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Original Research Article

Rib Geometry as Functional Parameter on Bond Strength of Exudate-Coated and Non-Coated Reinforcing Steel Exposed to Corrosive Media

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Abstract

The interaction between concrete and reinforcement is expected to be perfectly warm to allow high bond loads on the surrounding concrete structure. The research work investigated the application of exudates/resin as an inhibitory substance in averting the effect of corrosion on reinforced concrete structures in the built environment of high salinity. The experimental data tests were carried out on 36 concrete cubes with the first set of 12 controlled concrete samples placed in freshwater for 360 days and the second set of 24 cubes divided into 2 with 12 uncoated samples and 12 coated samples with exudate/resin as described in the test procedure and immersed in 5% aqueous sodium chloride (NaCl) solution for 360 days, routine three months with 90-day intervals, 180 days, 270 days, and 360 days. Comparatively, the minimum and maximum values for average and percentile for failure bond loads, bond strength and maximum slip, cross-sectional reduction/increase, the diameter of rebar before /after corrosion, weight loss/gain. The listed results show reduced values with the application of lower failure loads of corroded samples compared to controlled and coated samples with closer values and higher failure loads. The calculated and comparable value for the bond strength of the controlled samples was 69.572% compared to the corroded and coated samples with -42.481% and 98.031%. The indicative count results showed a reduced value and lower failure load of corrosive samples and for samples coated with a value that increases with the reference value in the controlled sample range. In comparison, the corroded samples showed a lower slip value compared to the controlled and coated samples with a higher slip value compared to the failure status, indicating a contribution to the exudate/resin effect in the slip test. The calculation results show an indication of the effect of corrosion on failure bond load, bond strength, and maximum slip. The presence of corrosion reduces the efficiency of the material used, reduces mechanical properties, and affects the bonding and interactions between the concrete and the steel reinforcement and the surrounding concrete. The results obtained indicate that the effect of corrosion on reinforcing steel hurts the mechanical properties of the cross-sectional area, a decrease in diameter and weight loss and surface modification, thereby reducing the value of control slip and coated samples and reducing the interaction between concrete and reinforcing steel.

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

1.0 INTRODUCTION

Corrosion of steel reinforcement presence can reduce the serviceability of concrete structures in many ways. First, it produces corrosion-enhancing products, which produce tensile stress in the concrete around the reinforcing steel, which can cause concrete cracking. Second, corrosion products are highly porous, weak, and form around reinforcing steel, thereby reducing the bond strength between reinforcement and concrete [1]. In addition, corrosion reduces the cross-sectional area of steel reinforcement, reducing the ductility of the structure, especially when corrosion occurs.

Bonding ensures that the steel bars slip little or no in relation to the concrete and the way stresses are transferred to the reinforced concrete [2]. Adhesion resistance consists of chemical adhesion, friction and mechanical blocking between the rod and the surrounding concrete. To prevent hardened concrete and structural forms from sticking, oils are now widely used in construction site construction.

The adhesive strength of reinforcing steel to concrete has been investigated by many authors.

Investigated the strength properties of epoxy-coated steel reinforcement embedded in concrete, taking into account many tensile tests [3]. The degradation of the bond strength of steel bars and concrete under cyclic loading was measured by [4]. The effect of different corrosion rates of steel bars on the adhesive strength of concrete was demonstrated by [5].

Investigated the effect of a rust remover on the adhesive strength of reinforcing steel. He has studied the effect of a new chemical developed by a chemical company called stopping rust, or removing rust, in removing rust and its effect on the bond between reinforced concrete bars and concrete. The results showed that the adhesive strength was reduced by 7.6% when the bars were covered with rust [6].

Investigated the bond strength of corrosive and exudates /resin coated specimens of reinforced concrete structures of 150mm x 150mm x150mm concrete cubes, immersed in accelerated media for 150 days with non-coated and coated reinforcements. Non-corrosive and exudates / resin-coated specimens have high bond strength and low failure load over corroded members [7].

Investigated the adhesive strength of high-strength concrete with high-strength reinforcing steel. Concrete with a compressive strength of about 70 MPa and steel of 500 MPa are used. It was concluded that the reduced samples with smaller rod sizes had higher adhesive strength than samples with large rod diameters. The test results also show that the initial hardness increases with the amount of concrete around the reinforcement [8].

Investigated the bond strength of reinforcing steel bars in self-compacting concrete [9]. They came to the conclusion that self-compacting concrete samples had a higher bond with reinforcement than normal concrete samples and that the correlation between bond strength and compressive strength of normal concrete was more consistent. The adhesive strength of self-sealing concrete and steel bars was also investigated by [10] as a function of various parameters.

Investigated the effect of various barrier layers on steel bars to protect them from corrosion. They used four different layers, namely polyimide silicon epoxy with two different pigments, polyaromatic polyester isocyanate and polyol aromatic acrylic isocyanate. It was concluded that the coating formulation based on epoxy-silicon-polyamide resin had good mechanical properties in addition to protecting steel rods against corrosive media [11].

Evaluated the effect of non-coated and exudates/resin coating on the bond strength parameters of reinforced concrete structures under a harsh corrosive environment. The results of the average failure bond load are 16. 019% percent difference of control and coating. Relatively, corroded members showed lower failure load and bond strength properties for the coated and controlled samples. High values of the failure load, bond strength, and pull-out bond tests of the maximum slips of the exudates/resin coating samples are recorded on the depleted samples [12].

Studied the premature and reduced service life and durability of reinforced concrete and attributed it to the corrosion effect on the reduction of bond strength between steel and concrete. Experimental results showed decreased percentile values against control and exudates/resins coated members. In comparison, obtained values of corroded specimens decrease while non-corroded and exudates/resins coated members increases, these indications clearly showed the potential of acacia senegal exudates/resins in coated activities of reinforcing steel. Entire results showed higher values of pullout bond strength and low failure load in control and coated to corroded specimens [13].

Studied chloride and carbonation contamination presence in marine zones of the Niger Delta of Nigeria are primary causes of poor bonding between steel reinforcement and concrete that has led to premature deterioration in reinforced concrete structures in harsh environments. Reinforcing steel bars were coated with varying thicknesses of 150μm, 300μm, and 450μm against non-coated and embedded in concrete cubes, cured in accelerated corrosive media, and investigated pull-out bond strength parameters. Relatively, results of corroded specimens decreased while control and cola acuminata exudates/ resins steel bar coated specimens increased resulted due to layered bonding agent properties of exudate specimens. Entire results showed that natural exudates/resins should be explored as inhibitors to corrosion effects in steel reinforcement in a concrete structure in chloride expected regions [14].

Studied the bond strength of reinforcing steel and concrete of non-corroded, corroded, and khaya senegalensis exudates/resin coated specimens. The bond strength of the corrugated and non-coated specimens exhibited a higher affinity for drag compared to the depleted ones. Exudates/resins coated specimen's performance. The investigated exudates/resins showed maximum slip strength over corrosion resistance with its recorded low failure load, high bonding, and corrosion resistance [15].

Investigated the effect of corroded and coated reinforcement on the pull-out bond separation of control, corroded and resins/exudates paste coated steel bar. Overall results showed that coating values increased compared to corroded specimens, resulting in adhesion properties from resins/exudates to strengthen reinforcement and as a protective coat against corrosion [16].

Studied the bond behavior of corroded reinforcement bars and found heavy loss of reinforcement due to corrosion reaches 2%, concrete fractures along the bar. A low amount of corrosion increases both bond strength and bond stiffness but decreases significantly at slip failure. However, they claim that when the mass loss exceeds 2%, the bond strength decreases [17].

Charles *et al*., (2018) the experimental models were subject to tensile and pull-out bond strength and the results obtained were not deteriorated by failure load, bond strength, and maximum slip [18].

Charles *et al*., (2018) investigated as a major contributor to service life, integrity, and the ability of reinforced concrete structures in the marine environment of saline origin. The results obtained on the comparison show that failure bond, 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 corrugated and coated members. Values of corroded members are lower compared to coated members. The overall results suggested the application of resins/exudates to reinforcement as a protective layer against corrosion [18].

Investigated the strength of the bond between concrete and reinforcement that led to diameter reduction due to the diminishing effect of reinforcing steel from the coastal area with saltwater. The application of Artocarpus altilis resin extracts on reinforcing steel with a coating thickness of 150µm, 300µm, and 450µm, and non-coated reinforcing steel was embedded into a concrete cube, immersed in sodium chloride, and accelerated corrosion process implored for 150 days. Comparative results show that the values of the corroded samples decreased and the exudates/resins coated samples increased. Overall results showed higher values of pull-out bond strength under control and coated exudates/resins against corroded specimens [20].

Explored the impact 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 evaluate the effects of corrosion. Tests have shown that the values of non-coated samples have deteriorated due to reduced corrosion attacks. The average percentage bond strength load is 33.13% and the coating members are 45.66% and 71.84% compared to the control differential. The mean maximum slip values were 0.083mm and mean 33.87% and 75.30%, respectively, compared to the control and finish - 25.30%. Experimental results show that reduced samples have lower bond strength and higher failure bond load and lower maximum slip, while exudates/resin coated samples have lower test specimens and higher percentage values compared to corrosive samples [21].

2.0 TEST PROGRAM

The use of exudate/resin pastes extracted from plant trunks coated to steel reinforcement was studied; different coating thicknesses were introduced and then embedded in concrete cubes. The corrosion acceleration process was introduced as a corrosive medium of sodium chloride (NaCl) to determine the potential use of exudate/resin materials in controlling the changes and effects that usually occur to reinforcing steel in concrete structures in coastal waters. The test sample refers to the level of hard acidity, which is 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 of which are centrally coated specimens for the control, uncoated, and coated specimens for pullout - bond testing with a diameter of 12 mm and immersed in sodium chloride for 360 days. The initial cube cured days were 28 days. Acid-corrosive media solutions were changed monthly and concrete samples were reviewed for greater efficiency and modification.

2.1 Materials and Methods for Testing

2.1.1 Aggregates

Both (fine and coarse) aggregates were purchased. Both met the requirements of [22].

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 [23].

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 [24] requirements.

2.1.4 Structural steel reinforcement

Reinforcements are obtained directly from the market at Port Harcourt [25].

2.1.5 Corrosion Inhibitors (Resins / Exudates) *Calotropis procera*

Exudates were extracted from the root and fruit with toxic milky sap of gluey coating properties. It was obtained from Abiya Village bush in Bogoro Local Government of Bauchi State, Nigeria.

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 placed in a metal mold and de-molded 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 approximately 3 months between 90 days, 180 days, 270 days, and 360 days intervals, as well as failure bond loads, bond-slip, maximum slip, cross-sectional reduction/increase, 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 marine media. To test the surface and mechanical properties of the modifiers and effects, test both non-coating and exudate/resin coated specimens and immersed in 5% NaCl solution for 360 days.

2.4 Pullout-Bond Strength Test

The tensile-bond strength test of concrete cubes was carried out on a total of 36 specimens with control, uncoated, and coated members in each of the 12 specimens, and subjected to a 50 kN universal test machine according to [26]. Total numbers of 36 cubes measuring 150 mm × 150 mm × 150 mm embedded in the center of a 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 barrier, 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-sectional area, and weight loss/steel reinforcement.

3.1 EXPERIMENTAL RESULTS AND DISCUSSION

The interaction between concrete and reinforcement is expected to be perfectly warm to allow high bond loads on the surrounding concrete structure. The harmful effects of corrosion attacks have resulted in many buildings being renovated and repaired over a lifetime. The experimental data presented in Tables 3.2, 3.2, and 3.3 which are summarized in Tables 3.4 and 3.5 s are experimental tests carried out on 36 concrete cubes with the first set of 12 controlled concrete samples placed in freshwater for 360 days, and the second set of 24. Cubes divided into 2 with 12 uncoated samples and 12 coated samples with exudate/resin as described in the test procedure and immersed in 5% aqueous sodium chloride (NaCl) solution for 360 days, routine three months with 90-day intervals, 180 days, 270 days, and 360 days. Corrosion is a long-term process that can take decades to fully function. However, the ingress of sodium chloride causes corrosion to occur in a short time. The experimental work presents a suitable high salinity marine environment and the possible use of calotropis procera exudates/resins as a barrier to prevent corrosion and corrosion from exposure to high salinity or reinforced concrete structures constructed in these zones.

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

Sample Numbers	**CPC**	**CPC 1**	**CPC 2**	**CPC 3**	**CPC 4**	**CPC 5**	**CPC 6**	**CPC 7**	**CPC 8**	**CPC9**	**CPC10**	**CPC11**
	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)	29.966	27.876	28.440	29.037	29.852	29.553	30.076	29.894	29.958	31.769	30.894	31.095
Bond strength (MPa)	11.299	12.192	10.689	11.620	11.993	12.916	13.009	12.339	12.374	13.079	12.391	12.937
Max. slip (mm)	0.144	0.145	0.136	0.141	0.140	0.139	0.152	0.156	0.164	0.161	0.166	0.164
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)	11.950	11.958	11.958	11.949	11.955	11.948	11.959	11.949	11.958	11.949	11.958	11.959
Rebar Diamete r- at 28 Days Nominal(mm)	11.950	11.958	11.958	11.949	11.955	11.948	11.959	11.949	11.958	11.949	11.958	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)	0.580	0.583	0.582	0.582	0.582	0.582	0.583	0.582	0.582	0.583	0.581	0.582
Rebar Weights- at 28 Days Nominal(Kg)	0.580	0.583	0.582	0.582	0.582	0.582	0.583	0.582	0.582	0.583	0.581	0.582
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)	0.079	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)	11.947	11.968	11.950	11.958	11.958	11.969	11.958	11.948	11.958	11.959	11.948	11.959
Rebar Diameter- After Corrosion(mm)	11.908	11.929	11.910	11.919	11.918	11.929	11.919	11.908	11.918	11.919	11.908	11.919
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
Rebar Weights- Before Test(Kg)	0.582	0.582	0.582	0.589	0.582	0.582	0.583	0.582	0.582	0.583	0.581	0.589
Rebar Weights- After Corrosion(Kg)	0.542	0.542	0.540	0.543	0.543	0.542	0.543	0.542	0.543	0.543	0.541	0.549
Weight Loss /Gain of Steel (Kg)	0.040	0.041	0.042	0.040	0.040	0.041	0.046	0.040	0.046	0.039	0.040	0.033

Table 3.3: Results of Pull-out Bond Strength Test (τu) (MPa) of Calotropis procera 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)	32.294	30.204	30.768	31.365	32.180	31.881	32.404	32.222	32.286	34.097	33.222	33.423
Bond strength (MPa)	13.448	14.340	12.838	13.768	14.141	15.064	15.158	14.488	14.522	15.228	14.539	15.086
Max. slip (mm)	0.156	0.158	0.148	0.153	0.152	0.151	0.164	0.168	0.176	0.174	0.178	0.176
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	11.959	11.948	11.949	11.968	11.958	11.959	11.955	11.960	11.950	11.955	11.959
Rebar Diameter- After Corrosion(mm)	12.014	12.015	12.004	12.005	12.024	12.014	12.015	12.011	12.016	12.005	12.011	12.015
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056
Rebar Weights- Before Test(Kg)	0.580	0.589	0.582	0.582	0.582	0.582	0.583	0.582	0.582	0.582	0.581	0.580
Rebar Weights- After Corrosion(Kg)	0.640	0.640	0.638	0.641	0.641	0.640	0.641	0.640	0.641	0.641	0.639	0.647
Weight Loss /Gain of Steel (Kg)	0.059	0.051	0.056	0.059	0.059	0.058	0.059	0.057	0.058	0.641	0.057	0.067

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)	28.761	29.480	29.976	31.253	16.914	16.108	16.120	16.754	31.089	31.808	32.304	33.581
Bond strength (MPa)	11.393	12.176	12.574	12.802	7.789	7.693	7.513	7.550	13.542	14.325	14.723	14.951
Max. slip (mm)	0.142	0.140	0.157	0.164	0.081	0.087	0.080	0.079	0.154	0.152	0.169	0.176
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)	11.955	11.951	11.955	11.955	11.955	11.962	11.955	11.955	11.955	11.958	11.958	11.955
Rebar Diameter-After Corrosion(mm)	11.955	11.951	11.955	11.955	11.915	11.922	11.915	11.915	12.011	12.014	12.014	12.010
Cross-Sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.040	0.040	0.040	0.040	0.056	0.056	0.056	0.056
Rebar Weights-Before Test(Kg)	0.581	0.582	0.582	0.582	0.582	0.584	0.582	0.584	0.583	0.582	0.582	0.581
Rebar Weights-After Corrosion(Kg)	0.581	0.582	0.582	0.582	0.541	0.542	0.543	0.544	0.639	0.640	0.641	0.642
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.041	0.040	0.044	0.037	0.056	0.058	0.058	0.062

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)	70.041	83.014	85.957	86.543	-45.595	-49.358	-50.100	-50.110	83.805	97.466	100.399	100.439
Bond strength (MPa)	46.270	58.271	67.368	69.572	-42.481	-46.294	-48.971	-49.503	73.854	86.199	95.968	98.031
Max. slip (mm)	74.613	61.195	95.616	105.942	-47.387	-43.076	-52.661	-54.898	90.068	75.674	111.244	121.718
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)	0.022	0.023	0.024	0.022	0.026	0.028	0.027	0.024	0.0270	0.028	0.027	0.024
Rebar Diameter-After Corrosion(mm)	0.335	0.239	0.338	0.336	-0.796	-0.768	-0.823	-0.792	0.802	0.774	0.830	0.799
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	-28.980	-28.980	-28.980	-28.980	40.806	40.806	40.806	40.806
Rebar Weights-Before Test(Kg)	0. 259	0.257	0.261	0.256	0.258	0.251	0.259	0. 257	0.254	0.254	0.257	0.256
Rebar Weights-After Corrosion(Kg)	7.381	7.320	7.318	6.889	-15.325	-15.303	-15.299	-15.255	18.099	18.068	18.062	18.001
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	-26.710	-31.446	-24.612	-40.073	36.444	45.870	32.648	66.868

3.2 Failure load, Bond Strength, and Maximum slip

It is known that the use of deformation bars can significantly increase the bond strength of steel and concrete. The three main components that determine the bond strength between adjacent ribs are shear stress due to bonding to the beam surface, stress on the ribs (mechanical interlock), and friction. The relationship between concrete and length of reinforcement is very important for the effect of bonding on reinforced concrete structures [27, 28]. The characteristics of steel-concrete interface are influenced by an extensive range of parameters related to both steel and concrete, besides the interactions between them. This diversity of aspects, detailed in [29], results in heterogeneities in the whole steel-concrete interface influencing, among other aspects, the steel-concrete adhesion. Also, as a phenomenon influenced by many variables, it is a challenge to establish how the steel-concrete adhesion can be described in standards used for reinforced concrete design. Scientific studies on this property have been performed since the 1940s, as in [30] which investigated the factors that influence the bond between steel bars and concrete. Other relevant studies are those by [31-38]. This work implored the improvement of the bonding strength of non-deformed, less deformed, and deformed rebars embedded in concrete and exposed to corrosive media using exudates/resin and the reduction of damages faced by reinforcing steel from corrosion attacks.

Detailed results of failure bond load, bond strength, and maximum slip made on 36 concrete cubes as shown in tables 3.1, 3.2, and 3.3 and detailed into average and percentile 3.4 and 3.5 and were figured presented in 1 - 6b. The results obtained were 12 controlled, 12 non-coated, and 12 coated samples pressured to failure with 50kN Instron Universal Testing Machines as described in the testing process.

The minimum and maximum values obtained results from average and the percentile of the failed loads was controlled 28.761kN and 31.253kN (70.041% and 86.543%), corroded 16.108kN and 16.914kN (-50.11% and -45.595%), and coated 31.089kN and 33.581kN (83.805% and 100.439%). Bond strength values are controlled 11.393MPa and 12.802MPa (46.27% and 69.572%), corroded 7.513MPa and 7.789MPa (-49.503% and -42.481%), coated are 13.542MPa and 14.951MPa (73.854% and 98.031%).

The results of the maximum slip are controlled 0.14mm and 0.164mm (61.195% and 105.942%), corroded 0.079mm and 0.087mm (-54.898% and -43.076%), coated 0.152mm and 0.176mm (75.674% and 121.718%).

The evaluated differential maximum computed results are failure bond load controlled value 86.543% against corroded and coated as -45.595% and 98.031%. Obtained results enumerated showed decremented value with lower failure load application from the corroded sample as compared to controlled and coated samples having nearer values and the exhibition of higher failure load application.

Computed differential comparable maximum bond strength percentile values of the controlled sample are 69.572% against corroded and coated samples with -42.481% and 98.031%. Indicative computed results showed decreased values and lower failed to load application of the corroded samples towards coated sample with increased values with reference range value from the controlled sample. Evidenced showed the ranges of values between controlled and coated are closed with exhibitive higher failure load application.

The computed peak differential values obtained from controlled, corroded, and coated samples of maximum slip are 105.942%, -43.076%, and 121.718%. Comparably, it can be seen that corroded samples possess lower slippage values towards controlled and coated samples with higher slippage values to failure states indication the contributive effect of exudate/resin in the slipping test as related to the works of [7, 12, 13, 15, 14]. The computed results showed indications of the effect of corrosion on bond failure, bond strength, and maximum slip. The presence of corrosion reduces the efficiency of the material used by reducing the mechanical properties and affecting the bonding and interaction between the concrete and the steel reinforcement and surrounding concrete.

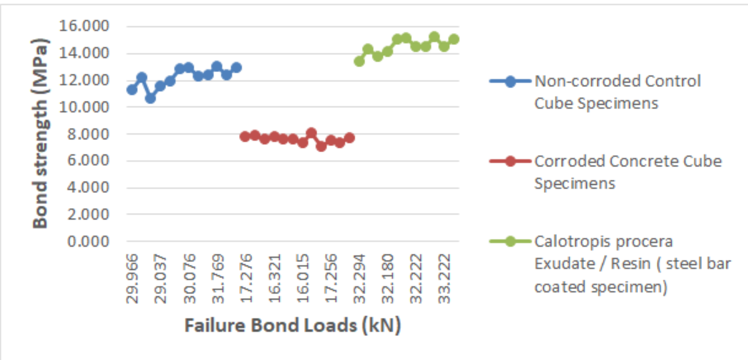

Figure 1: Failure Bond loads versus Bond Strengths

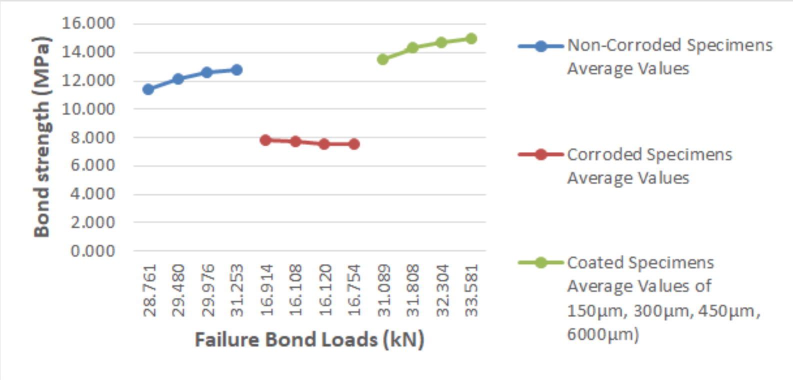

Figure 1a: Average Failure Bond loads versus Bond Strengths

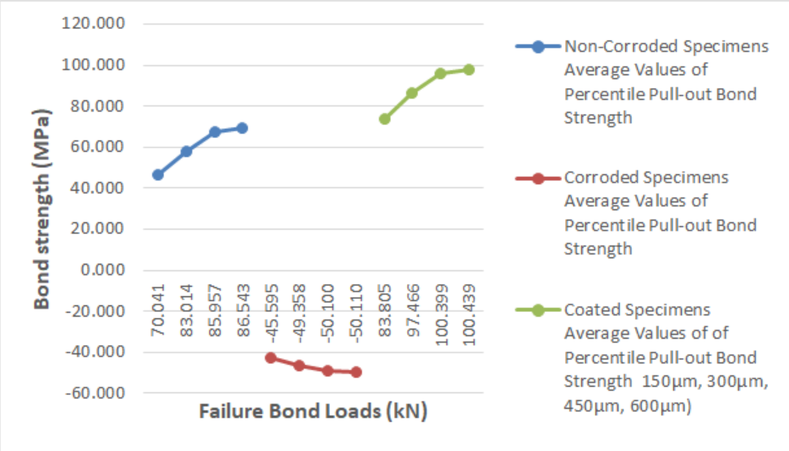

Figure 1b: Average Percentile Failure Bond loads versus Bond Strengths

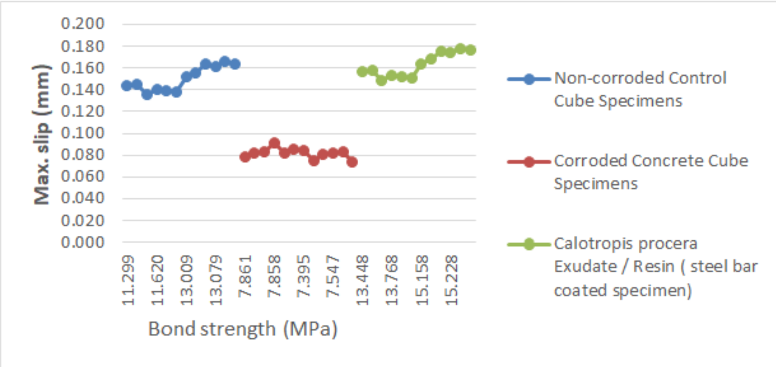

Figure 2: Bond Strengths versus Maximum Slip

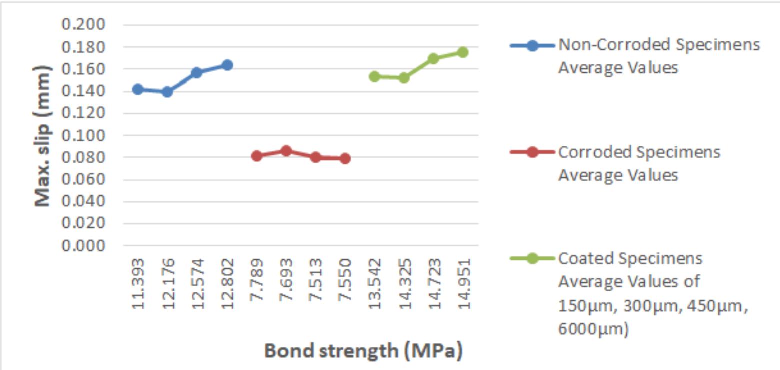

Figure 2a: Average Bond Strengths versus Maximum Slip

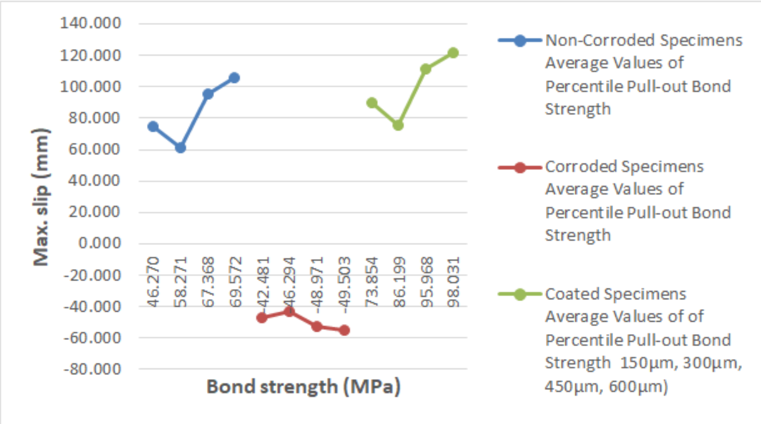

Figure 2b: Average Percentile Bond Strengths versus Maximum Slip

3.3 Mechanical Properties of Reinforcing Bars

The bond strength is derived mainly from the weak chemical bond between the steel and the reinforced concrete, but this force is destroyed under minimal pressure. Once slippage occurs, friction will help bond. In smooth steel bars, friction is an important part of strength. Strengthening steel bars with ribs under increasing sliding connections mainly depends on the contact or mechanical contact between the ribs and the concrete around the surface. This study investigated the effectiveness in the use of exudates/resins to reduce the problem of slippages, cross-sectional area, diameter reduction, and weight loss of reinforcing steel resulting from the surface and interface modification caused by corrosion of reinforcing steel embedded in concrete and exposed to a harsh environment with a high level of salinity.

The results presented in tables 3.1, 3.2, and 3.3, in table 3.4, and summarized into 3.5 and graphically represented in figures 3- 6b are the results of controlled, corroded, and coated concrete cube samples totaling 36 numbers, divided into 3 sets with set 1 (controlled) pooled in freshwater for 360 days and sets 2 of non-coated and coated immersed in 5% sodium chloride (NaCl) aqueous solutions for 360days, all routinely monitored, checked and tested to failure state using Instron Universal Machine Test of 50kN load and assessed the effect of surface modifications at 90 days, 180 days, 270 days and 360 days.

The result of controlled samples is 100% value because they are integrated into a freshwater tank that complied with the requirements of [24].

The results are summarized with the lowest and highest values found in Tables 3. 4 and 3.5., of the averaged and percentiles. Nominal diameter steel bars of all samples are 100%, and the lowest and highest diameters of the steel bars measured before the test are within the range of 11.951mm and 11.955mm representing 0.239% and 0.338% percentile values. The diameter of the rebar uncoated samples (corroded) after corrosion test is 11.915mm and 11.922mm with percentile values of -0.823% and -0.768%, after coated are 12.01mm and 12.014mm with percentile values of 0.774% and 0.83%). The results of cross-sectional area for uncoated (corroded) are 0.04mm and 0.04mm representing percentile values of -28.98% and -28.98%, for coated are samples are 0.056mm and 0.056mm with percentile values of 40.806% and 40.806%. The result for rebar weight before the test for all samples are 0.581Kg and 0.582Kg having percentile conversion of 0.256% and 0.261%, weight after corrosion test for corroded are for 0.541Kg and 0.544Kg having percentile values of -15.325% and -15.255%), coated are 0.639Kg and 0.642Kg with percentile values of18.001% and 18.099%, and weight loss /gain of steel are corroded 0.037Kg and 0.044Kg with percentile values of -40.073% and -24.612%, and coated values are 0.056Kg and 0.062Kg with percentile values of 32.648% and 66.868%. 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 (-0.768% and coated increased by 0.83%, for the cross-sectional area, corroded has maximum reduction value -28.98% and coated increased by 40.806%, weight loss and gain are corroded -24.612% decreased (loss) and coated 66.868% increase (gain).

Results obtained showed that the effect of corrosion on reinforcing steel has negatively influenced its mechanical properties of cross-sectional area, diameter reduction, and weight loss, and surface modifications thereby causing lower slippages over-controlled and coated samples and reduction in the interaction between concrete and reinforcing steel as seen in the works of [7, 12, 13, 15, 14]. The application of exudates /resin on the reinforcing steel has positively increased the diameter of reinforcing with varying coating thicknesses, minute unit weight gain, and curbing the scourge of the damages caused by the effect of corrosion on reinforced concrete structures built and exposed to the coastal marine environment with a high level of salinity.

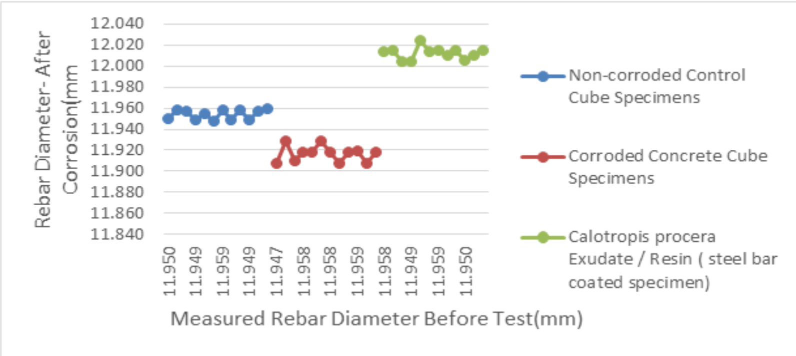

Figure 3: Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

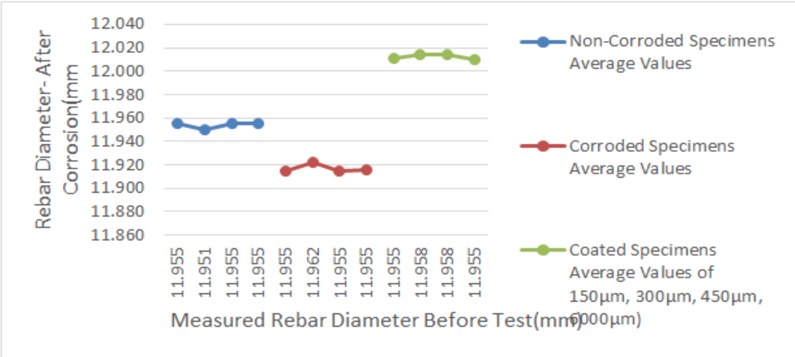

Fig 3a: Average Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion

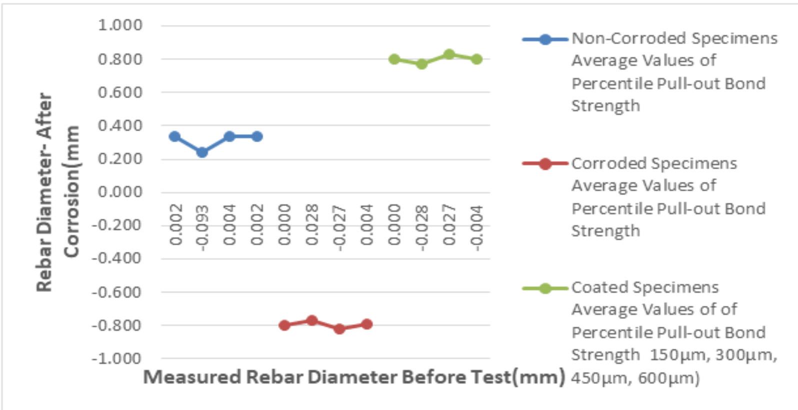

Figure 3b: Average Percentile Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion

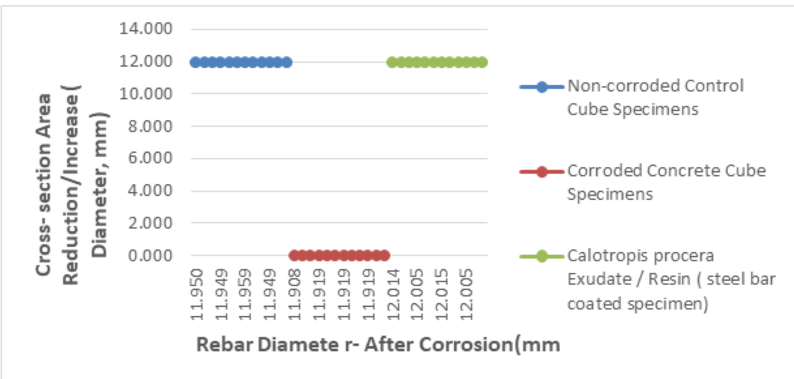

Figure 4: Rebar Diameter- After Corrosion versus Cross – Sectional Area Reduction/Increase

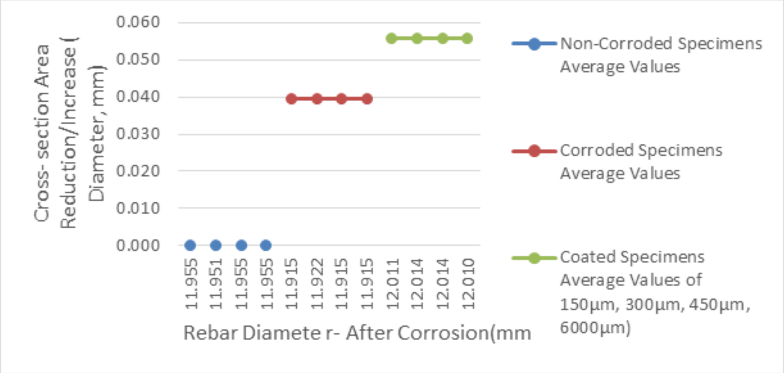

Figure 4a: Average Rebar Diameter- after Corrosion versus Cross – Sectional Area Reduction/Increase

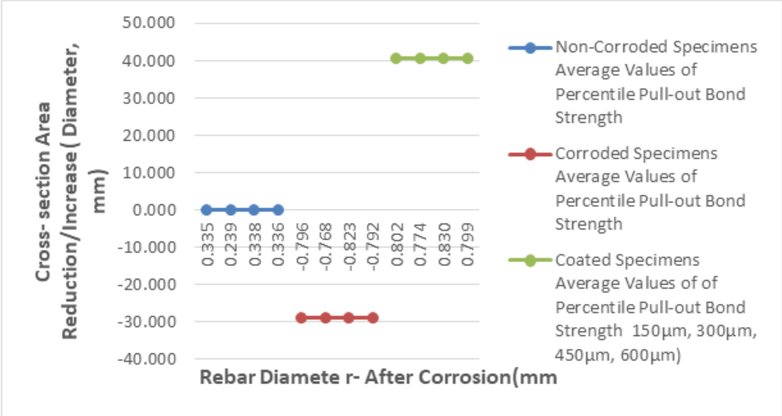

Figure 4b: Average percentile Rebar Diameter- after Corrosion versus Cross – sectional Area Reduction/Increase

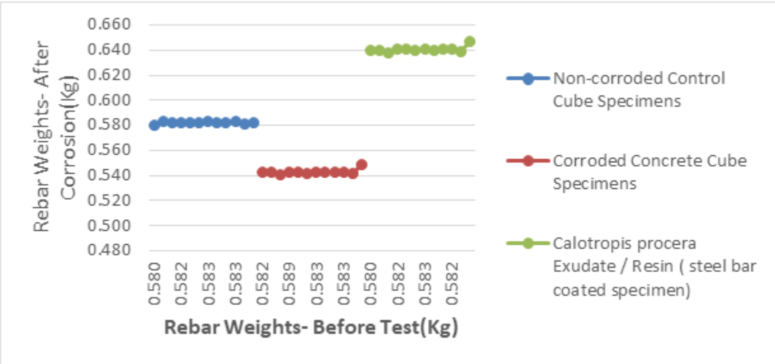

Figure 5: Rebar Weights- before Test versus Rebar Weights- after Corrosion

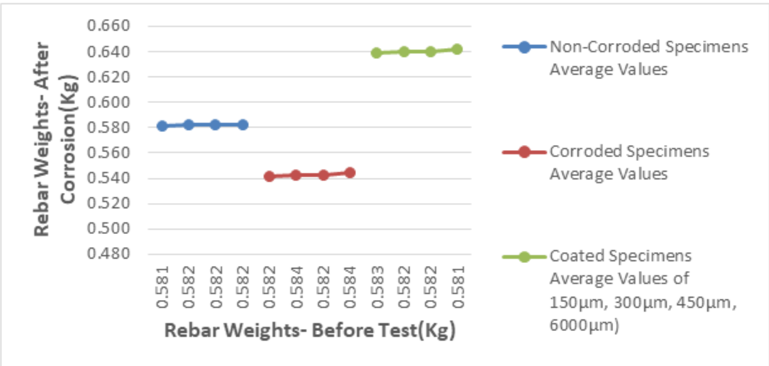

Figure 5a: Average Rebar Weights- before Test versus Rebar Weights- after Corrosion

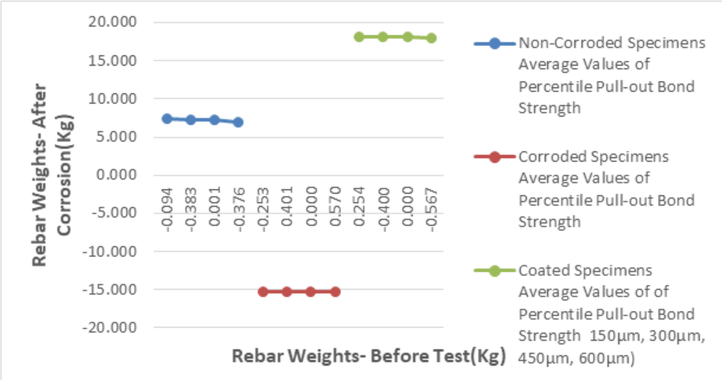

Figure 5b: Average Percentile Rebar Weights- before Test versus Rebar Weights- after Corrosion

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

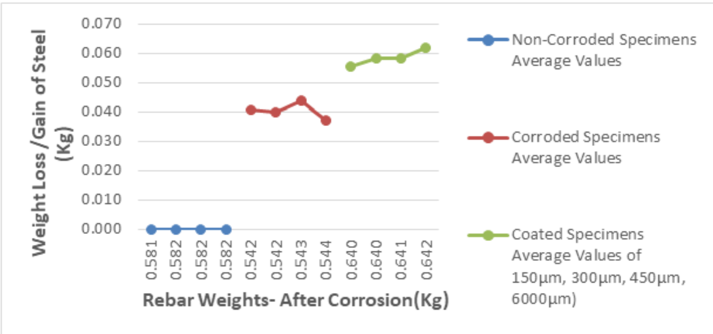

Figure 6a: Average Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

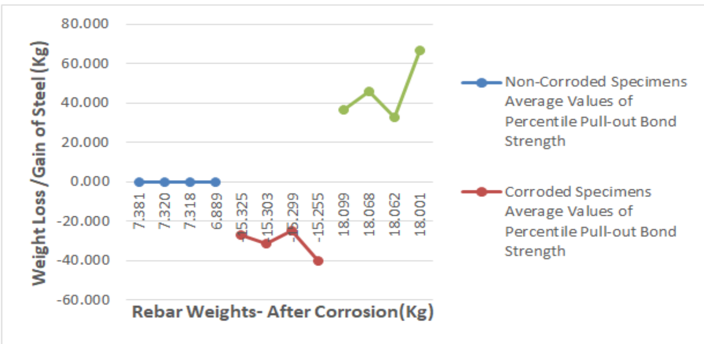

Figure 6b: Average percentile Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

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

Comparatively, the minimum and maximum values for average and percentile for failure bond loads, bond strength and maximum slip, cross-sectional reduction/increase, the diameter of rebar before /after corrosion, weight loss/gain. The estimated maximum differential yield calculated is the controlled value of the failure bond load is 86.543% compared to corroded and coating of -45.595% and 98.031%, respectively. The listed results show reduced values with the application of lower failure loads of corroded samples compared to controlled and coated samples with closer values and to higher failure loads.

The calculated and comparable value for the bond strength of the controlled samples was 69.572% compared to the corroded and coated samples with -42.481% and 98.031%. The indicative count results showed a reduced value and lower failure load of corrosive samples and for samples coated with a value that increases with the reference value in the controlled sample range. The verified ones showed that the range of values between controlled and closed is closed with a clear load application with a higher failure.

The calculated peak difference values obtained from controlled, corroded, and coated samples with maximum slip were 105.942%, -43.076%, and 121.718%, respectively. In comparison, the corroded samples showed a lower slip value compared to the controlled and coated samples with a higher slip value compared to the failure status, indicating a contribution to the exudate/resin effect in the slip test.

The calculation results show an indication of the effect of corrosion on failure bond load, bond strength, and maximum slip. The presence of corrosion reduces the efficiency of the material used, reduces mechanical properties, and affects the bonding and interactions between the concrete and the steel reinforcement and the surrounding concrete.

The results obtained indicate that the effect of corrosion on reinforcing steel has a negative effect on the mechanical properties of the cross-sectional area, a decrease in diameter and weight loss and surface modification, thereby reducing the value of control slip and coated samples and reducing the interaction between concrete and reinforcing steel [7, 12, 13, 15, 14]. The application of the exudate/resin to the reinforcement positively increases the diameter of the reinforcement with different layer thicknesses, minimizes the unit weight, and limits the specter of damage due to the effects of corrosion on reinforced concrete structures constructed and exposed to territoriality marine environment of high salinity.

4.0 CONCLUSION

In the experiment, the results obtained were plotted 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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