit higher resistance to adhesive properties and higher flow rates compared to coated elements [11].

Tore-Casanova *et al*., showed [12] that cracking and tensile damage depend on the concrete cover (crack damage for low concrete covers and tensile damage for other cases). In addition, several factors hurt bond strength, such as B. epoxy coating. This effect is due to reduced adhesion and friction components on smooth epoxy surfaces [13]. Compared with uncoated reinforcement, it was found that the decrease in bond strength depends on several factors such as layer thickness, size and position of reinforcement, deformation pattern, concrete properties, and casting conditions [14-16]. To compensate for such losses, the design code, therefore, provides for an increased length of stem development. For example, in ACI 318 is development time multiplied by a factor of 1.5 for epoxy-coated rods with a coating of less than 3 db or clearance between rods of less than 6 db (where db is the rod diameter) and a factor of 1.2 for other cases [17]. In the AASHTO bridge specification, these factors are 1.5 and 1.15, respectively [18]. These ribs interact with the surrounding concrete and are resistant to any translation movement. In deformed members (bars), the mechanical action of the ribs is a major factor. In smooth bars, very little is done due to the lack of ribs. So the adhesiveness gives most of the bond strength. The corrosion after the extraction of iron ore affects all these different sources of bond strength. Chemical adhesions are destroyed because steel and concrete are separated by a layer of rust products and are no longer compacted. Frictional strength is lost because the corrosion products that separate reinforcing steel from concrete act as a flab.

Investigated the effects of chloride and carbonate pollution in the marine region of the Niger Delta, Nigeria, as the main reason for the lack of connection between steel reinforcement and concrete, leading to premature deterioration of reinforced concrete structures in bad weather. Coated steel bars with varying thicknesses, embedded in concrete cubes, were treated in a corrosive environment and the tensile strength parameters against the uncoated were checked. The yield of the corroded sample was relatively decreased while the control exudates/resin Cola accuminata increased in the steel rod coating sample. The overall results suggest that natural exudates/resin should be investigated as an inhibitor of the corrosion effect of steel reinforcement on concrete structures in seawater areas [19].

Investigated the bond strength between concrete and the elasticity of reinforcement due to the reduction of steel reinforcement in the presence of saltwater. Introduction of resin exudates/extracts from Artocarpus altilis to improve reinforcing steel with varying layer thicknesses. Research evaluation of uncoated and coated steel samples immersed in concrete and saturated with sodium chloride for 150 days. Comparable results show that the value of the applied load decreases in the case of non-coating (corrosion) and increases in the case of the coating sample. The overall results showed high strength values of the controlled samples and the coating on the corroded samples due to the reduction of fiber and diameter of the corrosion effect [20].

Investigated the use of acacia exudates/resin from Senegal as a paste material in reinforcing steel layers with varying thicknesses. The experimental study checked that coated and uncoated samples were put into a concrete cube and immersed in sodium chloride for 178 days to influence the corrosion rating. In comparison, the value of the uncoated samples decreased due to corrosive attack on the mechanical properties of the steel reinforcement, but with increasing strength of the non-corrosive and exudates/resin-coated elements, indicating the efficiency of the steel. Acacia Senegal for use as exudates/resin reinforcing steel. The overall results showed high joint tensile strength values and low breaking loads in the control and corroded samples [21].

Investigated the effect of olibanum exudates/resin on the enhancement of steel corrosion in coastal areas under the influence of saltwater on concrete structures. To assess the effect of corrosion, the steel coating and the exudates/resin coating were embedded in a concrete cube and combined in a corrosive environment. Tests have shown that the value of uncoated samples decreases due to reduced corrosion attack. The percentile of average tension bond strength was 33.13% and the closed items were 45.66% and 71.84% compared to the different control. The mean maximum hatching value was 0.083 mm and the average was 33.878% and 75.32%, respectively, compared to control and final -25.31%. The experimental results showed that the reduced specimens had lower bond strength and higher breaking loads, as well as lower maximum slip, while specimens coated with exudates/resin had lower specimens and higher percentiles than corroded specimens [22].

Investigated the effect of inhibitors made of reinforced steel using a 150-day rapid strength test on the breakdown of embedded steel. Similar results showed a decrease in the value of the corroded sample, while the coated and controlled samples showed an increasing value. The overall results show a high level of exudates/adhesive tensile strength in the corroded samples [23].

Investigated the effect of reduction in bond strength and interaction between reinforcement and reinforced concrete structures in a saltwater marine environment using uncoated steel and Khaya Senegalensis resin coated steel bars were evaluated. The fracture load results showed a difference of -43.62% and 77.37 and 79.67% for coated and corrosive exudates/resin. The reduced mean load resistance of bonding varied between 57.06% and 36.33% or 106.57% for colored and coated samples. The results clearly show that the stress on the corrosion composites is higher with corrosion than with exudates/adhesives [24].

2.0 TEST PROGRAM

Exudates/resin paste was obtained from the trunk of the plant and coated to steel reinforcement and various coating thicknesses were introduced and then it was embedded in concrete cubes. The corrosion acceleration process was introduced as a corrosion medium of sodium chloride (NaCl) to determine the potential use of exudates/resin materials to control the changes and effects of seawater in the reinforcement of steel in concrete structures. The test specimen refers to the level of hardness acidity, which is the level of concentration of sea salt in the marine atmosphere in reinforced concrete structures. The embedded reinforcement steel is completely submerged and the samples for the corrosion acceleration process are maintained in the pooling tank. A concrete mix ratio of 1: 2: 4, water-cement ratio 0.65 by weight of concrete were used to design 36 reinforced concrete cubes of dimensions 150mm × 150mm x 150mm, all centrally embedded with 12 mm diameter reinforcement of control, uncoated, and coated specimens - immersed in sodium chloride for 360 days. The initial cube curing days were 28 days, thereafter pooled in acid-corrosive media solutions, and were modified monthly and cube samples were reviewed for further efficiency and improvement.

2.1 Materials and Methods for Testing

2.1.1 Aggregates

Both (fine and coarse) were purchased. Both met the requirements of [25].

2.1.2 Cement

Portland Lime Cement Grade 42.5 is the most common type of cement on the Nigerian market. It was used for all concrete mixes in this test. It meets the requirements of cement [26].

2.1.3 Water

The water samples were clean and free of impurities. Water was obtained from Civil Engineering Laboratory, Kenpoly, Rivers State. Water adhered to [27] requirements

2.1.4 Structural Steel Reinforcement

Reinforcements are obtained directly from the market at Port Harcourt [28].

2.1.5 Corrosion Inhibitors (Resins / Exudates) Albizia amara

Exudates was obtained by tapping from tree trunk from Auwaru Village in Akko Local Government of Gombe State, Nigeria

2.3 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 test. The size of the test cube was 150 mm x 150 mm x 150 mm and it was placed in a metal mold and de-molded after 72 hours. Samples were treated at room temperature in the tank 28 days before the initial treatment period, followed by rapid acceleration corrosion testing and

360-day monthly routine monitoring approved by the test regime. Cubes for corrosion-acceleration samples were taken at intervals of about 3 months, 90 days, 180 days, 270 days, and 360 days. Failure Bond loads, bond strength, maximum slip, decrease/increase in cross-sectional area, and weight loss/steel reinforcement pullout bond test was conducted.

2.3 Accelerated Corrosion Setting and Testing Method

In a real and natural phenomenon, the expression of corrosion effects on reinforcement embedded in concrete members is very slow and may take many years to achieve; but the laboratory-accelerated process will take less time to accelerate the marine media. Research work is to ascertain possible curb on the surface and mechanical properties of the imprint from corrosion attack on reinforcing steel of both non-coating and exudates/resin coated samples after 360 days immersion in 5% NaCl solution.

2.4 Pullout-Bond Strength Test

The Pullout-bond strength was carried out on 36 concrete cubes with dimensions 150 mm x 150 mm x 150 mm of controlled, non-coated, and coated samples with 12mm diameter reinforcing steel centrally embedded for pullout bond testing on a 50kN pressure load Universal Test Machine (UTM) as per BSEN 12390.2., and the record of pullout bond test on failure bond loads, bond strength, maximum slip, decrease/increase in cross-sectional area and weight loss/steel reinforcement were recorded.

2.5 Tensile Strength of Reinforcement Bars

To determine the yield and tensile strength of the strip, the Uncoated and Coated steel reinforcement was tested and subjected to direct pressure until the failure load was applied to the Universal Test Machine (UTM). To ensure stability, the remaining cut pieces are used in subsequent bond testing and failure bond loads, bond strength, maximum slip, decrease/increase in cross-sectional area, and weight loss/steel reinforcement.

3.1 EXPERIMENTAL RESULTS AND DISCUSSION

The interaction between concrete and reinforcing steel is expected to be cordially perfect to enable the exhibition of maximum bonding in the surrounding 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 tests 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 months at 90 days, 180 days, 270 days and 360 days. Indeed, the manifestation of corrosion is a long-term process that takes decades for full functionality, but the artificial 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 Albizia amara exudates/resin extract as inhibitory material in curbing the scourge and menace of corrosion effect on reinforced concrete structures exposed or built within such severe and harsh regions.

Table 3.1: Results of Pull-out Bond Strength Test (τu) (MPa)

	Non-corroded Control Cube Specimens											
Sample Numbers	AAC	AAC1	AAC2	AAC3	AAC4	AAC5	AAC6	AAC7	AAC8	AAC9	AAC10	AAC11
	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)	28.899	26.810	27.374	27.970	28.785	28.486	29.010	28.827	28.892	30.703	29.827	30.029
Bond strength (MPa)	11.446	12.338	10.836	11.766	12.139	13.062	13.156	12.485	12.520	13.226	12.537	13.084
Max. slip (mm)	0.131	0.133	0.123	0.128	0.127	0.126	0.139	0.143	0.151	0.149	0.153	0.151
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)	12.027	12.037	12.027	12.026	12.027	12.037	12.026	12.037	12.037	12.037	12.036	12.027
Rebar diameter r- at 28 Days Nominal(mm)	12.027	12.037	12.027	12.026	12.027	12.037	12.026	12.037	12.037	12.037	12.036	12.027
Cross- section 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)	0.564	0.567	0.564	0.564	0.565	0.571	0.567	0.564	0.563	0.563	0.567	0.571
Rebar Weights- at 28 Days Norminal(Kg)	0.564	0.567	0.564	0.564	0.565	0.571	0.567	0.564	0.563	0.563	0.567	0.571
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) Corroded Concrete Cube Specimen

Sampling g and Durations	**Samples 1 (90 days)**			**Samples 2 (180 Days)**			**Samples 3 (270 Days)**			**Samples 4 (360 Days)**		
Failure Bond Loads (kN)	18.894	18.206	18.496	17.939	17.187	18.054	17.633	17.942	17.639	18.874	17.754	18.487
Bond strength (MPa)	9.120	9.130	8.895	9.117	8.883	8.856	8.654	9.343	8.318	8.806	8.654	8.966
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)	12.029	12.025	12.019	12.018	12.029	12.019	12.019	12.025	12.018	12.029	12.019	12.019
Rebar Diameter- After Corrosion(mm)	11.980	11.976	11.970	11.969	11.980	11.970	11.970	11.976	11.969	11.980	11.970	11.970
Cross- section 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)	0.565	0.565	0.573	0.566	0.566	0.564	0.566	0.566	0.567	0.566	0.565	0.567
Rebar Weights- After Corrosion (Kg)	0.525	0.532	0.525	0.526	0.526	0.523	0.525	0.526	0.524	0.524	0.526	0.527
Weight Loss /Gain of Steel (Kg)	0.040	0.033	0.048	0.041	0.040	0.041	0.041	0.040	0.043	0.042	0.039	0.040

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

Sampling 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)	29.729	27.639	28.203	28.800	29.615	29.316	29.839	29.657	29.721	31.532	30.657	30.858
Bond strength (MPa)	13.684	14.577	13.074	14.005	14.378	15.301	15.394	14.724	14.759	15.464	14.776	15.322
Max. slip (mm)	0.126	0.128	0.118	0.123	0.122	0.121	0.134	0.138	0.146	0.144	0.148	0.146
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)	11.988	11.999	11.999	11.988	11.988	11.988	11.999	11.998	11.988	11.999	11.998	11.995
Rebar Diameter- After Corrosion(mm)	12.045	12.055	12.055	12.045	12.045	12.045	12.055	12.054	12.045	12.055	12.054	12.052
Cross- section 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)	0.566	0.567	0.564	0.567	0.567	0.567	0.567	0.566	0.564	0.567	0.567	0.565
Rebar Weights- After Corrosion (Kg)	0.618	0.619	0.616	0.618	0.618	0.619	0.619	0.618	0.616	0.619	0.618	0.617
Weight Loss /Gain of Steel (Kg)	0.051	0.054	0.050	0.052	0.053	0.053	0.052	0.052	0.052	0.052	0.052	0.052

Table 3.4: Results of Average Pull-out Bond Strength Test (τu) (MPa) Control, Corroded and Exudates/ 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)	27.694	28.414	28.909	30.186	18.532	17.726	17.738	18.372	28.524	29.244	29.739	31.016
Bond strength (MPa)	11.540	12.322	12.720	12.949	9.048	8.952	8.772	8.809	13.779	14.561	14.959	15.187
Max. slip (mm)	0.129	0.127	0.144	0.151	0.083	0.088	0.082	0.081	0.124	0.122	0.139	0.146
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)	12.030	12.030	12.033	12.033	12.024	12.022	12.021	12.022	11.995	11.988	11.995	11.997
Rebar Diameter- After Corrosion(mm)	12.030	12.030	12.033	12.033	11.975	11.973	11.972	11.973	12.052	12.045	12.051	12.054
Cross- section Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.049	0.049	0.049	0.049	0.057	0.057	0.057	0.057
Rebar Weights- Before Test (Kg)	0.565	0.567	0.565	0.567	0.568	0.566	0.566	0.566	0.566	0.567	0.566	0.566
Rebar Weights- After Corrosion (Kg)	0.565	0.567	0.565	0.567	0.528	0.525	0.525	0.526	0.617	0.618	0.617	0.618
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.040	0.041	0.041	0.040	0.052	0.052	0.052	0.052

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

	Non-corroded Control Cube				**Corroded Cube Specimens**				**Exudate / Resin steel bar coated specimens**			
Failure load (KN)	49.439	60.291	62.981	64.308	-35.029	-39.384	-40.355	-40.767	53.916	64.972	67.658	68.823
Bond strength (MPa)	27.533	37.646	45.014	46.996	-34.330	-38.519	-41.361	-41.999	52.276	62.653	70.535	72.410
Max. slip (mm)	55.986	44.041	76.406	86.420	-33.307	-27.728	-41.236	-44.521	49.940	38.366	70.171	80.247
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)	0.247	0.266	0.237	0.293	0.243	0.282	0.215	0.208	0.243	0.241	0.215	0.258
Rebar Diameter- After Corrosion(mm)	0.457	0.475	0.516	0.504	-0.634	-0.596	-0.662	-0.670	0.638	0.600	0.667	0.674
Cross- section Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	-13.251	-13.251	-13.251	-13.251	15.275	15.275	15.275	15.275
Rebar Weights- Before Test (Kg)	0.476	0.195	0.300	0.194	0.336	-0.177	0.106	-0.035	-0.335	0.177	-0.106	0.035
Rebar Weights- After Corrosion (Kg)	7.070	7.922	7.522	7.795	-14.545	-15.087	-14.950	-14.859	17.021	17.768	17.578	17.453
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	100.000	-22.631	-22.414	-20.310	-22.631	29.250	28.889	25.485	29.250

3.2 Failure load, Bond Strength, and Maximum slip

Like other composite elements, the performance of reinforced concrete structures depends on the relationship between steel and concrete, which ensures reliable load transfer between the two materials. In addition to the interactions between them, the interfacial properties of reinforced concrete are affected by a large number of parameters related to steel and concrete. These various aspects are discussed in detail in [29] causing heterogeneity throughout the reinforced concrete border region, which among other things affects the adhesion of reinforced concrete Thus, the operational and maximum strength of reinforced concrete structures is a function of the strength of the connection mechanism between the concrete and steel [30, 31]. Research on the steel-concrete bond has followed the materials evolution, such as high compressive strength concretes, concrete with additives, and self-compacting concretes [32-35]. Steel-concrete bond is also a subject associated with the quality control of reinforced-concrete structures [36-38], and the performance of reinforced concrete under extreme conditions, such as in high-temperatures environments and under corrosion [39]. However, although there are several studies on the steel-concrete bond, few of them have evaluated the performance of reinforcing bars with diameters less than 10.0 mm, which includes 5.0, 6.3, and 8.0 mm diameters, which are normally used in reinforced-concrete elements. In addition, the concrete evolution is making possible the design and production of slender reinforced concrete components, especially by the precast sector, applying predominantly thin rebars.

The bond strength values for the control were 11.54MPa and 12.949 MPa (27.533% and 46.996%), corroded 8.772 MPa and 9.048 MPa (-41.999% and -34.33%), coated 13.779 MPa and 15.187 MPa (52.276% and 72.41%). The peak values of bond strength percentiles recorded for comparison were controlled at 46.996% against corroded and coated -34.33% and 72.41%, respectively. The computed mean and percentile values were differential, controlled from 1.409MP and 19.463% against 0.276 MP and 7.669% corroded, the values covered were 1.408 MP and 20.134%. From the values obtained, the corroded samples showed lower adhesive tensile forces compared to the increasing values for coated samples and controlled with adhesive tensile strength. The decrease in value and the lower tensile strength of the corroded sample is due to the influence of corrosive attack, which causes a change in surface condition with swelling and reduction of fibers affecting the deformed rib, fine reinforcing steel. By cutting the ribs with bark, the interface between concrete and steel is significantly reduced. The proven properties of coated samples demonstrate the effectiveness and effectiveness of exudates/resin in preventing corrosion attacks on reinforced concrete structures installed in coastal marine environments. Different values between controlled, corrugated, and coated elements indicate corrosive curses and harmful effects on uncoated samples. The coated samples compared to the reference range (controlled) had closed values indicating the effectiveness and effectiveness of the exudates/resin-coated elements. The effect of corrosion attack was strongly observed in the uncoated samples, leading to high yields in low load applications.

Maximum hatching yield controlled mm and 0.127 mm and 0.121 mm (44.041% and 86.42%), corroded 0.081 mm and 0.088 mm (-44.521% and -27.728%), coated with 0.122 mm and 0.146 mm (38.366% and 80.247%). The mean and maximum percentile recorded values of the controlled samples were 86.42% versus the corroded and coated samples of -27.728% and 80.247% and with different recorded values from the control 0.024 mm and 42.379% versus the corroded values of 0.007 mm and 16.793% and closed values 0.024 mm and 41.881%. The maximum percentile values obtained for comparisons between tested samples show that corroded samples show less slip and lower failure percentiles and loads, whereas coated samples show higher slip and increased values. Controlled and coated sample reference range values maintain a very close range of values compared to corroded samples. The effects of experimental tests show corrosion attack on the reinforcement, resulting in poor slippage, reduction of deformed ribs, large and swollen changes, and surface modifications affecting the interface between reinforcement and concrete.

From the results, the average values of Tables 3.1, 3.2, and 3.3 are shown in Table 3.4 and summarized in 3.5 of 3.4 about the difference between the percentile value, bond breaking load, bond strength and maximum slippage in the application, failure under low load with percentile value reduced for controlled and sealed concrete cube samples. The results showed an indication of the effect of corrosion on destructive adhesion, adhesion strength, and maximum slip, as validated by the studies of [11, 19-24]. The presence of corrosion reduces the productivity of the corroded material and reduces the mechanical properties of the surface modification, which affects the bonding and interaction between the concrete and the reinforcing steel.

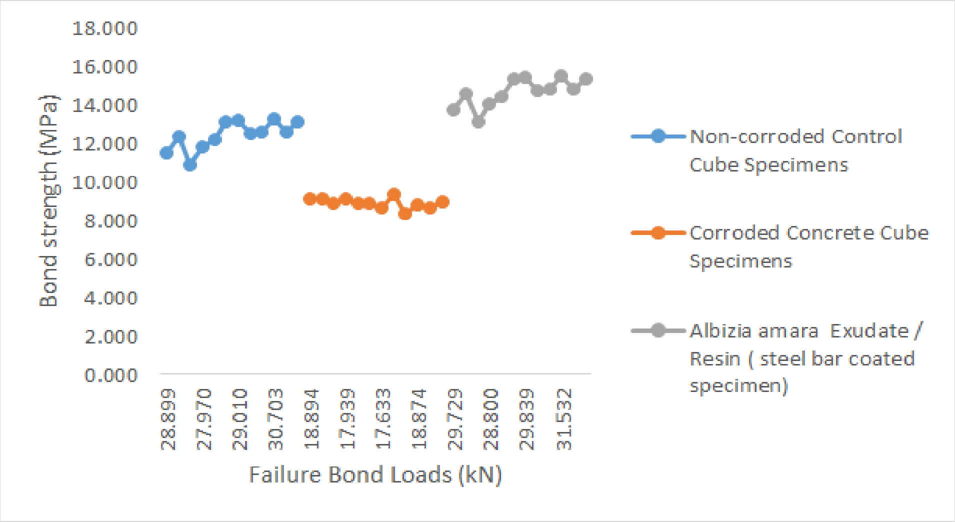

Figure 1: Failure Bond loads versus Bond Strengths

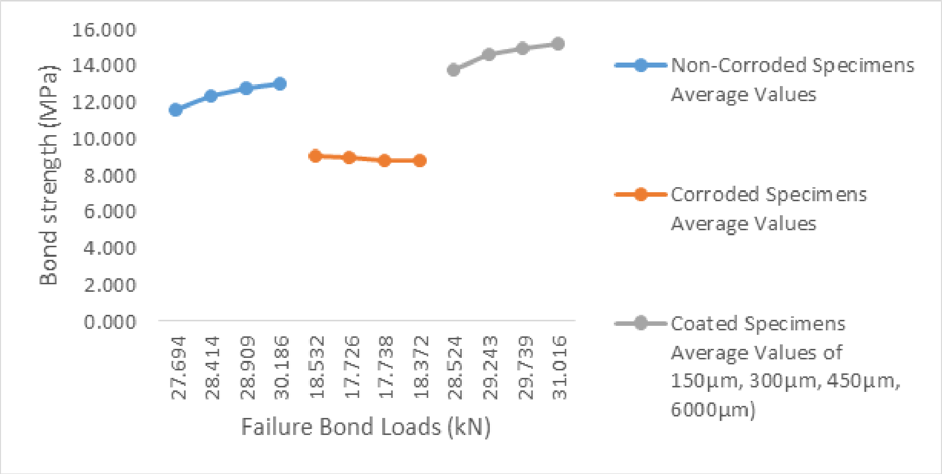

Figure 1a: Average Failure Bond loads versus Bond Strengths

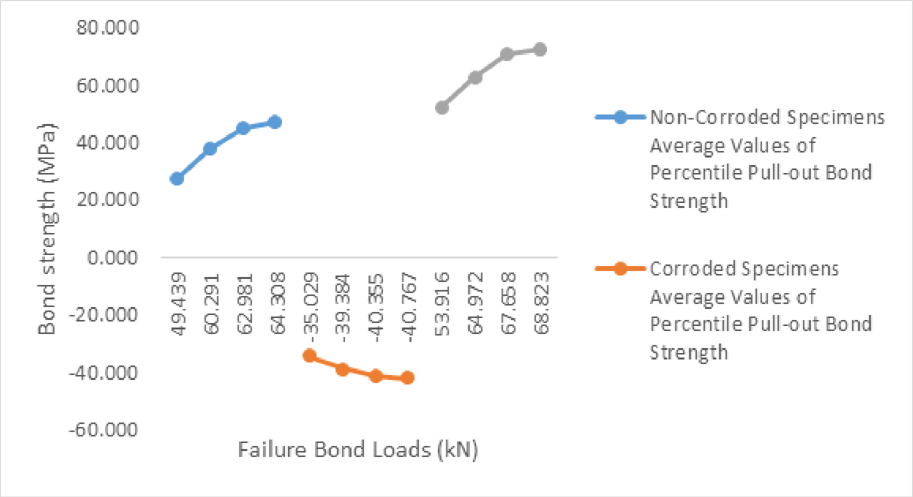

Figure 1b: Average Percentile Failure Bond loads versus Bond Strengths

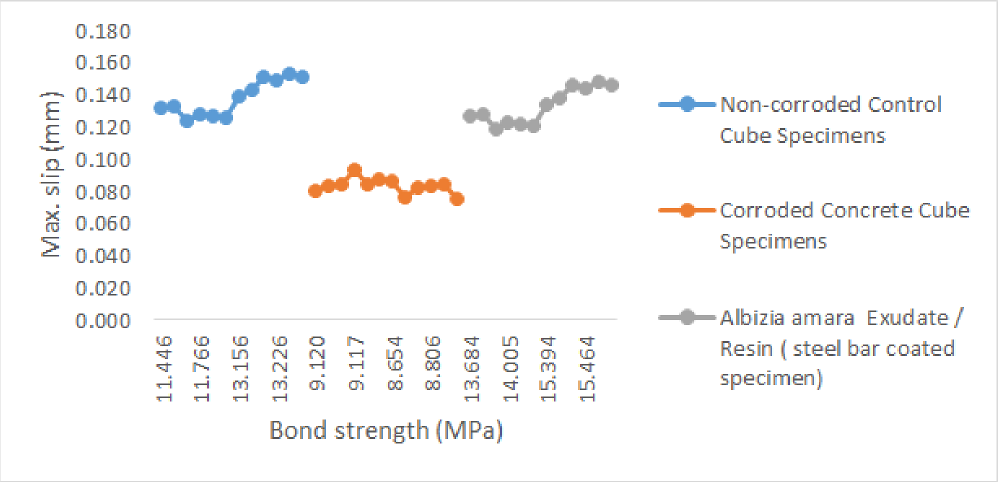

Figure 2: Bond Strengths versus Maximum Slip

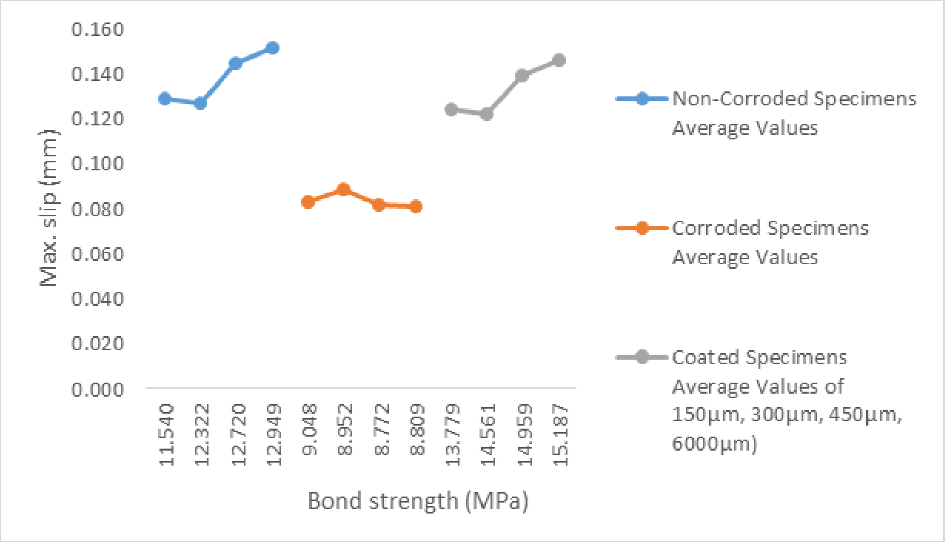

Figure 2A: Average Bond Strengths versus Maximum Slip

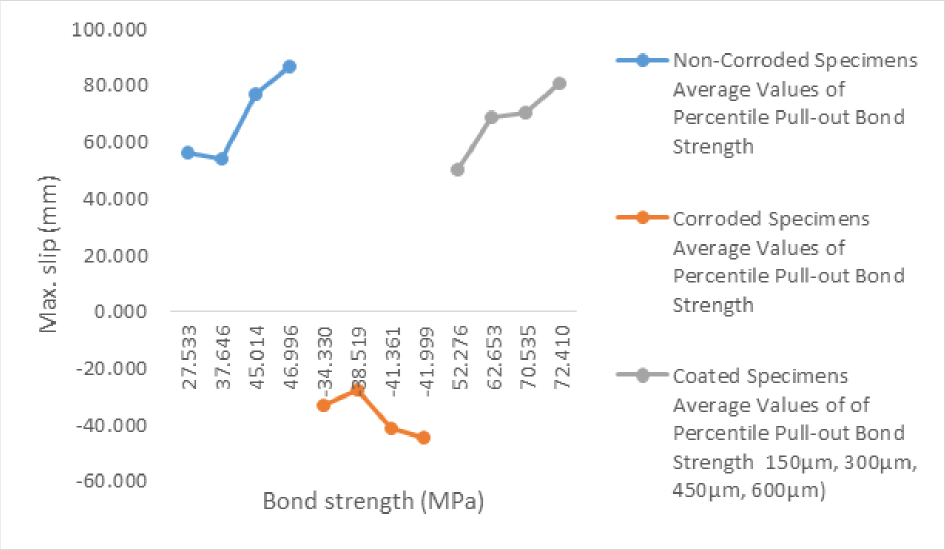

Figure 2B: Average Percentile Bond Strengths versus Maximum Slip

3.3 Mechanical Properties of Reinforcing Bars

The bond strength is mainly derived from the weak chemical bond between steel and hardened cement, but this strength is destroyed under a small pressure. Once slippage occurs, friction will help bond. In smooth steel bars, friction is an important part of strength. Reinforcing steel bars with ribs under increased sliding connections mainly depend on the bearing or mechanical interlocking between the ribs and the surrounding concrete on the surface. This research introduced the application of exudates/resin to increase the slippage problem encountered by smooth reinforcing steel. The effect of corrosion on reinforced concrete structures affects the mechanical properties of reinforcing steel, mainly due to the reduction in cross-section and bonding properties between concrete and reinforcing steel [40, 41]. In addition, corrosion products cause stresses in the radial direction to the axis of the reinforcement, which are not supported by the limited plastic deformation of the concrete, leading to damage and displacement of the concrete ceiling [42, 43].

The corrosion mechanism that causes reinforcement failure has been a problem in global research, but the impact of natural corrosion on the mechanical properties of reinforcement is an insignificant part of this study [40, 44, 45].

Data presented in table 3.1, 3.2, and 3.3 and collapsed into table 3.4 and further (finally) summarized into 3.5 accounted for the behavioral characteristics of the mechanical characteristics of controlled, uncoated (corroded) and coated concrete cube members subjected to failure state in Instron Universal Testing machine after corrosion accelerated induced process for 360 days and ascertained the periodic performances of the samples on an interval of 3 months respectively as stated in the tables and plotted in figures 1 – 6b. The controlled samples result are 100% values because they are pooled in a tank of freshwater of compliance to (BS 3148) requirements.

The results are summarized into minimum and maximum values obtained from tables 3. 4 and 3.5. Nominal diameter steel bars of all samples are 100%, and the minimum and maximum diameters of the steel bars measured before the test is within the range of 12.00mm and 12.00mm (0.457% and 0.516%). The diameter of the rebar uncoated samples (corroded) after corrosion test are 11.972mm and11.975mm (-0.67% and -0.596%), after coated are 12.045mm and 12.054mm (0.656% and 0.674%), having peak percentile values of -0.596% corroded and 0.674% coated.

The computed average and percentile differential values are controlled 0.003mm and 0.059, corroded is 0.003mm and -1.266% and coated samples are 0.009mm and 0.074%. The obtained computed results of the nominal reinforcing steel with no traces of corrosion effect is 100%, the comparative results after corrosion and the potential differential values of the tested samples showed percentile values reduction in corroded samples resulting from induced effect from corrosion while the coated samples exhibited a potential increase in volumetric based on varying coating thicknesses. Results confirmed the negative effect of corrosion on reinforcing steel embedded in concrete and exposed to corrosive media as validated by the studies of [11, 19-24]..

The results of cross - sectional area for uncoated (corroded) are 0.049mm and 0.049mm (-13.251% and -13.251%), for coated are 0.057mm and 0.057mm (15.275% and 15.275%). The result for rebar weight before test for all samples are 0.565Kg and 0.567 Kg (7.07% and 7.922%), weight after corrosion test for corroded are for 0.525Kg and 0.528Kg (-15.087% and -14.545%), coated are 0.617Kg and 0.618Kg (17.021% and 17.768%), and weight loss /gain of steel are corroded 0.041Kg and 0.044Kg (-22.631% and -20.31%) and coated values are 0.052Kg and 0.052Kg (25.485% and 29.25%).

The average and percentile differential values obtained of rebar weight after corrosion test are controlled 0.002Kg and 0.852%, corroded are 0.003Kg and 0.542%, the coated are 0.001Kg and 0.747%. The values for rebar unit weight loss/gain are corroded 0.001Kg and -2.321% and coated are 0.005Kg and 3.765%. The results of cross-sectional reduction/ increase, as well as rebar unit weight loss /gain, showed the effect of corrosion on uncoated reinforcing towards coated and reference range (controlled). The effect of corrosion causes cross-sectional reduction, decreased percentile values, and weight loss while coated samples exhibited a volumetric increase and minute weight gain resulting from varying coating thicknesses. Entire results showed the potential efficiency and effectiveness in the use of exudates/resin as inhibitory materials against corrosion attacks on reinforced concrete structures exposed in corrosive media as validated by the studies of [11, 19-24].

From the results obtained and presented in the figures, the effect of corrosion on uncoated and coated reinforcing steel are enumerated, in figures 3 and 6b on the diameter of rebar, it can be seen that the diameter of uncoated decreased by the maximum value of 0.596% and coated increased by 0.674%, for the cross-sectional area, corroded has maximum reduction value -13.251% and coated increased by and 15.275%, weight loss, and gain are corroded -20.31% decreased (loss) and coated 29.25% increase (gain). Indication, as analyzed from the experimental work, showed that the effect of corrosion on uncoated concrete cubes caused diameter and cross-sectional area reduction and weight decrease while coated concrete cubes have a diameter and cross-sectional area increases and weight gain resulting from

the varying thickness coated to reinforcing steel.

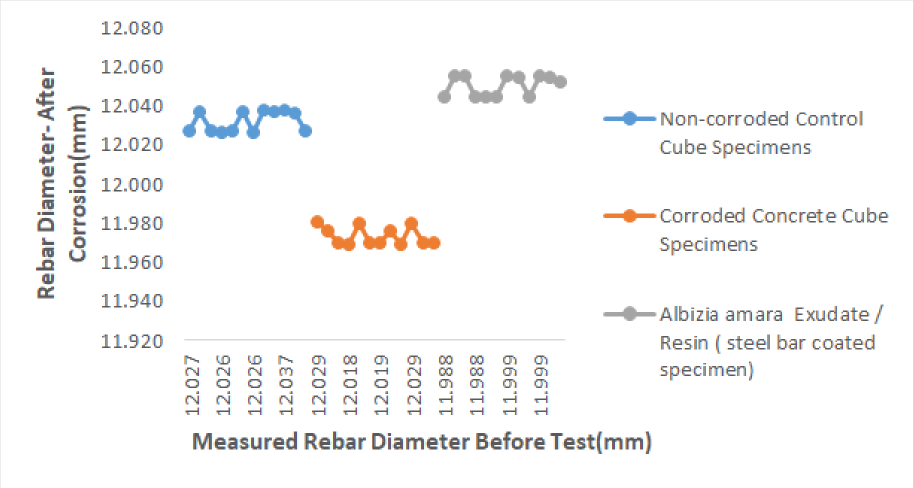

Figure 3: Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

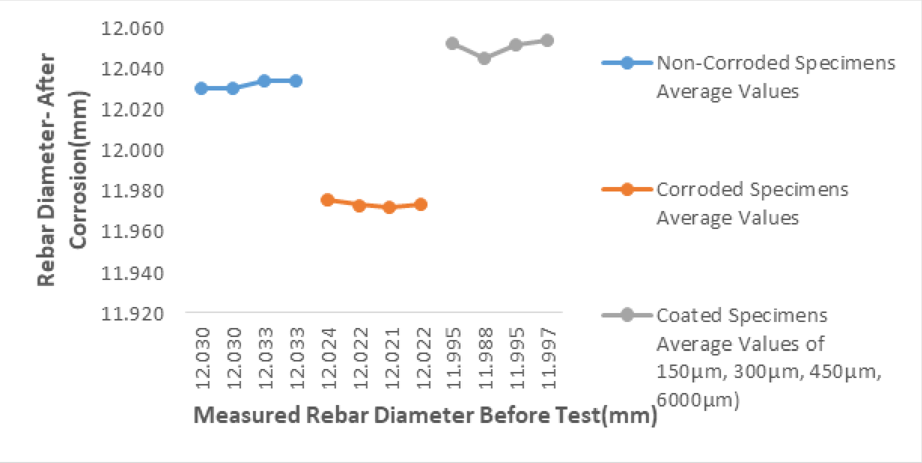

Figure 3A: Average Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

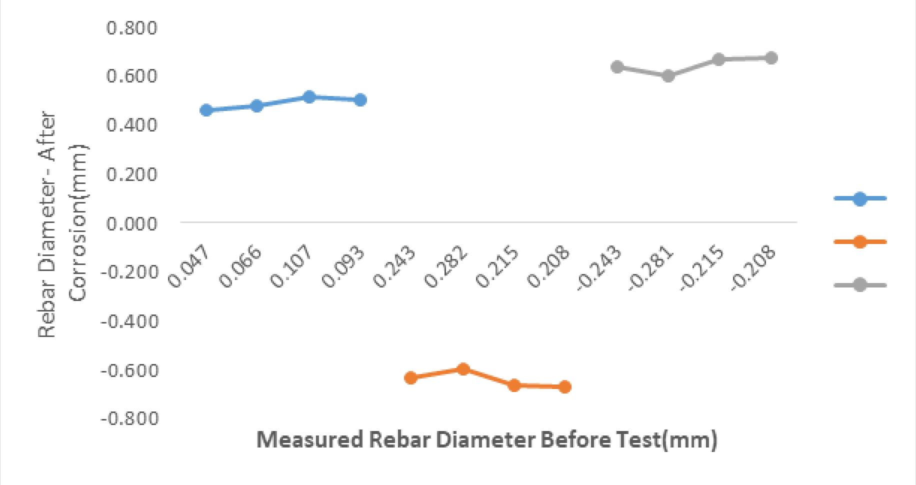

Figure3b: Average Percentile Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion

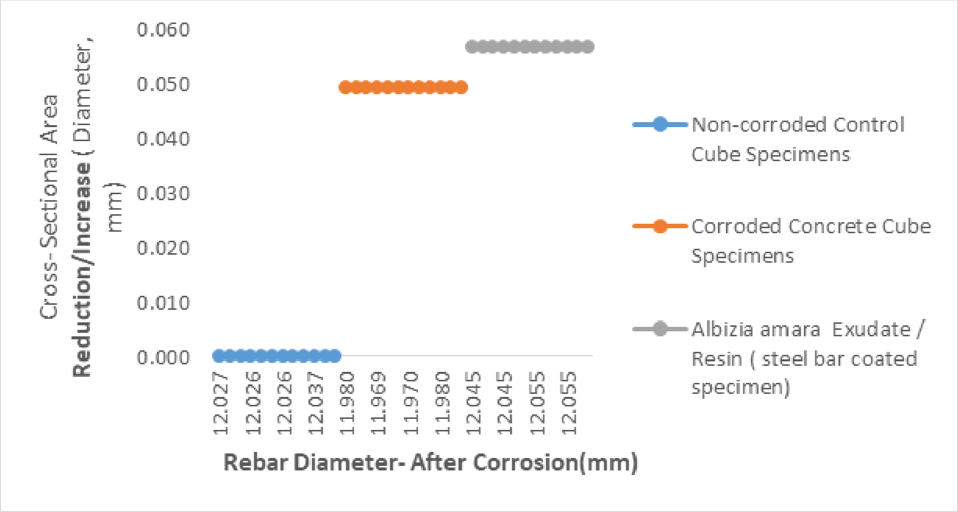

Figure 4: Rebar Diameter- After Corrosion versus Cross - Sectional Area Reduction/Increase

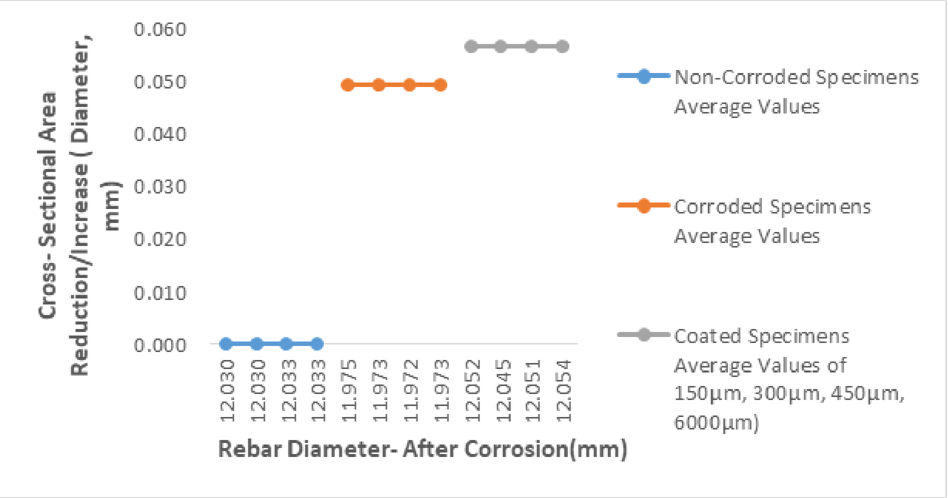

Figure 4A: Average Rebar Diameter- After Corrosion versus Cross – Sectional Area Reduction/Increase

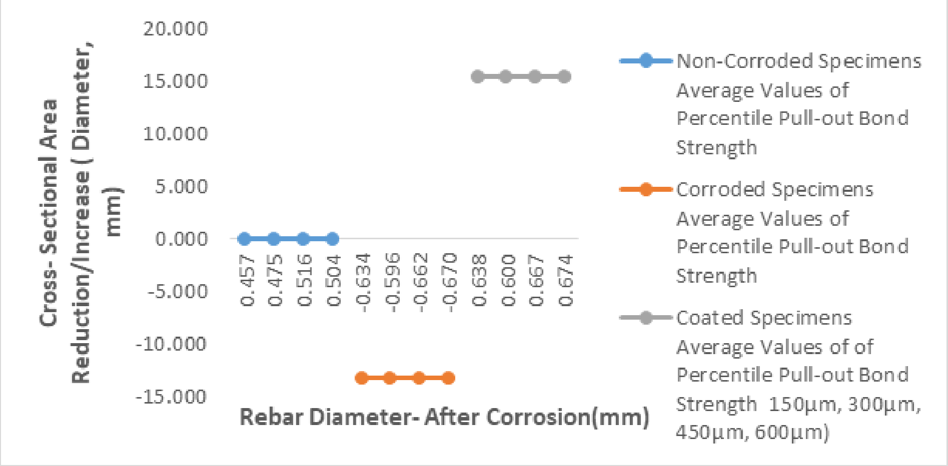

Figure 4B: Average percentile Rebar Diameter- After Corrosion versus Cross - sectional Area Reduction/Increase

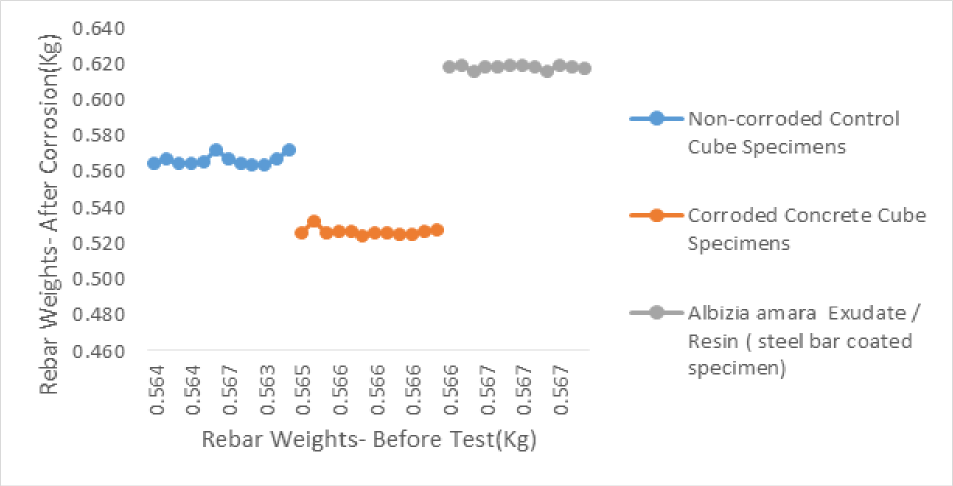

Figure 5: Rebar Weights- Before Test versus Rebar Weights- After Corrosion

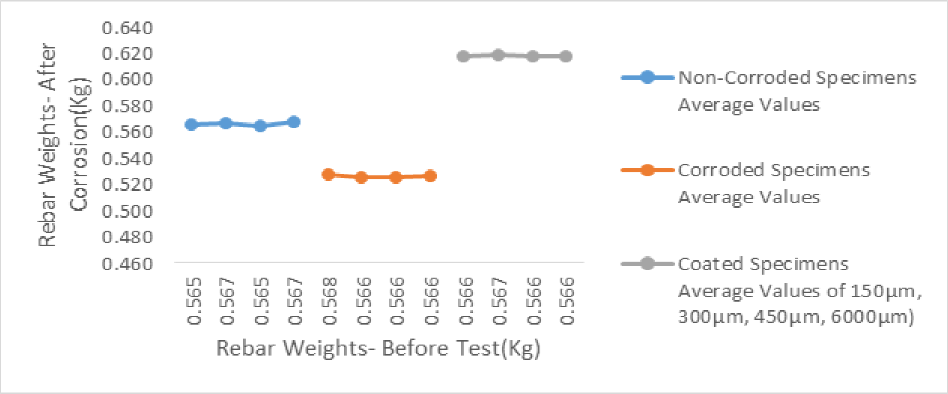

Figure 5A: Average Rebar Weights- Before Test versus Rebar Weights- After Corrosion

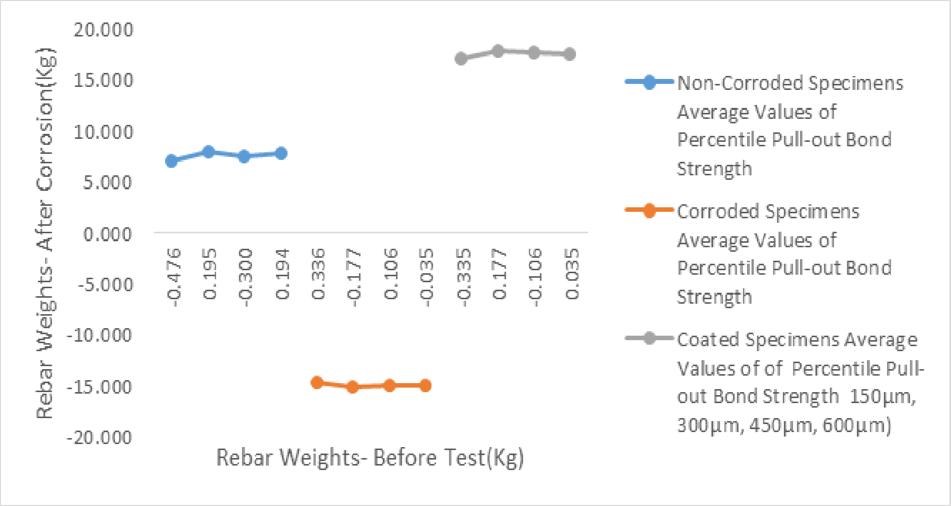

Figure 5B: Average Percentile Rebar Weights- Before Test versus Rebar Weights- After Corrosion

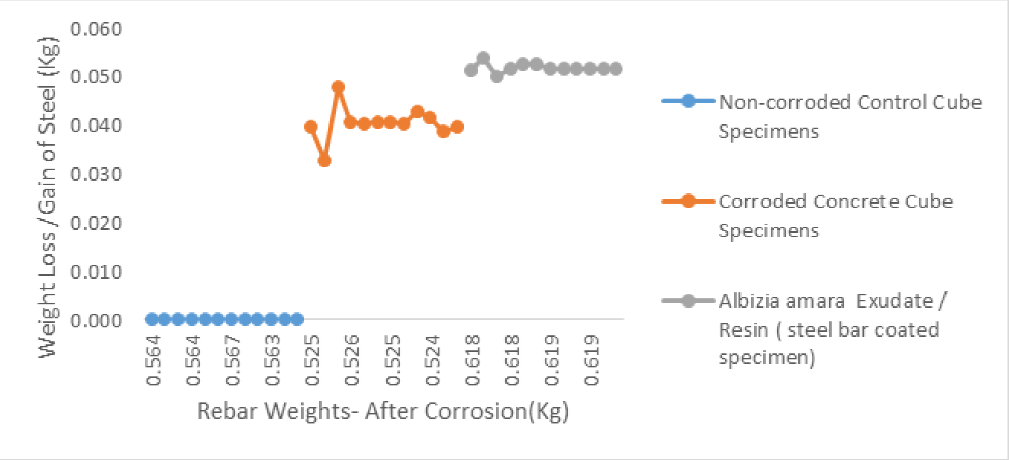

Figure 6: Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

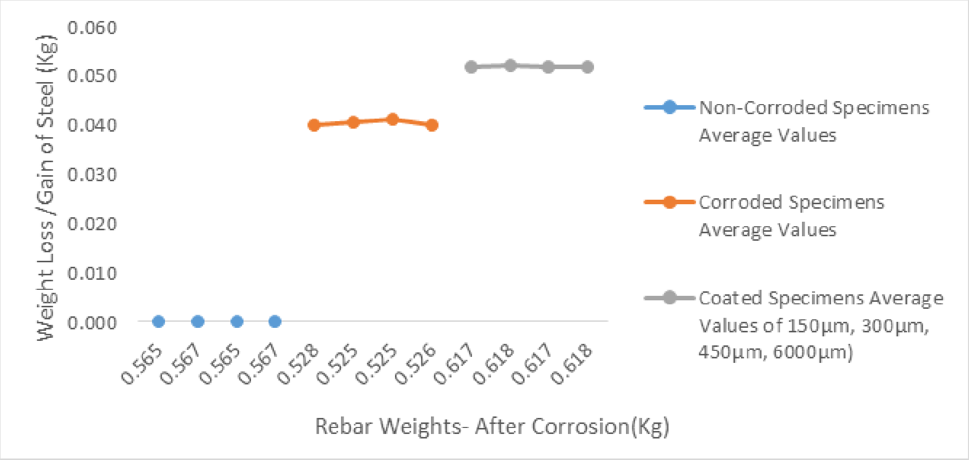

Figure 6A: Average Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

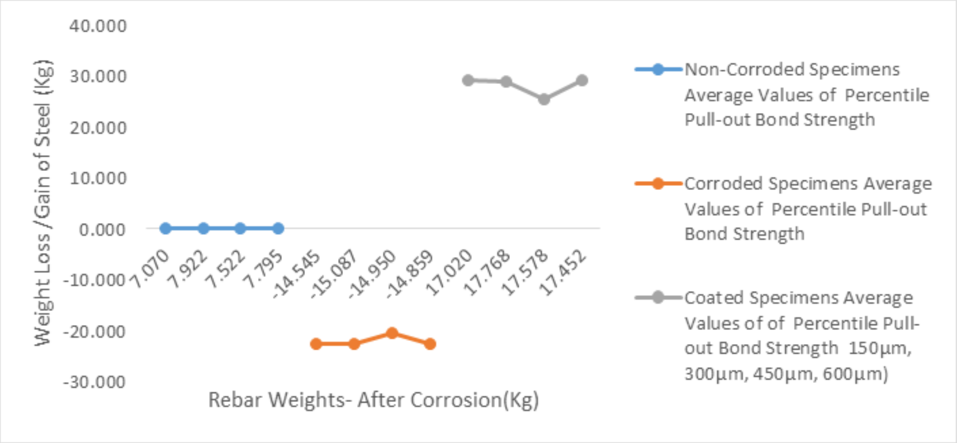

Figure 6B: Average percentile Rebar Weights-After Corrosion versus Weight Loss /Gain of Steel

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

For comparison: From the data in Tables 3.1, 3.2, and 3.3 and Figures 3, 4, 5, and 6 for 12 controlled samples collected in freshwater tanks for 360 days, 12 uncoated and 12 coated, collected in 5% aqueous sodium chloride solution. (NaCl) solutions for 360 days ad, are 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 and percentile values for joint load failure, maximum bond and slip strength, reduction/enlargement of cross-section, the diameter of reinforcement before/after corrosion, weight loss/increase. The differential maximum failure load potential, as well as the ratio of the maximum percentile values, indicate that the corroded samples exhibited lower breaking loads and higher deviation values from the mean range compared to the controlled and coated samples. The results obtained indicate the effect of corrosion on reinforced concrete structures immersed in a corrosive environment. The mechanical properties of the reinforcement have been adversely affected by the reduction of reinforcing steel fibers, the reduction of deformed ribs, and the swelling and volume changes in diameter and cross-sectional area. From the values obtained, the corroded samples showed lower adhesive tensile forces compared to the increasing values for coated samples and samples controlled with adhesive tensile strength. The decrease in value and the lower the tensile strength of the corroded sample is due to the influence of corrosive attack, which causes a change in surface condition with swelling and reduction of fibers affecting the deformed rib, fine reinforcing steel. By cutting the ribs with bark, the interface between concrete and steel is significantly reduced. The proven properties of coated samples demonstrate the effectiveness and effectiveness of exudates/resin in preventing corrosion attacks on reinforced concrete structures installed in coastal marine environments. Different values between controlled, corrugated, and coated elements indicate corrosive curses and harmful effects on uncoated samples. The coated samples compared to the reference range (controlled) had closed values indicating the effectiveness and effectiveness of the exudates/resin-coated elements. The effect of corrosion attack was strongly observed in the uncoated samples, leading to high yields in low load applications.

The maximum percentile values obtained for comparisons between tested samples show that corroded samples show less slip and lower failure percentiles and loads, whereas coated samples show higher slip and increased values. Controlled and coated sample reference range values maintain a very close range of values compared to corroded samples. The effects of experimental tests show corrosion attack on the reinforcement, resulting in poor slippage, reduction of deformed ribs, large and swollen changes, and surface modifications affecting the interface between reinforcement and concrete.

The calculation results of nominal concrete steel without corrosion marks, the comparison results after corrosion, and the value of the potential difference of the tested samples showed a decrease in the percentile of the samples corroded due to induced corrosion, while the coated samples showed a potential increase in volume, different layer thickness. The results confirmed the negative impact of corrosion on reinforcing steel embedded in concrete and exposed to a corrosive environment.

The results of the reduction/gain of the cross-section and the loss/increase in the weight of the reinforcement showed that there was a corrosion effect on the uncoated reinforcement in the coating and the reference (controlled) area. The corrosion effect causes a reduction in cross-section, a decrease in percentile value, and weight loss, while the coated samples show a minimal increase in volume and weight increase due to different coating thicknesses. The overall results show the potential effectiveness and effectiveness of using exudates/resin as an inhibitor against corrosive attack on reinforced concrete structures exposed to corrosive environments.

The evidence analyzed from experimental work showed that the corrosion effect on uncoated concrete cubes resulted in a reduction in diameter and cross-sectional area and a weight reduction, whereas coated concrete cubes resulted in diameter and cross-sectional area and an increase in weight of different thicknesses encased with reinforcing steel.

4.0 CONCLUSION

In the experiment, the results obtained are drawn as:

i. The exudate/resin has an inhibitory effect on corrosion as its waterproofing properties resisted to corrosion penetration and attacks.
ii. The interaction between concrete and steel in the coated component is greater than that in the corroded samples
iii. The properties of the bonds in the coated and controlled components are greater than those in the corroded
iv. The lowest failure bond load, bond strength, and maximum slip were recorded in corroded member
v. The coating and control sample registered higher values of bond load and bond strength.
vi. Weight loss and reduction in cross section are mainly recorded in corroded coatings and controlled samples

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