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Corrosion Resistivity of Inhibited Reinforcing Steel in Reinforced Concrete Pull-Out Bond Strength

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Abstract

The study investigated the behavioral responses between concrete and reinforcing steel interfaces of corroded and coated reinforced concrete structures from corrosion-induced accelerated activities exposed to corrosive media. The samples were designed with sets of reinforced concrete cubes of 150 mm × 150 mm × 150 mm with a single ribbed bar of 12 mm diameter embedded in the center of the concrete cube specimens for pull-out bond tests. From the results recorded, the maximum comparative percentile values computed are controlled 62.381% against corroded and coated samples of -38.666% and 73.549% and with differential maximum values computed of the average and percentile ranges of failure bond load are controlled (1.029kN and 10.061%) against corroded samples values are (0.806kN and 3.713%), coated are (0.371kN and 3.215%). The results of failure bond loads in comparison among controlled, corroded, and coated as enumerated in the average and percentile composition and further in percentile differential values showed the effect of corrosion on uncoated samples with decreased in maximum percentile values, resulting in higher-yielding in lower load applications over coated samples exhibition of higher load applications with higher values to failure. The exhibited coated sample characteristics showed the efficiencies and effectiveness in the utility of exudates in the prevention and the protection of reinforcing steel embedded in concrete and exposed to harsh and serves coastal marine areas. The computed comparative percentile values are controlled 53.642% against -40.577% corroded and 77.863% coated. The differential computed average and percentile values are controlled 0.783MP and 9.343% against corroded 0.096MP and 3.2%, coated values are 0.783MP and 9.577%. From the obtained values, corroded samples exhibited lower pullout bond strength with decreased percentile values as compared with coated samples with higher pullout bond strength and increased values as referenced to the controlled samples values. The differential values obtained among controlled corroded and coated members as shown clearly showed the scourge and menace effects of corrosion on uncoated samples. The peak percentile recorded values are controlled 68.493% against corroded and coated samples of -36.902% and 71.074% respectively. The results showed lower values of maximum slip of corroded samples against controlled and coated samples and higher slippage failure. The effect of low load applications and higher failure was attributed to the effects of corrosion on the reinforcing steel deformed rib, reduction in the fibre and swollen characteristics that resulted to increase in volumetric diameter, and the conversion of deformed ribs to smooth state with effect on the interaction between concrete and steel interface and the creation of stress in the concrete surrounding as confirmed in the works of 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 -0.88% and coated increased by 0.948%, for the cross-sectional area, corroded has maximum reduction value -54.98% and coated increased by and 32.443%, weight loss, and gain are corroded -23.784% decreased (loss) and coated 38.939% 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.

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

1.0 INTRODUCTION

Corrosion of reinforcing steel produces expansive material with a larger volume compared to the original steel. Due to the volumetric expansion of this material, the capillary pores are filled with corrosion products which exert pressure on the surrounding concrete causing cracking and spalling of the cover concrete (Ahmad, 2003; Zhou et al., 2014). This suggests that the certain corrosion amount needed to initiate the first crack at the cover concrete when exposed to corrosive environment and rate of corrosion production are essential in service life of reinforced concrete structures. The steel is tensioned in the reinforced concrete structural members after the concrete cracks. However, it is the bond between steel and concrete that makes this dynamic and situation possible. Corrosion of steel reinforcements affects this bond strength between steel and concrete can be divided into two parts; the adhesion itself comes from three different sources: first, it is a chemical bond between concrete and steel, second is the friction between concrete and steel, the last is the confining pressure that concrete exerts on the rebar. Transfer of the normal force from the reinforcing steel bar to the surrounding concrete, resulting from the development of a tangential stress component at the contact surface. The voltage acting in parallel with the bus at the interface is called the junction voltage (Pillai and Kirk 1938, Hadi 2008). In the case of reinforced concrete, suitable bonds shall be made between the steel bars and the surrounding concrete. 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 (Hadi 2008, Warner et al. 1998). Adhesion resistance consists of chemical adhesion, friction and mechanical interlock 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. This easy method can compromise the bond between the concrete and the steel rods because the steel rods are contaminated with oil before the concrete is poured.

The bond strength of reinforcing steel to concrete has been investigated by many authors. Moetaz and EL-Hawary (1999) investigated the strength properties of steel reinforcement coated with exposure embedded in concrete, taking into account many tensile tests. The degradation of the bond strength of steel bars and concrete under cyclic loading was measured by Cao and Chung (2001). The effect of different corrosion rates of steel bars on the bond strength of concrete was demonstrated by Fang et al. (2004) and Fang et al. (2006) examined.

Abdelbaky (2004) investigated the effect of a rust remover on the bond strength of steel reinforcement. He has studied the effect of a new chemical developed by a chemical company called stopping rust, or removing rust, on removing rust and its effect on the bond between reinforced reinforcement and concrete. The results showed that the bond strength was reduced by 7.6% when the bars were covered with rust.

Amadise et al. (2021). Direct use of exudates/resin extruded from plants, called inorganic inhibitors, coated with reinforcing steel and experimentally tested, is being investigated. The measured value of the diameter of the reinforcing steel obtained after the corrosion test decreased drastically as indicated by a negative value, the indicator value decreased and the measured value of the coated sample increased due to the weight of the reinforcing steel. Corroded samples have reduced (negative) values, leading to the formation of holes and thus as a result of changes in surface swelling and rib effect, which reduces the interactive natural coexistence between concrete and steel, while large interactions are observed in the layers. As an added result of the mechanical properties of the corroded, controlled and layered cube, all corroded cubes have a reduced cross-sectional area and lower weight loss compared to the controlled and coated elements.

Hadi (2008) investigated the bond strength of high-strength concrete with high-strength reinforcing steel. Concrete with a compressive strength of about 70MPa and a steel grade of 500MPa are used. It was concluded that the reduced samples with smaller rod sizes had higher bond strength than samples with large rod diameters. The test results also show that the initial hardness increases with the increase in the amount of concrete around the reinforcement.

Foroughi et al. (2008) investigated the bond strength of reinforcing steel bars in self-compacting concrete. 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 bond strength of self-sealing concrete and steel bars was also investigated by Valcuende and Parra (2009) as a function of various parameters.

Tobi et al. (2021) described the highly saline marine environment and the possible use of boswellia dalzielii hutch exudates/resin/resin as a barrier to prevent corrosion and corrosion risk in reinforced concrete structures exposed to or constructed in this highly corrosive coastal area. Results of failure loads, bond strength, maximum slip, reduction/increase in cross-sectional area and weight loss/reinforcement are checked. Results showed lower slip on the corroded sample compared to the controlled sample and coated with a higher shear force before failure, these factors indicate the effect of corrosion on the mechanical properties of reinforcing steel, where the interaction of concrete and steel shear as well as the negative effect of corrosion on the properties of reinforcing steel. The results of the comparison of the maximum diameter difference of uncoated reinforcement decreased to -0.623%, while the coated sample increased by 0.722%, for the maximum corroded cross-sectional area the reduction value was -23.296% and the coated sample increased by 33.218%, the weight loss of the corroded sample decreased -21.643% indicating a decrease (loss of) weight and coated samples increased by 35.916%.

Selvarag and Bhuvaneshwari (2009) 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. This conclusion is in line with the results of research by Verma and Balasubramaniam (2011) on the corrosion of reinforcement in concrete. They concluded that structures exposed to degreasing salts could benefit from the use of epoxy-coated steel bars. In another article about Alengaram et al. (2010) compared the mechanical and bond properties of palm kernel oil (OPKSC) and normal concrete (NWC). They arrived at the result that the bond strength (OPKSC) was about 86% of the normal concrete in question and there was no slip between (OPKSC) and reinforcement. They also showed that the experimental terminal voltage (OPKSC) was 2.5 times higher than the voltage calculated according to British standards. In 2010, Johnson (2010) conducted tests to join standard concrete blocks. Six types of reinforcement corrosion were examined. The mechanical slope of the joint and the tension of the joint are measured. It has been shown that an increase in the relative area of the steel bar ribs leads to an increase in initial adhesion.

Gbinu et al. (2021) tested on 36 samples of concrete cubes, 12 controlled samples, placed in fresh water for 360 days, 12 samples without coating and 12 samples with exudates/resin coated, all immersed in reinforcing steel and immersed in 5% sodium chloride (NaCl) solution for 360 days and assesses its properties by inspection, monitor, for 360 days. For comparison: The peak value obtained for the breaking load for the controlled sample is 97.586% against corrosive -46.845% and closed 106.118%. The calculation results show that the corroded samples have lower breaking loads and reduce the acceptable values compared to the reference range of the controlled samples, while the controlled and coated samples show higher breaking loads at increasing coating percentages. The decrease in mean and percentage values due to corrosion sampling is compared to the negative effect of corrosion attack affecting the modified interface between concrete and strong steel interactions. From the data obtained from the adhesive strength, the maximum comparison values of the controlled, corroded and coated samples were as follows; Calculation results of corroded samples show failure at low bond strengths and reduced values from the reference point to the controlled and coated samples, with a close range of values, but with some additional values in the coated reference. point. The results show lower slip errors and lower reported slip errors and reduced values for the controlled and coated samples with increasing values.

Assaad and Issa (2012) investigated the bond strength of steel bars coated with epoxy resin and embedded in underwater concrete. Experimental work has been carried out and it has been found that the final terminal voltage will be affected by the amount of wash loss. The effect of accelerated corrosion on the bond strength of steel bars and concrete has been described by Yalciner et al. (2012). The results showed that high-strength concrete and corroded reinforcement samples showed a greater reduction in bond strength because the concrete cracked during the test.

The mechanical side comes from the ribs of the rebar there by engaging with the surrounding concrete and resists any translational movement and motion. In deformed rebar, the mechanical action of the ribs is the main cause while on smooth bars; there is little mechanical action as there are no ribs and so it is adhesion that provides most of the adhesion.

Overo et al. (2021). Evaluated the ideal performance of high salinity coastal marine areas and the potential use of raphia hookeri exudates/resin as a retaining material coated with reinforced concrete embedded in the concrete to contain scourges and threats corrosive effect on exposed reinforced concrete structures or constructed in heavy and hard zones. The results of the average and percentage values for the composite breaking load, bond strength, and maximum slip, reduction/increase in area and decrease/increase in weight indicate that the breaking load maintains a narrow range of values for controlled and enclosed values, while the corroded elements accept higher loads. On the mechanical properties of reinforcing steel, the effect of corrosion on reinforcing steel showed a decrease in the cross-sectional diameter of the bar compared to the nominal diameter before the test, a decrease in weight was also observed, while the coated elements had a cross-section.

2.1 Experimental program

This study involved the direct application of resin/ exudates from the wood extract of Azadirachta indica (neem), which is known as an inorganic inhibitor, which was applied to the surface of reinforcing steel, tested in this test program. The main objective of this study was to determine the effectiveness of a corrosion inhibitor applied to a locally available surface in a highly corrosive environment and with chloride contamination. The test bench simulates a harsh marine environment with the concentration of salt in the concrete in the submerged part of the specimen; the corrosion activity of the steel cannot be maintained with the sample completely submerged. The specimens were laid with a set of reinforced concrete cubes measuring 150 mm × 150 mm × 150 mm with single ribs of 12 mm in diameter, embedded in the center of the concrete cube specimen for pulling, and examined. To simulate an ideal corrosive environment, the concrete sample is immersed in a solution (NaCl) and the depth of the solution is maintained.

2.1.1 Materials and Methods for Experiment

2.1.1 Aggregates

The fine aggregate and coarse aggregate were purchased. Both met the requirements of [14]

2.1.2 Cement

42.5 grade limestone cement is the most and commonly type of cement in Nigerian Market. It was used for all concrete mixes in this investigation. The cement met the requirements of [15]

2.1.3 Water

The water samples were clean and free from impurities. The fresh water used was gotten from the tap at the Civil Engineering Department Laboratory, Kenule Beeson Polytechnic, Bori, and Rivers State. The water met the requirements of [16]

2.1.4 Structural Steel Reinforcement

The reinforcements are purchased directly from the market in Port Harcourt, [17]

2.1.5 Corrosion Inhibitors (Resins / Exudates) Azadirachta indica tree (Neem tree)

The gum exudates are sticky foetid sap and were obtained from the stem by tapping from University of Port Harcourt, Rivers State, Nigeria

2.2 EXPERIMENTAL PROCEDURES

2.2.1 Experimental method

2.2.2 Sample Preparation for Reinforcement with Coated Resins / exudates

Corrosion testing was carried out on high-strength steel (reinforcement) with a diameter of 12 mm and a length of 550 mm for the cube, the surface roughness of the sample was treated with sandpaper / wire brush, and the sample was cleaned with distilled water, with acetone and properly dried. The cubes and test rods are poured into steel molds measuring 150 mm × 150 mm × 150 mm. Specimens were treated at room temperature in a hardening tank for an accelerated corrosion test process and the test procedure allowed 120 days for the first observed crack and an additional 30 days for a total of 150 days for further observations of the accelerated corrosion process.

2.3 Test procedure

Accelerated corrosion was tested on high-strength steel with a diameter of 12 mm and a length of 650 mm. Coated with 150 m, 300 m, 450 m and 600 m before corrosion test. The test cubes measured 150 mm x 150 mm x 150 mm and were placed in metal molds and disassembled after 72 hours. Samples were tank-treated and dried 28 days prior to the first treatment period at room temperature, followed by regular 360-day monthly monitoring for confirmation with corrosion testing and fast accelerated testing modes. Accelerated corrosion samples were taken at intervals of about 3 months 90 days, 180 days, 270 days and 360 days. Tests were carried out on damage, bond strength, maximum slip, reduction/increase in cross-sectional area and loss of reinforcement weight.

2.3 Accelerated adjustment and corrosion test method

In a real and natural phenomenon, the effect of corrosion on reinforcement embedded in concrete elements develops very slowly and can take years; but the laboratory acceleration process will take less time to accelerate the marine environment. To check the surface and mechanical properties of the test and fingerprints, test an uncoated exudates/resin sample and immerse it in 5% NaCl solution for 360 days.

2.4 Tensile strength test

Tensile tests were carried out on 36 concrete cubes of 150 mm x 150 mm x 150 mm with built-in reinforcement with a diameter of 12 mm in the center on controlled, uncoated and coated samples from a universal compression testing machine at 50 KN in accordance with BSEN 12390.2. , Test results of adhesive stress, adhesive tear strength, maximum slip, area reduction/enlargement, and weight loss/bone loss.

2.5 Tensile strength of reinforcing bars

To determine the density and tensile strength of uncoated and uncoated reinforcing steel, testing and direct loading were carried out on a universal testing machine (UTM) with a disturbance load. To ensure stability, the remaining pieces are used in subsequent tests for bonding and breaking loads, bond strength, maximum slip, reduction/increase in cross-sectional area, and weight reduction/reinforcement of steel.

3.1 Experimental Results and Discussion

The interaction between concrete and reinforcing steel must be perfect to allow maximum adhesion to the surrounding concrete structure. The increase in deformed (rib) rebar and slip joints mainly depends on bearings or mechanical locks between the concrete around the ribs on the bar surface. The harmful effects of corrosive attack render many structures unusable and their intended life shortens.

The experimental data shown in Tables 3.2.3.2 and 3.3, summarized in Tables 3.4 and 3.5, were tested on 36 samples of concrete cubes from 12 controlled samples placed in fresh water for 360 days, 12 samples without coating and 12 samples with exudates coating. / Resin, all combined with reinforcement and immersed in 5% sodium chloride (NaCl) solution for 360 days and assessed for performance by inspection, monitoring, review, and 3-month intervals at 90 days, 180 days, 270 days, and 360 days. In fact, the manifestation of corrosion is a long-term process that takes decades to fully function, but the artificial introduction of sodium chloride causes the manifestation and occurrence of corrosion in a shorter time. The experimental work presents an ideal high salinity coastal marine area and the potential use of Azadirachta indica resin exudates/extracts as a barrier material to limit bullfighting and corrosion risk in reinforced concrete structures exposed or constructed in such heavy and rugged areas.

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

	Non-corroded Control Cube Specimens											
Sample Numbers	AIC	AIC1	AIC2	AIC3	AIC4	AIC5	AIC6	AIC7	AIC8	AIC9	AIC10	AIC11
	Time Interval after 28 days curing											
Sampling g and Durations	**Samples 1 (28 days)**			**Samples 2 (28 Days)**			**Samples 3 (28 Days)**			**Samples 4 (28 Days)**		
Failure Bond Loads (kN)	31.908	29.818	30.382	30.979	31.794	31.495	32.018	31.836	31.900	33.711	32.836	33.037
Bond strength (MPa)	14.274	15.167	13.664	14.595	14.968	15.891	15.984	15.314	15.349	16.054	15.366	15.912
Max. slip (mm)	0.146	0.147	0.138	0.143	0.142	0.141	0.154	0.158	0.166	0.163	0.168	0.166

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)	11.960	11.952	11.961	11.960	11.951	11.970	11.961	11.950	11.960	11.952	11.961	11.960
Rebar Diameter- at 28 Days Nominal(mm)	11.960	11.952	11.961	11.960	11.951	11.970	11.961	11.950	11.960	11.952	11.961	11.960
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)	0.579	0.579	0.579	0.580	0.580	0.587	0.578	0.579	0.582	0.578	0.578	0.587
Rebar Weights- at 28 Days Nominal (Kg)	0.579	0.579	0.579	0.580	0.580	0.587	0.578	0.579	0.582	0.578	0.578	0.587
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)	20.518	19.831	20.121	19.563	18.811	19.679	19.258	19.566	19.264	20.499	19.378	20.112
Bond strength (MPa)	10.029	10.039	9.804	10.026	9.793	9.765	9.563	10.252	9.227	9.715	9.563	9.875
Max. slip (mm)	0.083	0.086	0.087	0.096	0.086	0.090	0.089	0.079	0.085	0.086	0.087	0.078
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)	11.970	11.961	11.950	11.960	11.951	11.970	11.961	11.950	11.960	11.957	11.960	11.952
Rebar Diameter- After Corrosion(mm)	11.936	11.927	11.916	11.926	11.917	11.936	11.927	11.916	11.926	11.923	11.926	11.918
Cross- section Area Reduction/Increase (Diameter, mm)	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
Rebar Weights- Before Test (Kg)	0.580	0.580	0.578	0.579	0.580	0.580	0.580	0.578	0.582	0.578	0.578	0.580
Rebar Weights- After Corrosion (Kg)	0.538	0.538	0.536	0.538	0.538	0.539	0.539	0.536	0.540	0.537	0.537	0.538
Weight Loss /Gain of Steel (Kg)	0.042	0.041	0.042	0.044	0.042	0.042	0.041	0.044	0.040	0.041	0.042	0.042

Table 3.3: Results of Pull-out Bond Strength Test (τu) (MPa of Azadirachta indica Exudates / Resin (Steel Bar Coated Specimen)

Sampling and Durations	**Samples 1 (90 days)**			**Samples 2 (180 Days)**			**Samples 3 (270 Days)**			**Samples 4 (360 Days)**		
Sample	**150µm (Exudates/Resin) coated**			**300µm (Exudates/Resin) coated**			**450µm (Exudates/Resin) coated**			**600µm (Exudates/Resin) coated**		
Failure Bond Loads (kN)	34.069	31.980	32.543	33.140	33.955	33.656	34.179	33.997	34.061	35.872	34.997	35.198
Bond strength (MPa)	16.663	17.555	16.053	16.983	17.356	18.279	18.373	17.703	17.737	18.443	17.754	18.301
Max. slip (mm)	0.148	0.149	0.140	0.145	0.144	0.143	0.156	0.160	0.168	0.165	0.170	0.169
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)	11.951	11.961	11.961	11.960	11.951	11.960	11.957	11.951	11.961	11.957	11.951	11.961
Rebar Diameter- After Corrosion(mm)	12.026	12.037	12.036	12.036	12.026	12.035	12.033	12.026	12.037	12.033	12.026	12.037
Cross- section Area Reduction/Increase	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075

(Diameter, mm)												
Rebar Weights- Before Test (Kg)	0.580	0.580	0.580	0.578	0.578	0.587	0.580	0.580	0.580	0.580	0.579	0.582
Rebar Weights- After Corrosion (Kg)	0.638	0.637	0.637	0.636	0.635	0.644	0.638	0.637	0.638	0.638	0.637	0.639
Weight Loss /Gain of Steel (Kg)	0.058	0.057	0.057	0.056	0.054	0.063	0.060	0.056	0.051	0.064	0.058	0.057

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)	30.703	30.393	31.052	31.422	20.157	19.838	19.499	19.351	32.864	32.554	33.213	33.584
Bond strength (MPa)	14.368	14.475	14.409	15.151	9.957	9.956	9.874	9.861	16.757	16.864	16.797	17.540
Max. slip (mm)	0.134	0.142	0.141	0.142	0.085	0.090	0.090	0.091	0.146	0.145	0.143	0.144
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)	11.957	11.958	11.957	11.961	11.960	11.957	11.954	11.960	11.958	11.961	11.957	11.957
Rebar Diameter- After Corrosion(mm)	11.957	11.958	11.957	11.961	11.926	11.923	11.920	11.927	12.033	12.036	12.033	12.032
Cross- section Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.034	0.034	0.034	0.034	0.075	0.079	0.075	0.078
Rebar Weights- Before Test (Kg)	0.579	0.580	0.580	0.582	0.579	0.579	0.579	0.580	0.580	0.579	0.578	0.581
Rebar Weights- After Corrosion (Kg)	0.579	0.580	0.580	0.582	0.537	0.537	0.537	0.538	0.637	0.637	0.636	0.638
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.041	0.042	0.043	0.043	0.058	0.057	0.056	0.058

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**				**Exudates / Resin steel bar coated specimens**			
Failure load (KN)	52.320	53.203	59.251	62.381	- 38.666	- 39.060	- 41.292	- 42.379	63.041	64.097	70.334	73.549
Bond strength (MPa)	44.299	45.387	45.926	53.642	- 40.577	- 40.960	- 41.217	- 43.777	68.286	69.377	70.116	77.863
Max. slip (mm)	68.493	59.111	56.756	56.057	- 41.546	- 38.106	- 37.190	- 36.902	71.074	61.568	59.210	58.483
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)	0.224	0.226	0.232	0.231	0.222	0.232	0.232	0.228	0.222	0.232	0.232	0.228
Rebar Diameter- After Corrosion(mm)	0.260	0.290	0.316	0.285	-0.885	-0.939	-0.939	-0.880	0.893	0.948	0.948	0.888
Cross- section Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	- 54.980	- 54.980	- 54.980	- 54.980	26.226	22.344	22.124	32.443
Rebar Weights- Before Test (Kg)	0.375	0.337	0.345	0.380	0.338	0.332	0.381	0.351	0.368	0.382	0.381	0.352
Rebar Weights- After Corrosion (Kg)	7.872	7.941	7.948	8.188	- 15.711	- 15.650	- 15.521	- 15.676	18.640	18.553	18.373	18.590
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	- 28.026	- 25.764	- 23.784	- 26.439	38.939	34.705	31.205	35.941

3.2 Failure load, Bond Strength, and Maximum slip

The bond slip Mechanisms between reinforcement and concrete consists of three different mechanisms: chemical adhesion, friction and mechanical locking (ACI 408, 2003).

(i) Chemical Adhesion: Adhesion is a chemical bond that forms at the contact surface between steel reinforcement and the surrounding concrete. It can be crushed at very low loads, which allows it to slip between reinforcing steel and concrete. (ii) Friction: friction, especially between the surface of the steel bar and the concrete. Frictional forces play an important role between the concrete and the deformed bars (ribs). Mechanical interlocking: These sliding joints become more important as the relative displacement between the composite mechanisms increases. The power transmission mechanism is mainly based on mechanical locking between steel reinforcement and concrete. The mechanisms of chemical adhesion and friction are most important with smooth rods. In the case of deformed reinforcing bars, the mechanical locking of steel bars to the concrete is the main mechanism that determines the bonding strength behavior (Bamonte and Gambarova, 2007; Gambarova, 2012). The results of failure bond load, bond strength and maximum slip conducted on 36 concrete cubes as presented in tables 3.1. 3.2 and 3.3 and concise into 3.4- 2.5 and graphically plotted in figures 1 – 6b. The obtained results are for 12 samples of controlled, 12 corroded and 12 coated tested to failure using Instron Universal Testing Machines with 50kN as described in the test procedure. The average and percentage of the minimum and maximum calculation results obtained from the controlled disconnection load 30.393 kN and 31.422 kN (52.32% and 62.381%), corroded 19.351 kN and 20.157 kN (-42.379% and - 38.666%), covered with 32,554 kN and 33,584 kN (63.041% and 73,549%). From the recorded results, the calculated maximum comparison percentage was 62.381% versus the corroded and coated samples of -38.666% and 73.549% and with the maximum difference values controlled from the average and range of the percentage of disconnection loads (1.029kN and 10.061%)) compared with the corroded samples were values (0.806kN and 3.713%), they were closed (0.371kN and 3.215%). The results of the destructive bond loads compared to controlled, corroded and coated, which are listed in the mean composition and percentile and also in percentage difference values, indicate the effect of corrosion on the uncoated samples with reduced maximum percentile values, leading to better results. high in applications with lower loads to layered sample exposures from high-voltage applications with higher failure values. The results clearly show that the effect of corrosion has a negative impact on the mechanical properties of reinforcing steel, from diameter and cross-section reduction to heavy loading and surface modification. The properties of exposed coated samples demonstrate efficiency and effectiveness in using exudates to prevent and protect reinforcement embedded in concrete exposed to harsh marine environments and service shorelines.

The adhesive strength values for control were 14.368 MPa and 15.151 MPa (44.299% and 53.642%), corroded 9.861 MPa and 9.957 MPa (-43.777% and -40.577%), coated 16.757 MPa and 17.54 MPa (68,286% and 77.863%). Comparison values calculated from percentiles were checked with 53.642% against -40.577% corroded and 77.863% coated. The calculated mean and percentage values differ controlled by 0.783MP and 9.343% compared to 0.096MP and 3.2% which corroded, the covered values were 0.783MP and 9.577%. From the values obtained, the corroded samples exhibited lower adhesive tensile forces with lower percentile values compared to the coated samples with higher tensile forces and values, relative to the controlled sample values. The reduced values and lower tensile strength measured in corroded samples can be attributed to the effect of corrosion attack, which causes a change in surface properties with significant swelling and fiber reduction affecting the deformed steel ribs. The existing interface between concrete and steel is drastically reduced by freestanding ribs. The exposure properties of the coated samples demonstrate the effectiveness and efficiency of exudates/resin in preventing corrosion attack on reinforced concrete structures in coastal marine environments. As shown, the difference values obtained between the controlled, corroded and coated elements clearly indicate the adverse effect and threat of corrosion in the uncoated samples.

The maximum slip results were checked: mm and 0.134 mm and 0.142 mm (56.057% and 68.493%), corroded 0.085 mm and 0.091 mm (-41.546% and -36.902%), coated 0.143 mm and 0.146 mm (58.483% and 71.074%). The different recorded values of the controlled ones were 0.008 mm and 12.436% compared to the corroded values of 0.006 mm and 4.644% and the closed values of 0.003 mm and 12.591%, respectively. The recorded value of the controlled peak percentile was 68.493% compared to the corroded and coated samples -36.902%

and 71.074%, respectively. The results show that the maximum slip value of corroded specimens is lower than that of controlled and coated specimens and greater slip damage. The effect of light loads and greater damage is caused by the effect of corrosion on deformed reinforcing steel bars, reduced fiber properties and swelling, resulting in an increase in diameter volume and transformation of deformed ribs into smooth. with the interaction between the concrete and the steel boundary and the generation of stresses in the concrete environment as defined in the(Tobi et al., 2021**;** Amadise et al., 2021; Gbinu et al., 2021; Overo et al.,2021).

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 application, failure under low load with percentile value reduced for controlled and sealed concrete cube samples. The results showed evidence of the effect of corrosion on destructive adhesion, adhesion strength and maximum slip (Tobi et al., 2021**;** Amadise et al., 2021; Gbinu et al., 2021; Overo et al.,2021).

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.

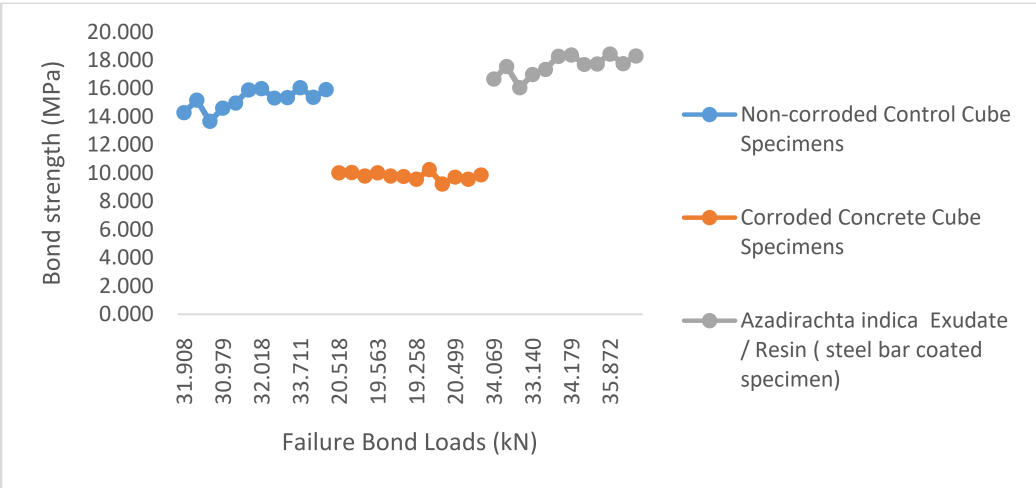

Figure 1. Failure Bond loads versus Bond Strengths

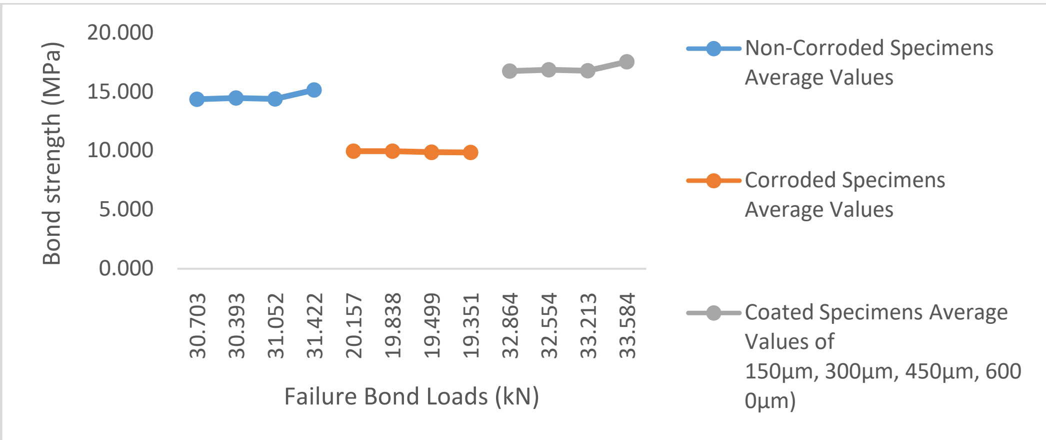

Figure 1a. Average Failure Bond loads versus Bond Strengths

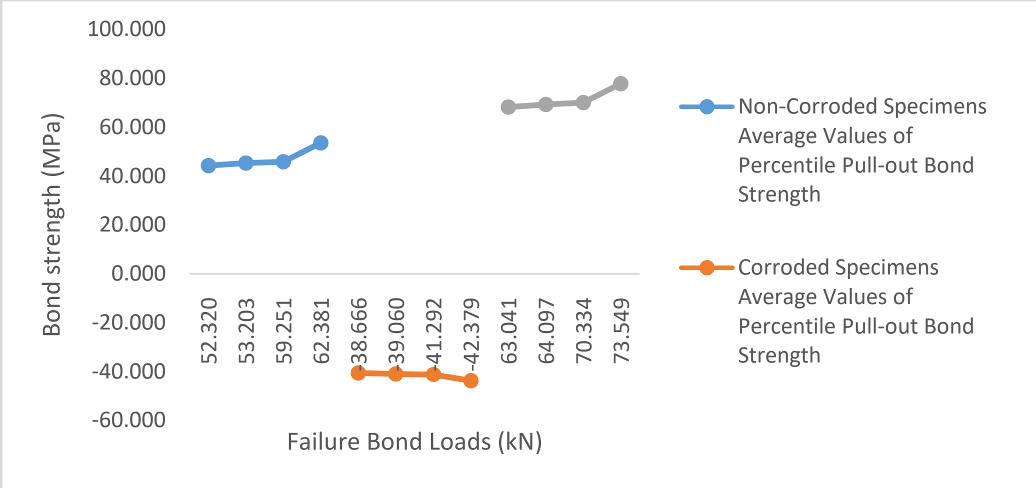

Figure 1b. Average Percentile Failure Bond loads versus Bond Strengths

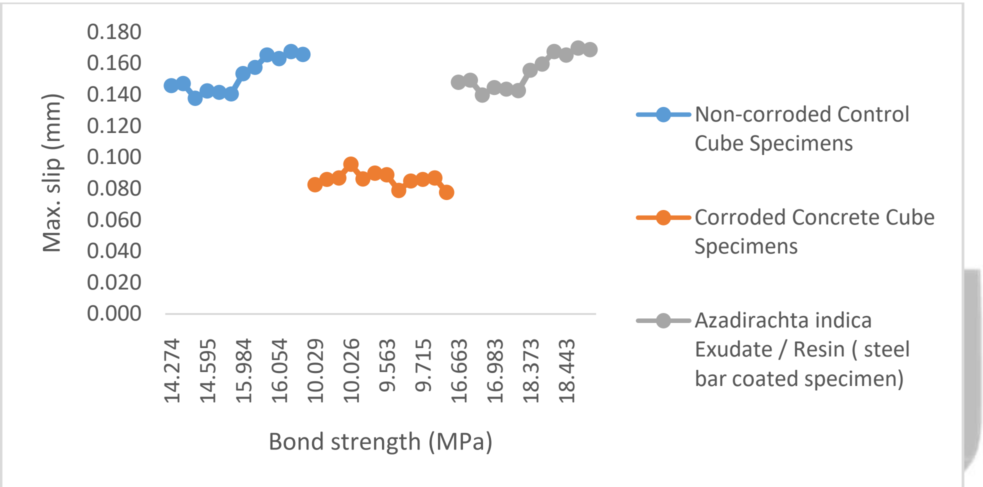

Figure 2. Bond Strengths versus Maximum Slip

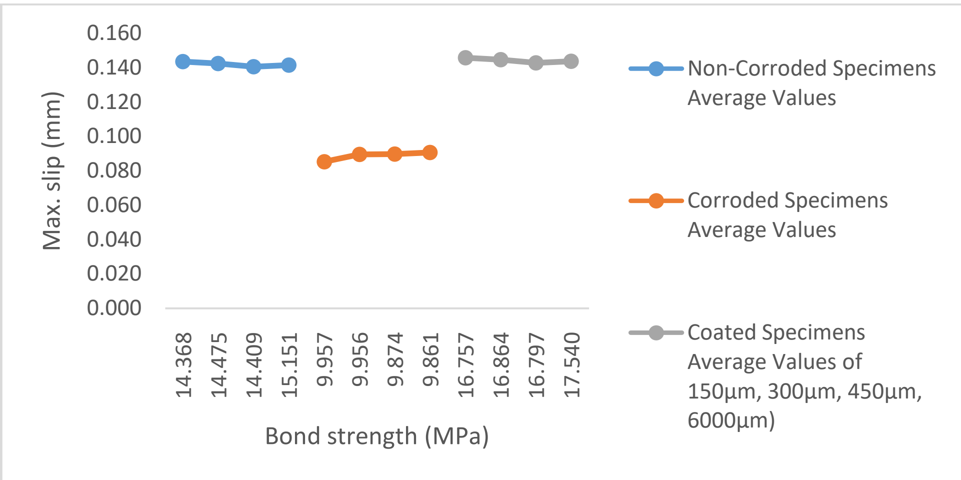

Figure 2a. Average Bond Strengths versus Maximum Slip

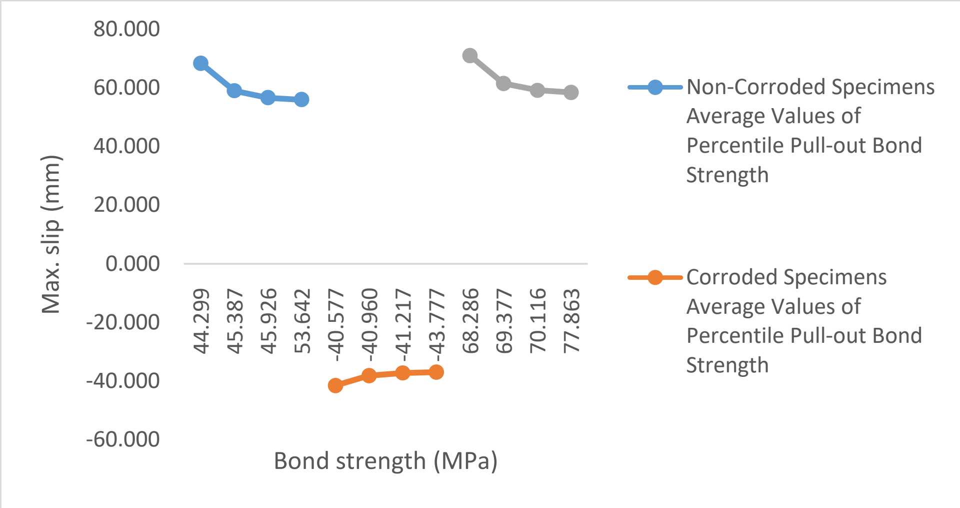

Figure 2b. Average Percentile Bond Strengths versus Maximum Slip

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 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 relationship between concrete and reinforcement is a complex phenomenon that reinforced concrete structures relies on to withstand design loads. Due to the different properties of the two materials, the transfer of stress from the concrete to the reinforcement is very important when designing a secure structure.

The connection load that causes a change in the force on the reinforcing bar is divided by the area of the bar where the change in force occurs (Hassan 2003). According to Shetty et al (2011), bond strength is caused by four factors: chemical adhesion of concrete to steel, boundary friction between rods and concrete from grinding, rust and other surface irregularities, bearing against ribs and shear action on a cylindrical concrete surface between adjacent ribs. In principle, the degree of corrosion can be calculated as the percentage loss of mass of the corroded sample. This mass loss is caused by the loss of the cross-sectional area of the reinforcement and the percentage loss is calculated based on the length of the corrosive rod installed. The results of the experimental study conducted by Hassan (2003) showed an increase in bond strength of 6% and 9% by 0.34 and 0.71 percent, respectively, from the decrease in weight for ordinary steel bars and stainless steel bars.

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 tank of freshwater of compliance to (BS 3148) requirements.

The results are summarized in the minimum and maximum values, which are taken from Tables 3.4A and 3.5.

The nominal diameter of the steel bars of all samples was 100%, and the minimum and maximum diameters of the steel bars measured before the test were in the range of 11.957 mm and 11.961 mm (0.26% and 0.316%). The diameters of the uncoated (corroded) reinforcement samples after the corrosion test were 11.92 mm and 11.927 mm (-0.939% and -0.88%), 12.032 mm and 12.036 mm (0.888% and 0.948%). The maximum comparative percentile yield was controlled by 0.316% compared to the corroded and coated samples by -0.88% and 0.948%, respectively. The cross-section results for uncoated (corroded) were 0.034 mm and 0.034 mm (-54.98% and -54.98%), for coated were 0.075 mm and 0.079 mm (22.124% and 32.443%). The comparison between corroded and coated was -54.98% compared to 32.443%.

The results for the weight of reinforcement before testing were 0.579 kg and 0.582 kg (7.872% and 8.188%) for all samples, the weight after corrosion testing for corrosion was 0.537 kg and 0.538 kg (-15.711% and -15.521%).), covering 0.636 kg and 0.638 kg (18.373% and 18.64%) and the weight loss/gain of corroded steel was 0.041 kg and 0.043 kg (-28.026% and -23.778%), and the coating values were 0.056 kg and 0.058 kg % and 38.939%). From the results obtained and shown in the figure, the effect of corrosion on uncoated and coated reinforcing steel is shown, in Figures 3 and 6b it can be seen from the diameter of the reinforcement that the diameter of the uncoated reinforcing steel is reduced to the maximum. the value of -0.88% and an increase in coverage of 0.948%, for the corroded cross-sectional area has a maximum reduction value of -54.98% and the coating increases by 32.443%, the loss of weight and gain is corroded -23.784% (loss) and the coating is reduced by 38.939% (Profit)). From the comparison results, the mechanical properties of reinforced concrete structures built with coastal sea areas with high salt content are negatively affected and strongly influenced by the corrosion effect, but the negative effect is stopped by the inclusion of exudates/resin as roofing material. 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 reduction in weight, whereas coated concrete cubes resulted in a diameter and cross-sectional area and an increase in weight of different thicknesses encased with reinforcing steel (Tobi et al., 2021**;** Amadise et al., 2021; Gbinu et al., 2021; Overo et al.,2021).

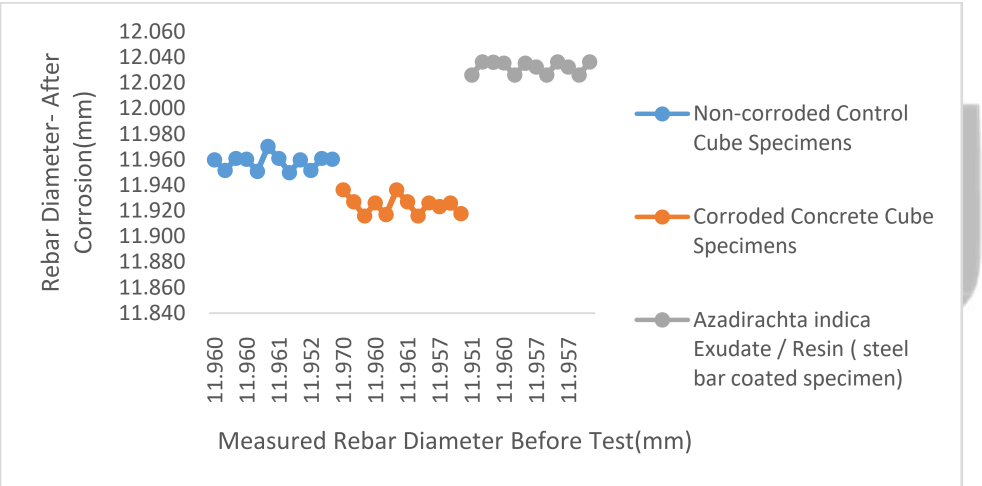

Figure 3: Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion)

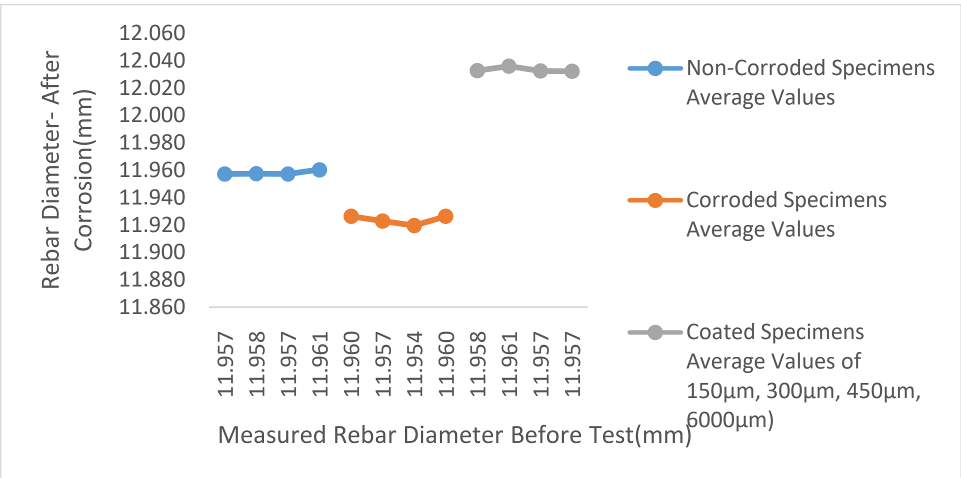

Figure 3a: Average Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion)

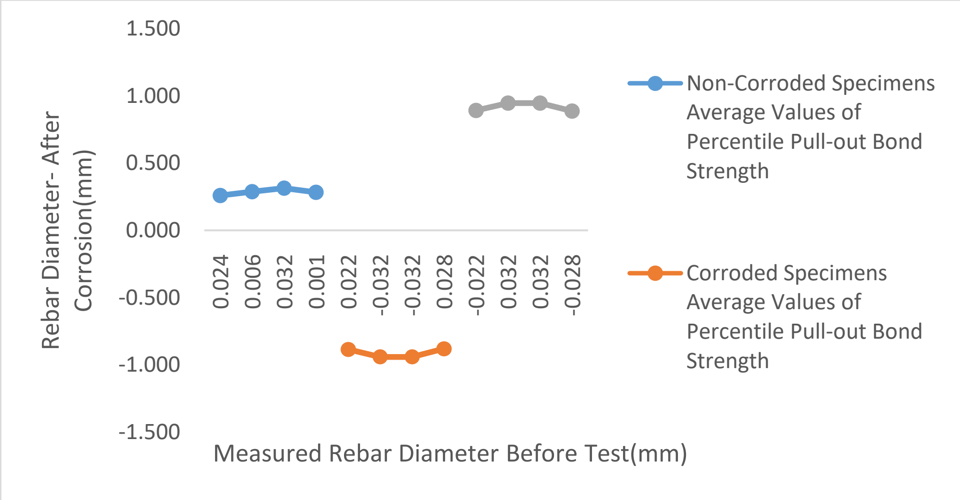

Figure 3b. Average Percentile Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion

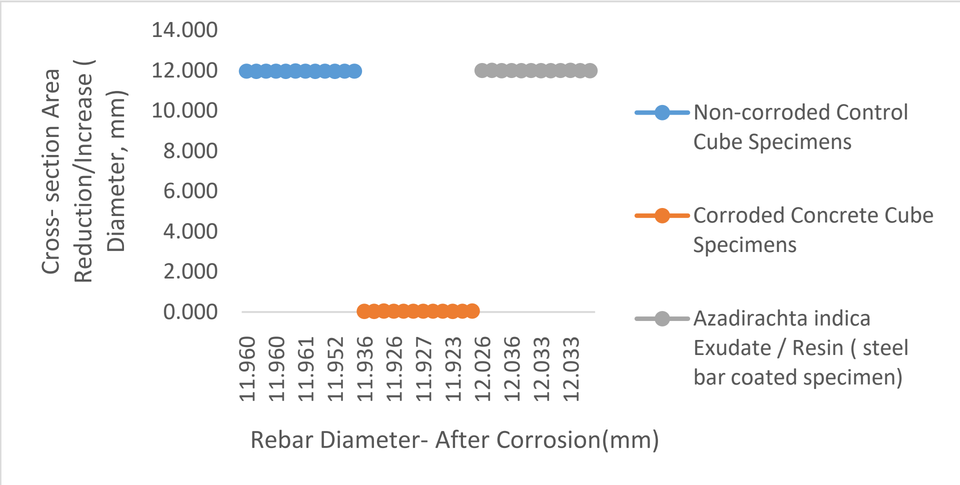

Figure 4. Rebar Diameter- After Corrosion versus Cross - Sectional Area Reduction/Increase

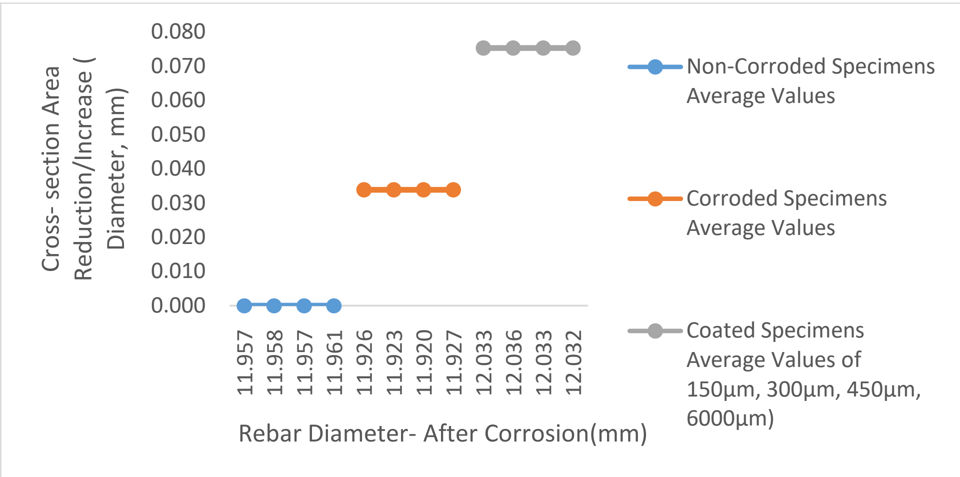

Figure 4a. Average Rebar Diameter- After Corrosion versus Cross – Sectional Area Reduction/Increase

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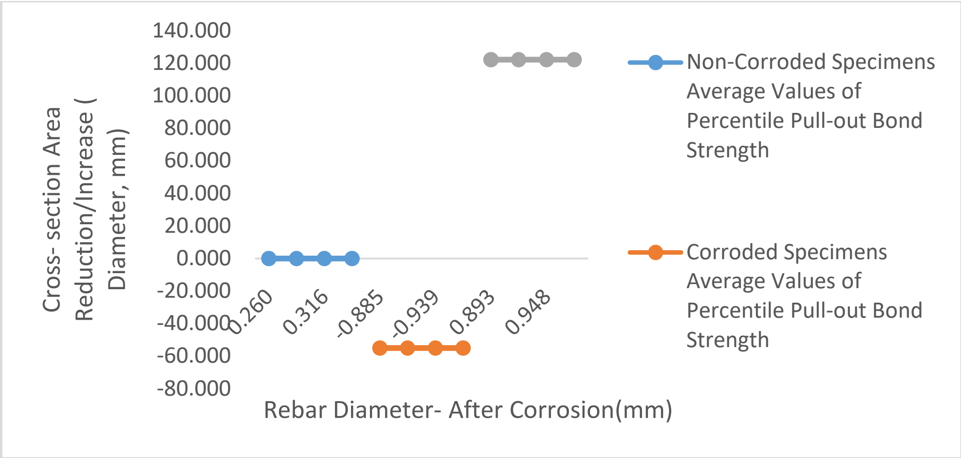

Figure 4b. Average percentile Rebar Diameter- After Corrosion versus Cross - sectional Area Reduction/Increase

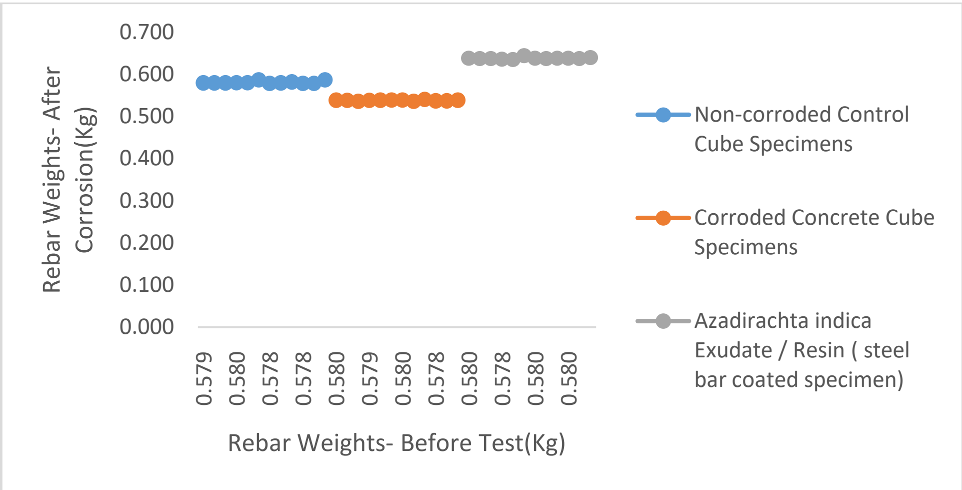

Figure 5. Rebar Weights- Before Test versus Rebar Weights- After Corrosion

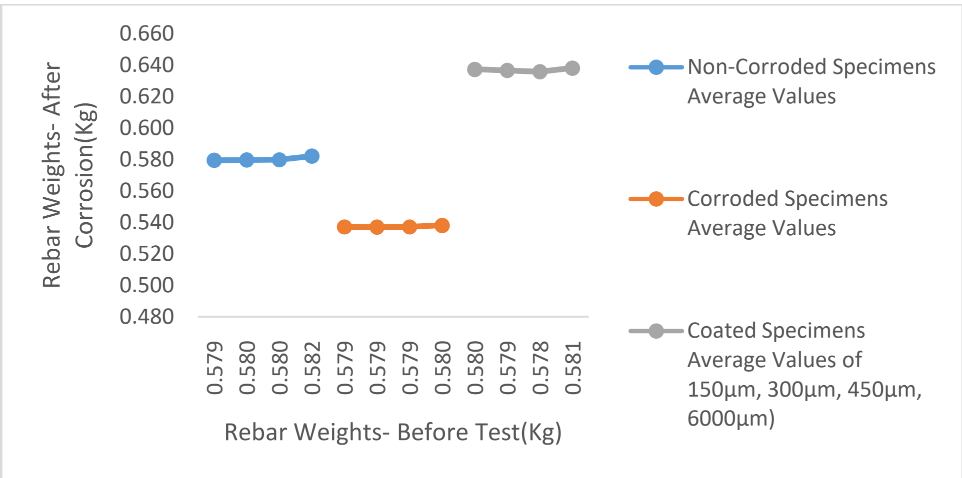

Figure 5a. Average Rebar Weights- Before Test versus Rebar Weights- After Corrosion

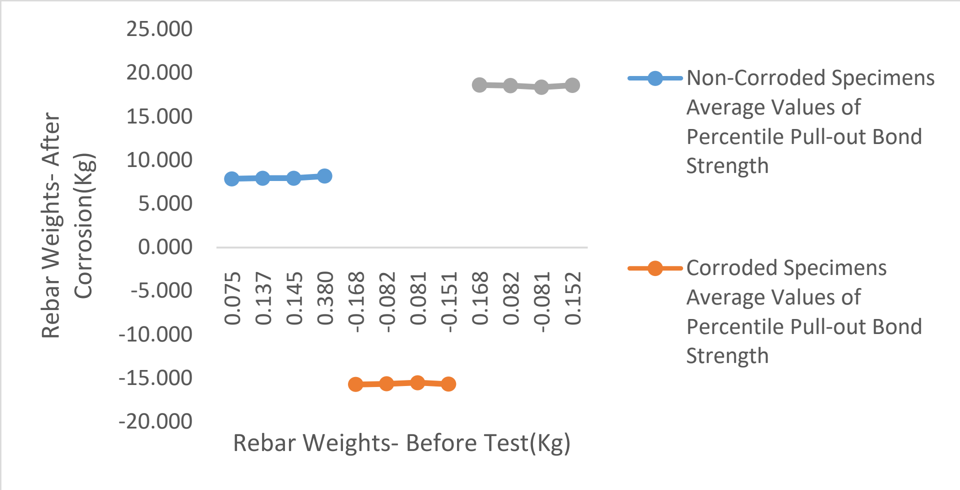

Figure 5b. Average Percentile Rebar Weights- Before Test versus Rebar Weights- After Corrosion

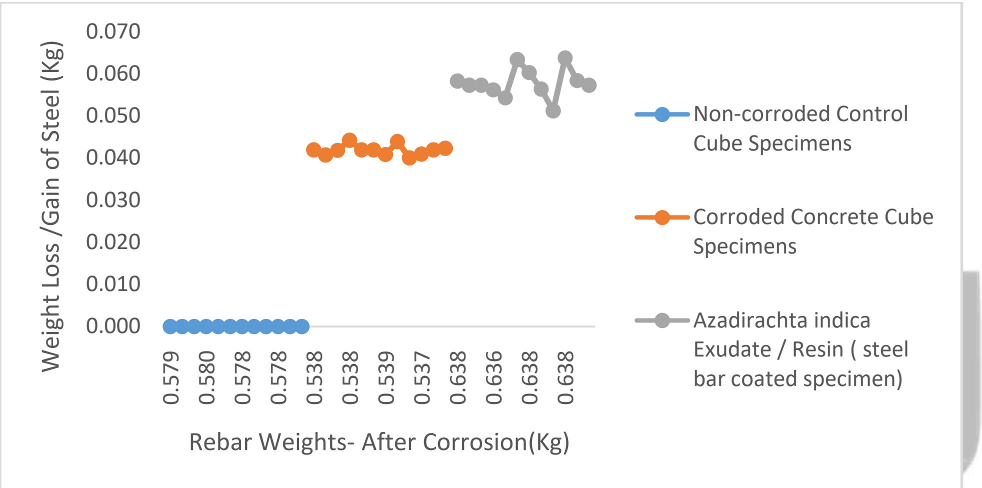

Figure 6. Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

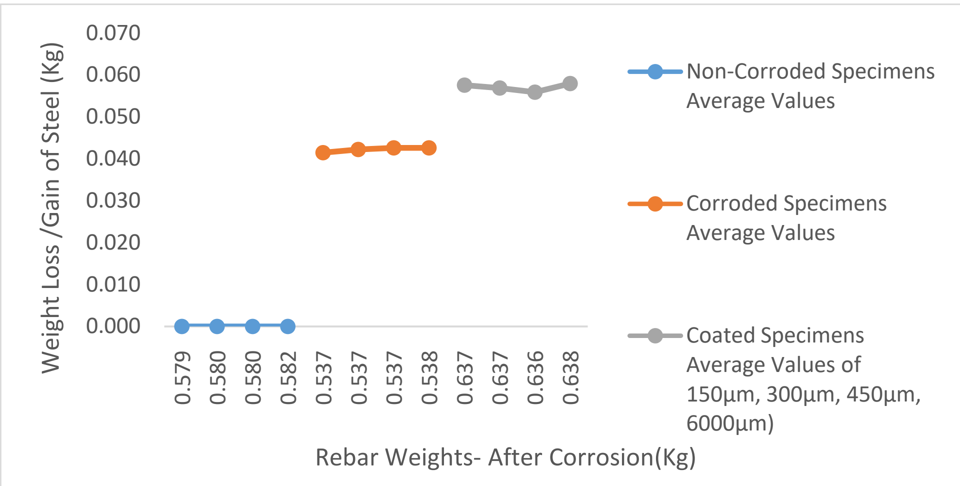

Figure 6a. Average Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

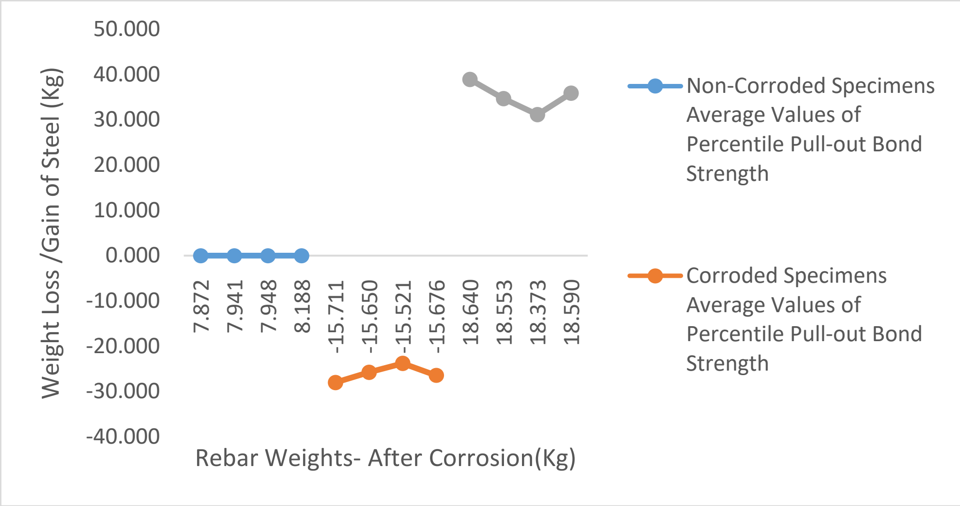

Figure 6b. Average percentile Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

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

The results of the destructive bond loads compared to controlled, corroded and coated, which are listed in the mean composition and percentile and also in percentage difference values, indicate the effect of corrosion on the uncoated samples with reduced maximum percentile values, leading to better results. high in applications with lower loads to layered sample exposures from high-voltage applications with higher failure values. The results clearly show that the effect of corrosion has a negative impact on the mechanical properties of reinforcing steel, from diameter and cross-section reduction to heavy loading and surface modification. The open nature of the coated samples demonstrates the efficiency and effectiveness of using exudates to prevent and protect reinforcement embedded in concrete exposed to harsh coastal and service areas.

From the values obtained, the corroded samples showed lower adhesive tensile strength with lower percentile values than samples coated with higher peel bond and higher values than the controlled sample values. The reduced values and lower tensile strength measured in corroded samples can be attributed to the effect of corrosive attack, which causes surface modification with significant swelling and fiber reduction affecting deformed reinforcement, resulting in smooth reinforcing steel. The existing interface between concrete and steel is drastically reduced by freestanding ribs. The exposure properties of the coated samples demonstrate the effectiveness and efficiency of exudates/resin in preventing corrosion attack on reinforced concrete structures in coastal marine environments. As shown, the difference values obtained between corroded and coated elements clearly demonstrate the specter and threatening effects of corrosion on uncoated samples.

The results show that the maximum slip value of corroded specimens is lower than that of controlled and coated specimens and greater slip damage. The effect of low stress and higher damage is on the corrosion effect on the deformed rib, the reduction of the fiber properties and swelling, which leads to an increase in the volume diameter, and the transformation of the deformed rib into a smooth state with an effect on the interaction between the concrete and the steel interface and the creation of stress in the concrete environment

From the results obtained and shown in the figure, the effect of corrosion on uncoated and coated reinforcing steel is shown in Figures 3 and 6b on the diameter of the reinforcement. From the comparison results, the mechanical properties of reinforced concrete structures built with territorial sea areas with high salt content are negatively affected and strongly influenced by the effect of corrosion, but with the inclusion of exudates/resin as roofing material the negative effects are stopped. Indications analyzed from experimental work show that the corrosion effect on uncoated concrete cubes causes a reduction in cross-sectional diameter and cross-sectional area as well as a decrease in weight, while the coated concrete cube has a cross-sectional diameter and cross-sectional area and an increase in weight, as a result of the change in thickness encased in reinforcing steel.

4.0 Conclusion

In the experiment, the results obtained are plotted as follows:

1. The exudates/resin has a corrosion-inhibiting effect, as the impregnation is resistant to perforation and rust attack.
2. The interaction between concrete and steel in the coated component is greater than in the corroded sample
3. The adhesive properties of the coated and controlled components are higher than those that corrode
4. The lowest breakdown load, bond strength and maximum slip are listed on the corroded element
5. Coatings and control samples recorded higher load values and bond strengths.
6. . Loss and reduction in cross-section are mainly detected in corroded layers and controlled samples

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