Evaluation of Corrosion-Induced Degree on Bond Strength of Reinforced Concrete Structures Interaction

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ABSTRACT

The experimental work presents an ideal high salinity coastal marine area and the possible use of Chrysophyllum albidum exudates/resin as a barrier to limit rising movement and the risk of corrosion effects on exposed reinforced concrete structures constructed in rough and harsh areas. From the result of the average are percentile values are controlled 86.543% against the corroded values of -45.595, and coated 99.43%. The bond strength maximum values are controlled 69.572%, corroded -42.481%, and coated 98.031%. While the maximum slip for controlled is 95.942% as against a reduced value of corroded -43.076%), and increased coated value of 121.718%. Comparatively, the results of corroded concrete cubes percentile differences for failure bond load, bond strength, and maximum slip, all failed in low load applications with reduced percentile values compared to controlled and coated concrete samples. The result showed indications of the effect of corrosion on the failure bond load, bond strength, and maximum slip. The presence of corrosion reduces the efficiency of the reinforcing steel by reducing the mechanical properties of the surface transformation and affecting the bonding and interaction between the concrete and the steel reinforcement. The results obtained showed the effect of corrosion on uncoated and coated reinforcing steel. The diameter of reinforcement without layers decreases by a maximum value of -0.768% % and the coated increase by 0.83%, for the cross-sectional area of the corroded layer has a maximum decrease of -27.92% and coated increase by 48.348%, weight loss and gain decreased by -24.612% (loss) and layer increased by 66.868% % (gain). Results from experimental work showed that the effect of corrosion on uncoated concrete cubes causes a decrease in the cross-sectional area as well as a decrease in unit weight, while the cube-layer concrete has a cross-sectional area and increased weight, due to differences in the thickness of the reinforcing steel layer.

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

1.0 Introduction

Reinforced concrete structure mainly based on the connection mechanism between steel bars and concrete. The properties of the steel-concrete interface are affected by a large number of parameters related to steel and concrete and their interactions. These various aspects are discussed in detail in (Angst et al. [1]) causes heterogeneity at the steel-concrete interface, which among other things affects the steel-concrete adhesion. Studies have shown that when the bond between the reinforcement and surrounding concrete is decreased due to the mass loss of reinforcement caused by corrosion, the widths of the corrosion- induced cracks are increased 'therefore, in order to assess the impact of corrosion on the bond strength, the models based on the width of corrosion-induced cracks have been developed [Lin et. al, 2019[2]). In addition, as a phenomenon that is influenced by many variables, it is a challenge to know how steel-concrete bonding can be explained in reinforced concrete construction standards. This property has been explored since the 1940s, such as (Rehm [3]), who investigated the factors influencing the relationship between steel bars and concrete. Another suitable study is the study of (Wattstein [4], Mains [5], Ferguson et al. [6], Perry and Thompson [7], Goto [8], Mirza and Houde[9], Kemp [10], and Jiang et al. [11]). All these basic investigations were carried out using reinforcing steel with a diameter greater than 12.0 mm.

Research on steel-concrete composites has followed the development of materials such as high-strength concrete, additional concrete and self-compacting concrete (Barbosa [12], Barbosa et al. [13], Almeida Filho [14], Araujo et al. [15], Michael and Catherine [16]).

Recently, it has been claimed that the use of mineral admixtures in concrete can reduce the corrosion of reinforcements. It has been confirmed in many studies that mineral admixtures, especially finely ground pumice and silica fume, hinder the corrosion of reinforcements [Binici et al. [17]; Kayali and Zhu, [18]). There are many studies about in the selection of corrosion prevention methods; the basic parameter is the atmospheric conditions. Reinforced concrete bondings are also an issue in relation to quality control of reinforced concrete structures (Lorrain et al. [19], Silva et al. [20] and Jacintho et al.[21]) and the operation of reinforced concrete under extreme conditions, for example in high temperature environment and corrosion (Caetano [22] and Márquez et al. [23]). Although there have been several studies on steel-to-concrete bonding, few have evaluated the properties of reinforcement less than 10.0 mm in diameter, including the 5.0, 6.3 and 8.0 mm diameters commonly used in elements of reinforced concrete. In addition, the evolution of concrete allows the construction and manufacture of thin reinforced concrete components, especially from the precast sector, mainly using thin reinforcement Although there are many methods to prevent corrosion, the most common way of increasing corrosion resistance is painting or coating the reinforcement (Elshami and Ali, [24]). Due to environmental issues, there is a tendency to use new organic coating materials (Ahmed et. al, 2015[25]; Ahmed e al. [26]). The purpose underlying all of these studies is to produce impermeable concrete and investigate the corrosion resistance of reinforcements with organic ash-based coating. However, there is still a need for further investigations on the development of novel environment friendly, organic coating materials to prevent.

Toscanini et al. [27] investigated the effect of chloride and carbonate pollution in the marine region of the Niger Delta, Nigeria, on the poor bonding properties of steel reinforcement and concrete, leading to premature deterioration of reinforced concrete structures. Reinforced steel is coated with varying thicknesses and embedded in cubes of concrete, hardened in an accelerated corrosive environment and analyzed for tensile strength parameters. In comparison, the yield of deformed samples decreased while those with resin-coated control exudates increased. The complete results show that the exudates/natural resins exhibit resistance to the effects of corrosion on steel reinforcement in concrete structures.

Charles et al. [28] studied the effect of reduced bond strength and interaction between reinforcing steel and reinforced concrete structures in a saltwater marine environment was assessed with uncoated steel and Khaya senegalensis. The results of the bond fracture stress showed a difference of -43.622% and 77.37% and 79.67% for corrosive and coated exudates/resin elements. The reduced average load strength of the bond strength varied from 57.06% to 36.33% and 106.57% for colored and coated samples. The results clearly show that the stresses at the corrosion joints are higher with corrosion than with the exudates/adhesives of the corrosion model coatings. The combined strength of the corroded and coated samples showed a greater affinity for the coated samples than for the corroded samples.

Charles et al. [28] investigated the effect of exudates/resin to prevent corrosion attack on bond strength between steel and concrete. Coated samples of uncoated and exudates/resin were combined into different concrete thicknesses and combined for a 178 day corrosion acceleration process. The comparison results show that the corrosion sample values decreased but increased for corrosion and elements with exudates/resin, indicating the ability of acacia exudates/resin from Senegal to strengthen steel layers. The overall results show a high value of joint tensile strength and low stress in the case of failure of the control and occupied by exhausted samples.

Terence et al. [30] investigated the effect of inhibitors on steel reinforcement in an experimentally accelerated process of the breaking strength of embedded steel for 150 days. The overall results showed a higher level of control tensile strength and exudates/adhesive coating compared to corroded samples.

Gede et al. [31] investigated the bond strength between concrete and the elasticity of reinforcement due to the effect of reducing steel reinforcement in the presence of salt water. Improved reinforcing steel with varying thickness of 150 m, 300 m and 450 m exudates/resin with Artocarpus altilis extract and without coating was placed in concrete and saturated with sodium chloride for 150 days. The comparison results show that the value of the applied load decreases for the uncoated (corroded) and coated samples. The overall results showed a high degree of strength of the controlled bond and the precipitate/resin layer on the samples corroded due to the reduction of fibers and diameters due to the corrosive effect.

2.0 Test program

The use of exudate/resin pastes extracted from the trunk of plants and coated to steel reinforcement was studied; various coating thicknesses were introduced and then embedded in concrete cubes. The corrosion acceleration process was introduced as a corrosion medium of sodium chloride (NaCl) to determine the potential use of exudate/resin material to control the changes and impacts that occur in coastal water to reinforcing steel in concrete structures. The test sample 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. These samples are designed with 36 reinforced concrete cubes of dimensions 150 mm × 150 mm x 150 mm, all of which are centrally embedded with 12mm diameter reinforcement embedded to the control, uncoated, and coated specimens for pullout - bond testing with and immersed in sodium chloride for 360 days. The initial cube curing days was 28 days. Acid-corrosive media solutions were modified 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) were purchased. Both meet the requirements of (BS882; [32])

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 the requirements of cement (BS EN 196-6 [33])

2.1.3 Water

The water samples were clean and free of impurities. Water was obtained from the Civil Engineering Laboratory, Kenule Beeson Polytechnic, Bori, Rivers. Water met (BS 3148 [34]) requirements

2.1.4 Structural Steel Reinforcement

Reinforcements are obtained directly from the market at Port Harcourt, met (BS4449: 2005 + A3 [35])

2.1.5 Corrosion Inhibitors (Resins / Exudates) Musanga cecropioides

The natural gummy exudates were extracted from the tress trunk and gotten from Uyanga Village in Akamkpa Village bush of Cross – Rivers State of Nigeria.

4.2 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 test. The test cubes were 150 mm x 150 mm x 150 mm and were placed in a metal mold and de-molded after 72 hours. Samples were treated at room temperature in the tank for 28 days before the initial treatment period, after which 360-day monthly routine monitoring was approved by rapid acceleration corrosion testing and test regime. Cubes for corrosion-acceleration samples were taken at intervals of approximately 3 months, 90 days, 180 days, 270 days, and 360 days. Conducted pullout bond testing of failure bond loads, bond strength, maximum slip, reduction/increase of cross-sectional area, and weight loss/steel reinforcement were examined and recorded.

2.3 Accelerated Corrosion Setting and Testing Method

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

2.4 Pullout-Bond Strength Test

The pullout-bond strength test of concrete cubes, control in each of the 12 samples, was carried out on a total of 36 samples with uncoated and coated members were tested on a 50 kN pressure load according to BSEN12390.2 [36] using the Universal Testing Machine. A total number of 36 cubes measuring 150 mm × 150 mm × 150 mm, embedded in the center of a concrete cube of 12 mm diameter were examined and the result recorded

2.5 Tensile Strength of Reinforcement Bars

To determine the yield and tensile strength of the bar, uncoated and coated steel reinforcement was tested and subjected to direct pressure until the failure load was recorded under pressure on 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 surroundings concrete structures. The increase in deformed (rib) reinforcing bars and slip bonds mainly depends on the bearings or mechanical interlocks between the concrete around the ribs on the surface of the bar. The damaging effect from the attack by corrosion has rendered many structures unserviceable and designed life span shortened.

Experimental data presented in tables 3.2.3.2 and 3.3, summarized into tables 3.4 and 3.5 are test conducted on 36 concrete cubes samples of 12 controlled placed in freshwater for 360 days, 12 uncoated and 12 exudates/resin coated samples all embedded with reinforcing steel and immersed in 5% sodium chloride (NaCl) aqueous solution for 360 days and evaluated their performances with examinations, monitoring, checking and testing intervals of 3 months at 90 days, 180 days, 270 days and 360 days. Indeed, the manifestation of corrosion is a long-term process which takes decades for full functionality, but the artificially introduction of sodium chloride triggers the manifestation and occurrence of corrosion with lesser time. The experimental work represented the ideal coastal marine region of high salinity and the potential application for of raphia hookeri exudate / resin extract as inhibitory material in curbing the scourge and menace of corrosion effect on reinforced concrete structure exposed or built within such severe and harsh region.

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

	Non-corroded Control Cube Specimens											
Sample Numbers	MCC	MCC1	MCC2	MCC3	MCC4	MCC5	MCC6	MCC7	MCC8	MCC9	MCC10	MCC11
	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)	29.642	27.553	28.117	28.713	29.529	29.229	29.753	29.570	29.635	31.446	30.570	30.772
Bond strength (MPa)	11.309	12.201	10.699	11.629	12.002	12.925	13.019	12.349	12.383	13.089	12.400	12.947
Max. slip (mm)	0.130	0.132	0.122	0.127	0.126	0.125	0.138	0.142	0.150	0.148	0.152	0.150
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	11.986	11.989	11.980	11.990	11.989	11.986	11.989	11.989	11.989	11.979	11.979
Rebar Diamete r-at 28 Days Nominal(mm)	11.988	11.986	11.989	11.980	11.990	11.989	11.986	11.989	11.989	11.989	11.979	11.979
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)	0.569	0.569	0.569	0.576	0.569	0.569	0.570	0.569	0.569	0.570	0.568	0.568
Rebar Weights- at 28 Days Nominal (Kg)	0.569	0.569	0.569	0.576	0.569	0.569	0.570	0.569	0.569	0.570	0.568	0.568
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 Specimens

	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)	16.946	16.259	16.549	15.991	15.239	16.107	15.686	15.994	15.692	16.927	15.806	16.540
Bond strength (MPa)	7.551	7.561	7.326	7.548	7.314	7.287	7.085	7.774	6.749	7.237	7.085	7.397
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)	11.980	11.979	11.999	11.988	11.989	11.990	11.978	11.979	11.989	11.986	11.989	11.990
Rebar Diameter-After Corrosion(mm)	11.950	11.949	11.968	11.958	11.959	11.959	11.948	11.949	11.958	11.955	11.958	11.959
Cross- section Area Reduction/Increase (Diameter, mm)	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
Rebar Weights- Before Test (Kg)	0.569	0.569	0.569	0.570	0.569	0.570	0.569	0.569	0.569	0.570	0.568	0.576
Rebar Weights- After Corrosion (Kg)	0.529	0.529	0.529	0.529	0.536	0.529	0.530	0.529	0.529	0.530	0.528	0.536

Weight Loss /Gain of Steel (Kg)	0.040	0.041	0.040	0.040	0.033	0.040	0.040	0.040	0.046	0.039	0.040	0.034

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

Samplin g and Durations	**Samples 1 (90 days)**			**Samples 2 (180 Days)**			**Samples 3 (270 Days)**			**Samples 4 (360 Days)**		
Sample	**150µm (Exudate/Resin) coated**			**300µm (Exudate/Resin) coated**			**450µm (Exudate/Resin) coated**			**600µm (Exudate/Resin) coated**		
Failure Bond Loads (kN)	31.972	29.882	30.446	31.043	31.858	31.559	32.082	31.900	31.964	33.775	32.900	33.101
Bond strength (MPa)	13.636	14.529	13.026	13.957	14.330	15.253	15.346	14.676	14.711	15.416	14.728	15.274
Max. slip (mm)	0.145	0.147	0.137	0.142	0.141	0.140	0.153	0.157	0.165	0.163	0.167	0.165
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)	11.999	11.989	11.979	11.978	11.988	11.989	11.980	11.989	11.999	11.978	11.979	11.989
Rebar Diameter- After Corrosion(mm)	12.399	12.389	12.380	12.379	12.389	12.389	12.381	12.390	12.399	12.379	12.380	12.390
Cross- section Area Reduction/Increase (Diameter, mm)	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401
Rebar Weights- Before Test (Kg)	0.569	0.569	0.576	0.576	0.569	0.569	0.570	0.569	0.576	0.569	0.576	0.569
Rebar Weights- After Corrosion (Kg)	0.627	0.628	0.627	0.627	0.627	0.627	0.628	0.627	0.627	0.627	0.626	0.627
Weight Loss /Gain of Steel (Kg)	0.052	0.059	0.051	0.059	0.058	0.052	0.059	0.057	0.059	0.627	0.050	0.058

Table 3.4: Results of Average Pull-out Bond Strength Test (τu) (MPa) Control, Corroded and Exudate/ Resin Coated Steel bar

	Control, Corroded and Resin Steel bar Coated											
Sample	Non-Corroded Specimens Average Values				Corroded Specimens Average Values				Coated Specimens Average Values of 150µm, 300µm, 450µm, 6000µm)			
Failure load (KN)	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	0.153	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- section Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.043	0.040	0.040	0.046	0.052	0.056	0.056	0.058
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) 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	93.03	99.43
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	95.942	-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)	0.032	0.033	0.034	0.032	0.035	0.038	0.037	0.034	0.037	0.038	0.037	0.034
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- section 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. 384	0.383	0.381	0.386	0.383	0.401	0.378	0.379	0.394	0.389	0.385	0.387
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

The process of bonding in the boundary between steel and concrete affects the load transfer between steel and concrete. This makes it possible to withstand the strength and performance of reinforcing bars mixed with concrete and create reliable structural elements that can withstand the forces and stress (Amleh and Mirza, [37]).

The above factors gave rise on the results of the failure bond load, bond strength, and maximum slips made on 36 concrete cubes are presented in Table 3.1. 3.2, and 3.3 and finalized in 3.4- 3.5 and were graphically represented in 1 - 6b. The results obtained were 12 controlled, 12 (uncoated) corroded, and 12 exudates /resin coated samples subjected to failure load of 50kN in Instron Universal Testing Machines as described in the testing process.

The obtained minimum and maximum values of the average and percentile failure bond loads of controlled samples are 28.761kN and 31.253kN, this represented standard working and reference values of (70.041% and 86.543%), corroded samples are 16.108kN and 16.914kN representing decremented values (-50.11% and -45.595%), the coated samples are 31.089kN and 33.581kN, representing incremental percentile values of (93.03% and 99.43%).

The obtained results of the bond strength are controlled samples (reference point) 11.393MPa and 12.802MPa representing (46.27% and 69.572%), the corroded samples are 7.513MPa and

7.789MPa representing decreased values judging from the reference (-49.503% and -42.481%). The coated samples are 13.542MPa and 14.951MPa representing incremental values (73.854% and 98.031%).

The results of the maximum slip, are controlled 0.14mm and 0.153mm (61.195% and 95.942%), corroded 0.079mm and 0.087mm (-54.898% and -43.076%), coated 0.152mm and 0.176mm (75.674 % and 121.718%).

From the result presented in table 3.4 the average values based on tables 3.1, 3.2, and 3.3 and summarized in table 3.5 percentile values are controlled 86.543% against the corroded values of -45.595, and coated 99.43%. The bond strength maximum values are controlled 69.572%, corroded -42.481%, and coated 98.031%. While the maximum slip for controlled is 95.942% as against a reduced value of corroded -43.076%), and increased coated value of 121.718%. Comparatively, the results of corroded concrete cubes percentile differences for failure bond load, bond strength and maximum slip, all failed in lower load applications with reduced percentile values compared to controlled and coated concrete cube samples. (Toscanini et al. [27]; Charles et a,[28], Charles et al.[29], Terence et al., [30], Gede et al. [31]).

The result showed indications of the effect of corrosion on the failure bond load, bond strength, and maximum slip. The presence of corrosion reduces the efficiency of the reinforcing steel by reducing the mechanical properties of the surface transformation and affecting the bonding and interaction between the concrete and the steel reinforcement

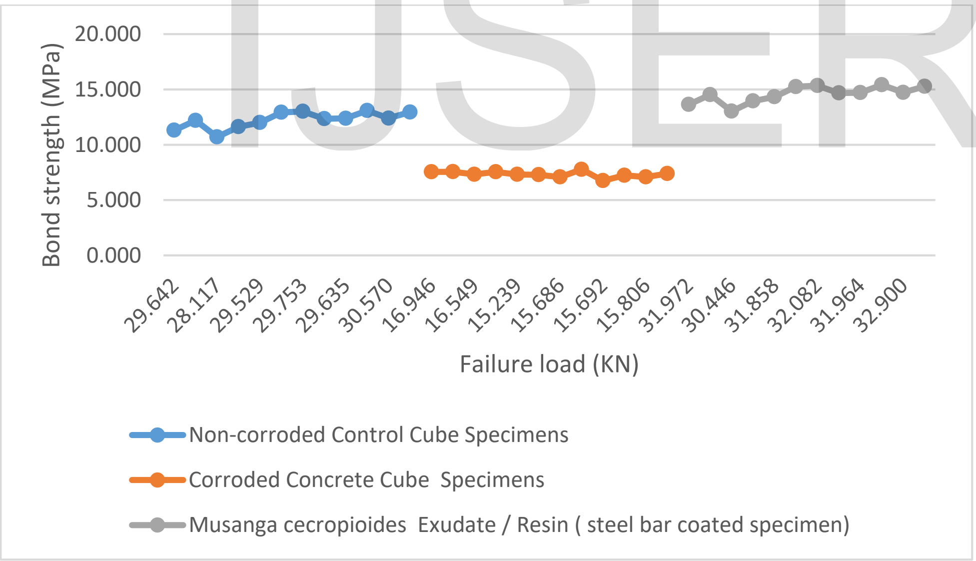

Figure 1. Failure Bond loads versus Bond Strengths

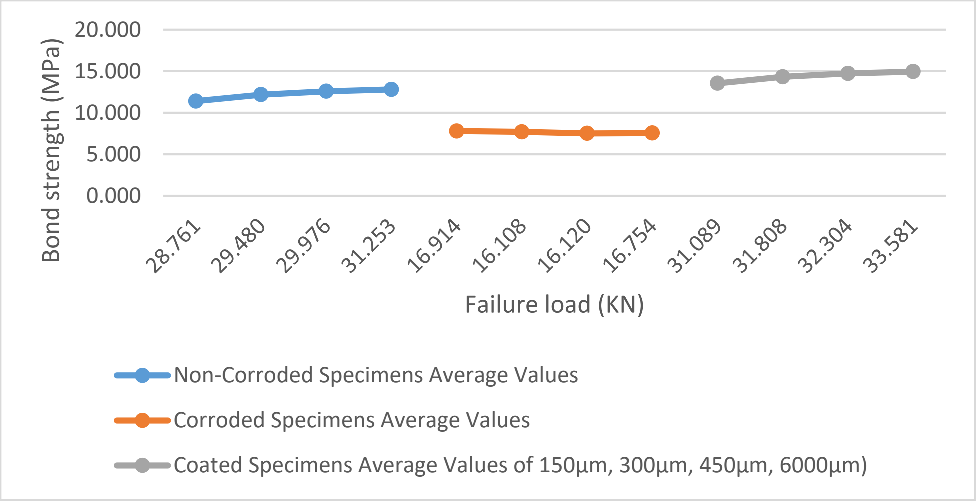

Figure 1a. Average Failure Bond loads versus Bond Strengths

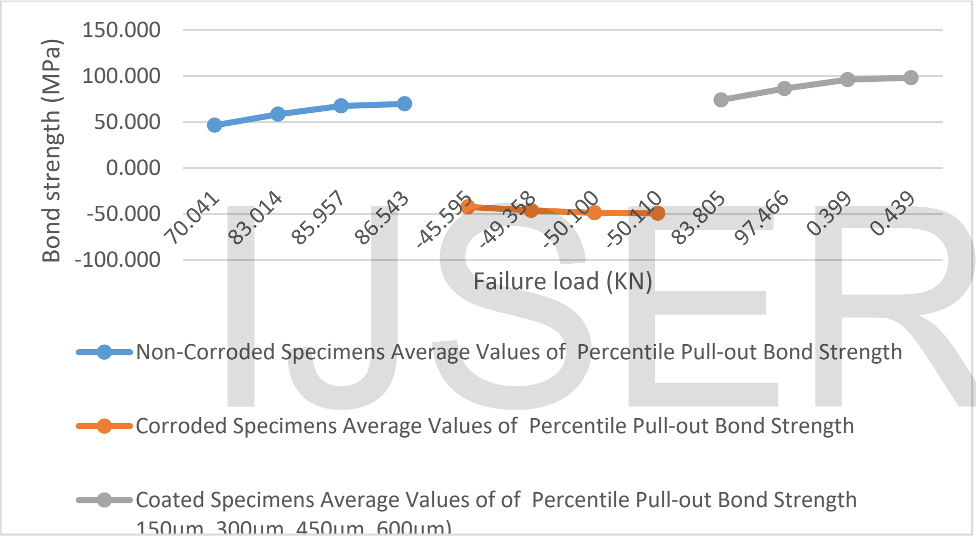

Figure 1b. Average Percentile Failure Bond loads versus Bond Strengths

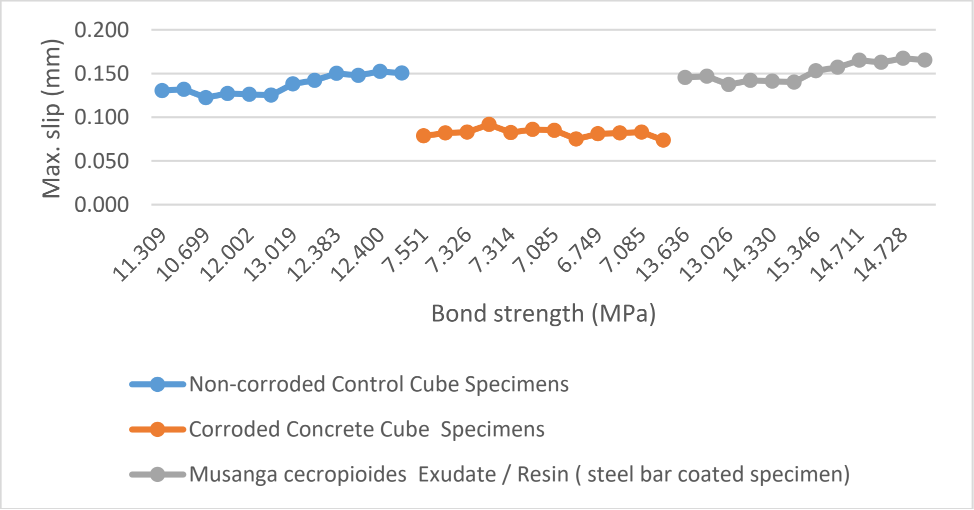

Figure 2. Bond Strengths versus Maximum Slip

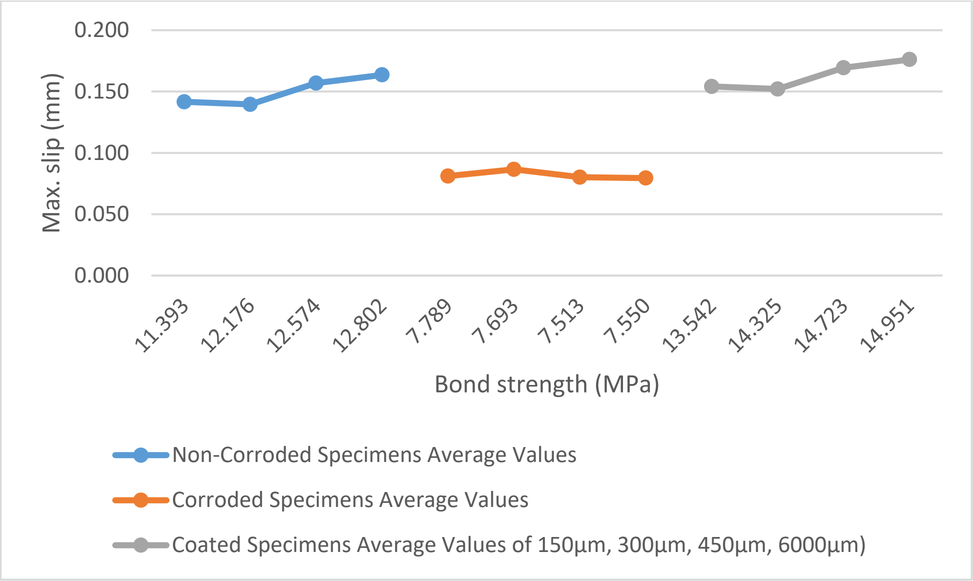

Figure 2a. Average Bond Strengths versus Maximum Slip

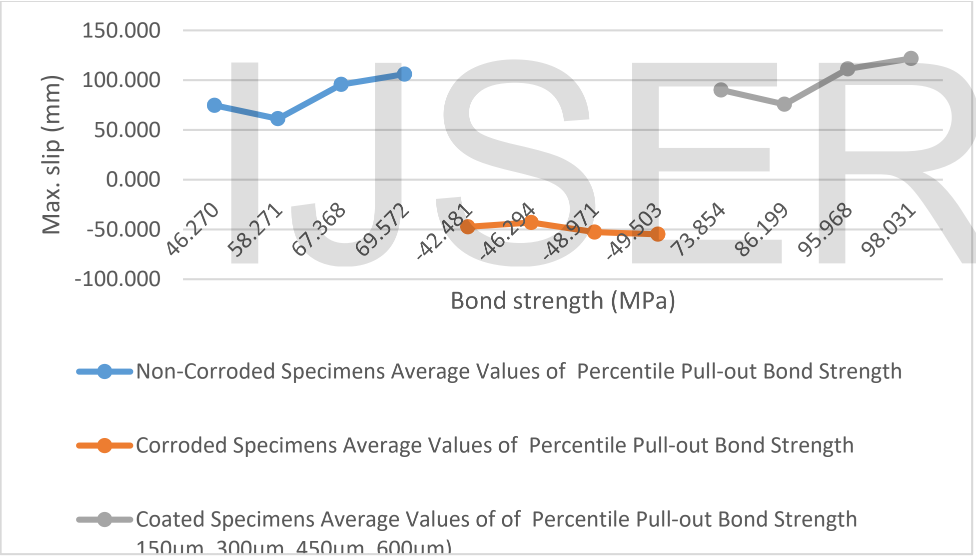

Figure 2b. Average Percentile Bond Strengths versus Maximum Slip

3.3 Mechanical Properties of Reinforcing Bars

The strength of the adhesive is mainly due to the weak chemical bond between the steel and the hardened cement, but this strength is destroyed at low pressure. Immediately after slipping, friction aids adhesion. With a fine steel bar, friction is an important part of strength. Reinforcement of steel bars with ribs with raised shear joints relies mainly on bearing or mechanical locking between the ribs and the surrounding concrete on the surface. This study introduces the use of exudates/resins to increase the slip problem in plain reinforcing steel.

The data are shown in Tables 3.1, 3.2, and 3.3 and summarized in Table 3.4 ff. (Finally), which is summarized in 3.5, takes into account the behavioral properties of the mechanical properties of controlled, uncoated (rusted) and coated concrete elements of a cube, subject to failure conditions of the Instron Universal Testing Machine after accelerated corrosion of the induced process for 360 days and Periodic performance arrangements of samples at 3-month intervals are as shown in the table and plotted in Figure 1-6b. The yield of the controlled samples is a value of 100%, as it is incorporated in a suitable freshwater tank (BS 3148).

The results are summarized in the minimum and maximum values obtained from tables 3. 4, and 3.5.

The nominal diameter of the steel bars of all samples was 100%, and the minimum and maximum diameters of steel bars measured before the test was 11.951mm and 11.955mm (0.239% and 0.338%), respectively. The diameter of the reinforcement sample without coating (corroded) after the corrosion test was 11.915mm and 11.922mm (-0.823% and -0.768%), after coating 12.01mm and 12.014mm (0.774% and 0.83%). The results for uncoated (corroded) cross-sectional areas were 0.04mm and 0.046mm (-28.98% and -27.92%), for coated areas were 0.639Kg and 0.642Kg (18.001% and 18.099%).

The results of the weight of reinforcement before testing for all samples were 0.581Kg and Kg (0.381% and 0.386%), the weight after the corrosion test for corrosion was 0.541Kg and 0.544Kg (-15.325% and -15.255%), for the coated are 0.639Kg and 0.642Kg (18.001% and 18.099%), and loss / weight of steel has been corroded 0.037Kg and 0.044Kg (-40.073% and -24.612%) and coating values of 0.056Kg and 0.062Kg (32.648% and 66.868%).

The results obtained and shown in the figure show the effect of corrosion on uncoated and coated reinforcing steel. In Figures 3 and 6b, the diameter of the reinforcement shows that the diameter of the reinforcement without layers decreases by a maximum of -0.768% % and the coated increase by 0.83%, for the cross-sectional area of the corroded layer has a maximum decrease of -27.92% and coated increase by 48.348%, weight loss and gain decreased by
-24.612% (loss) and layer increased by 66.868%% (gain). Indications analyzed from experimental work show that the effect of corrosion on uncoated concrete cubes causes a decrease in the cross-sectional diameter and cross-sectional area as well as a decrease in body weight, while the cube-layer concrete has a cross-sectional diameter and a cross-section area and increased weight, due to differences in the thickness of the reinforcing steel layer (Toscanini et al.[27]2019;Charles et al.[28] 2019;; Charles et al.,[29] 2019; Terence et al., [30]2019; Gede et al. [31]).

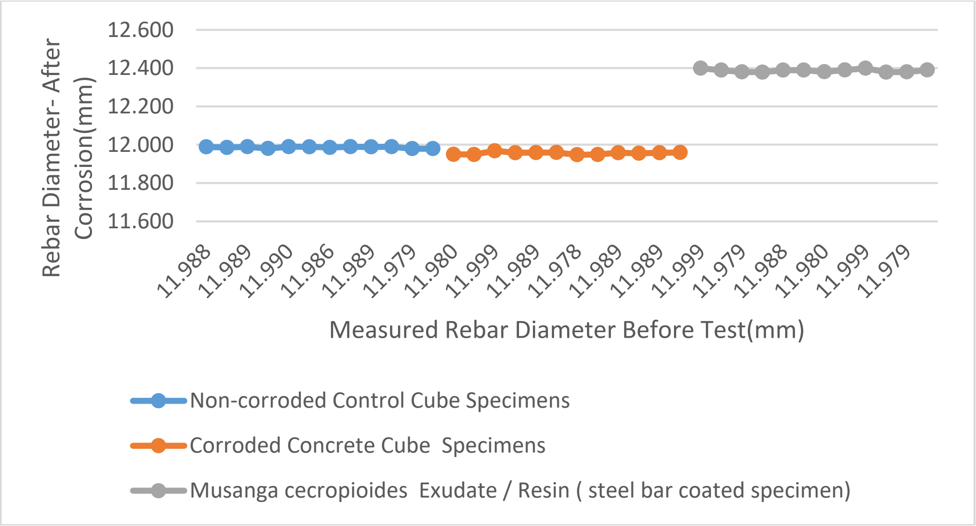

Figure 3. Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion)

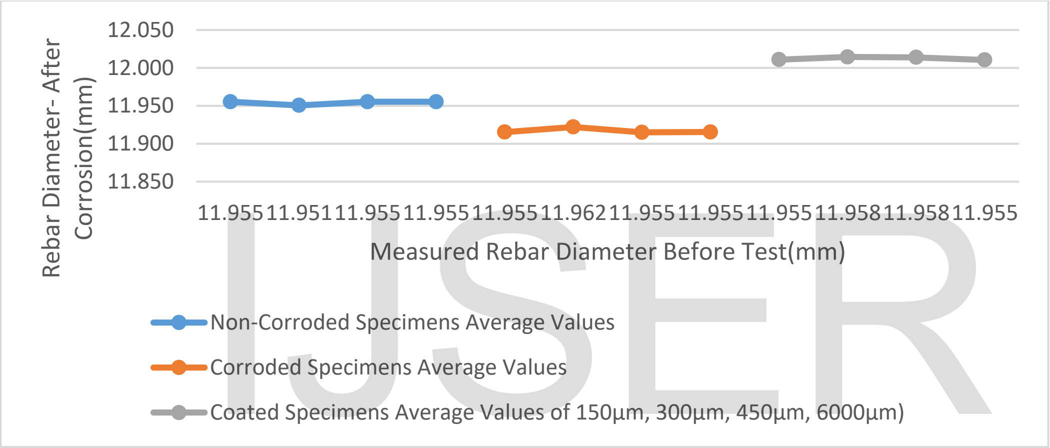

Figure 3a. Average Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion)

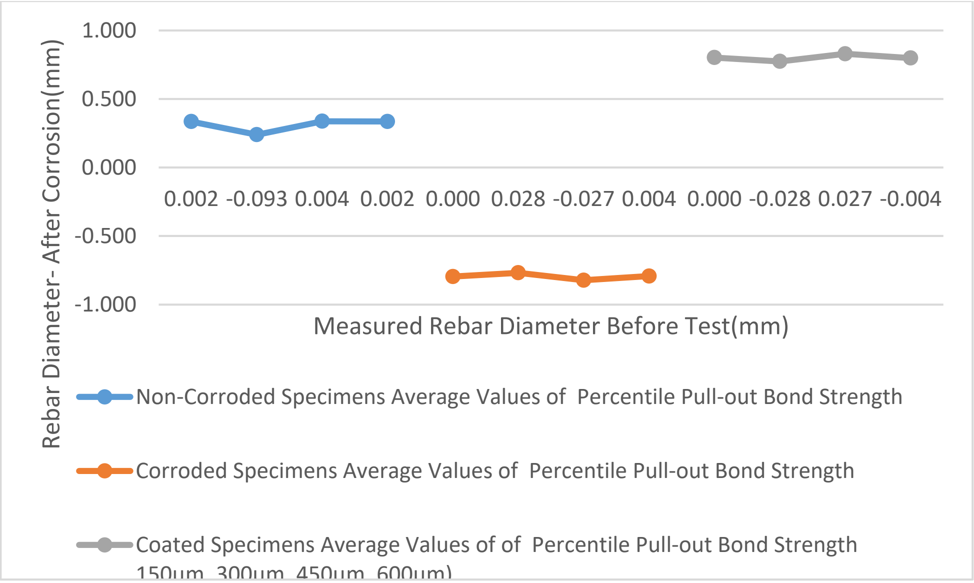

Figure 3b. Average Percentile Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion

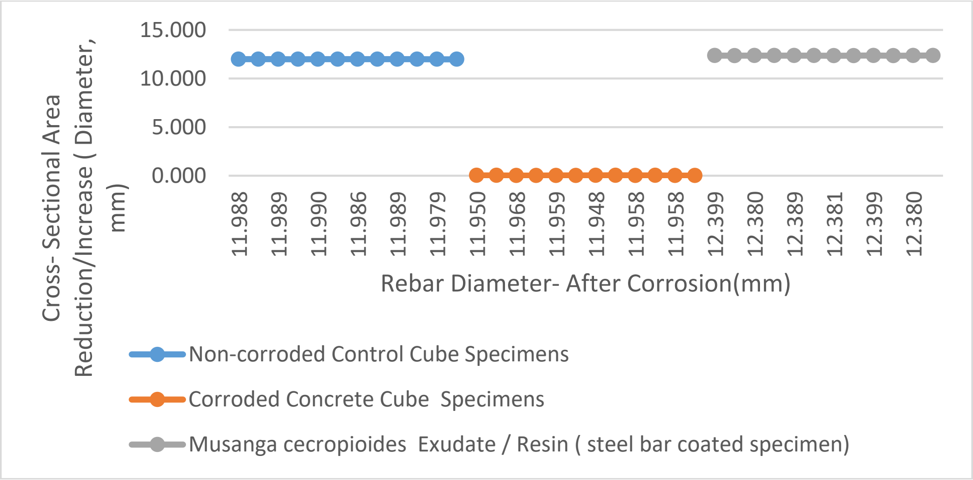

Figure 4. Rebar Diameter- After Corrosion versus Cross - Sectional Area Reduction/Increase

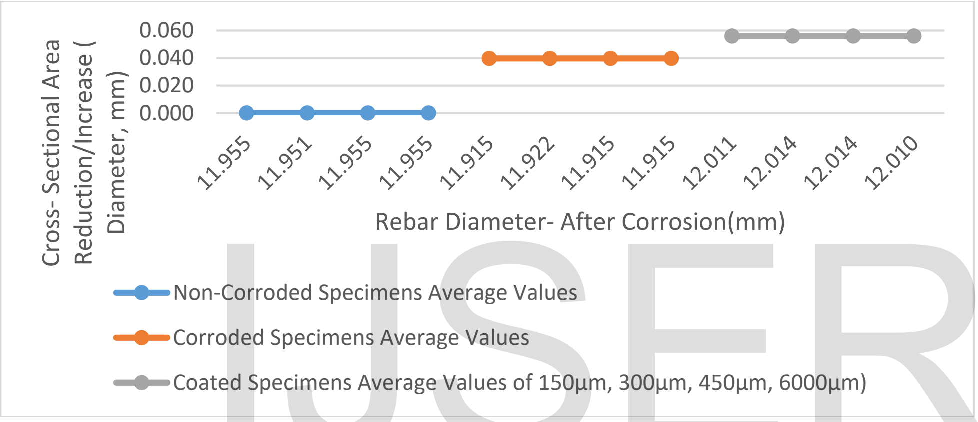

Figure 4a. Average Rebar Diameter- After Corrosion versus Cross – Sectional Area Reduction/Increase

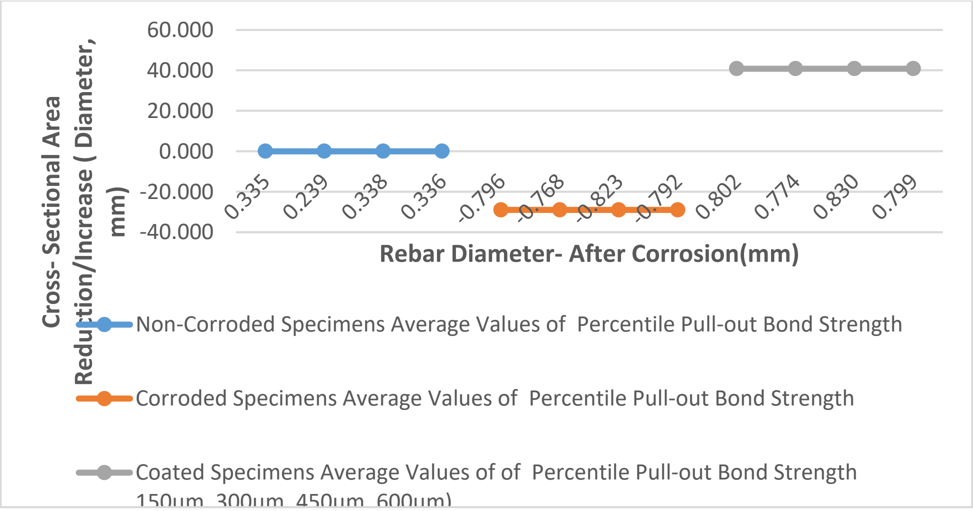

Figure 4b. Average percentile Rebar Diameter- After Corrosion versus Cross - sectional Area Reduction/Increase

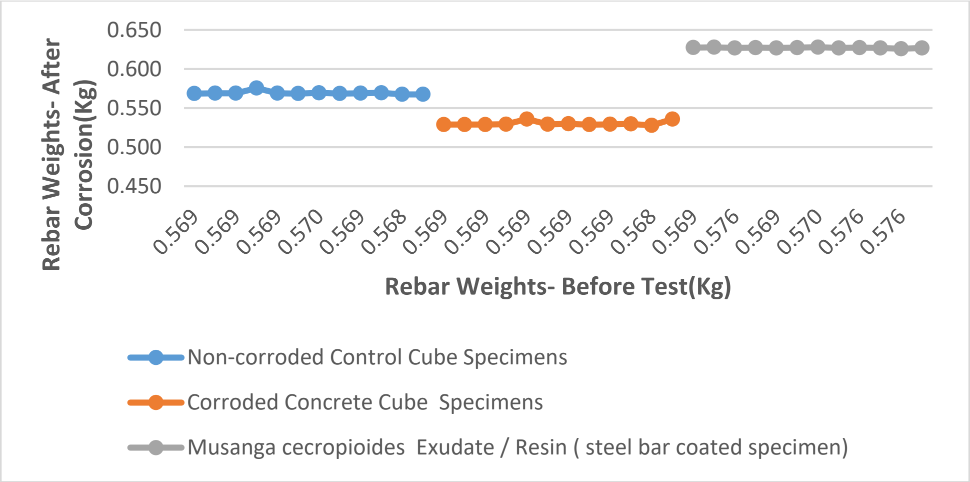

Fig. 5. Rebar Weights- Before Test versus Rebar Weights- After Corrosion

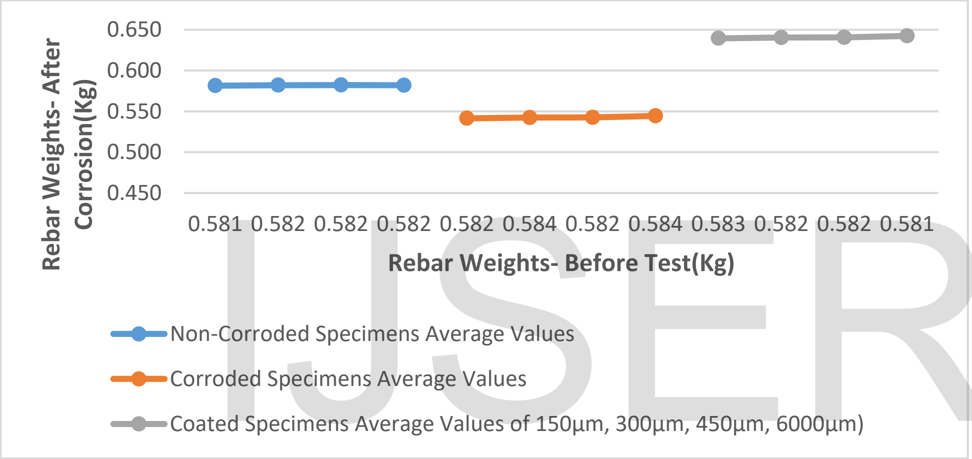

Fig. 5a. Average Rebar Weights- Before Test versus Rebar Weights- After Corrosion

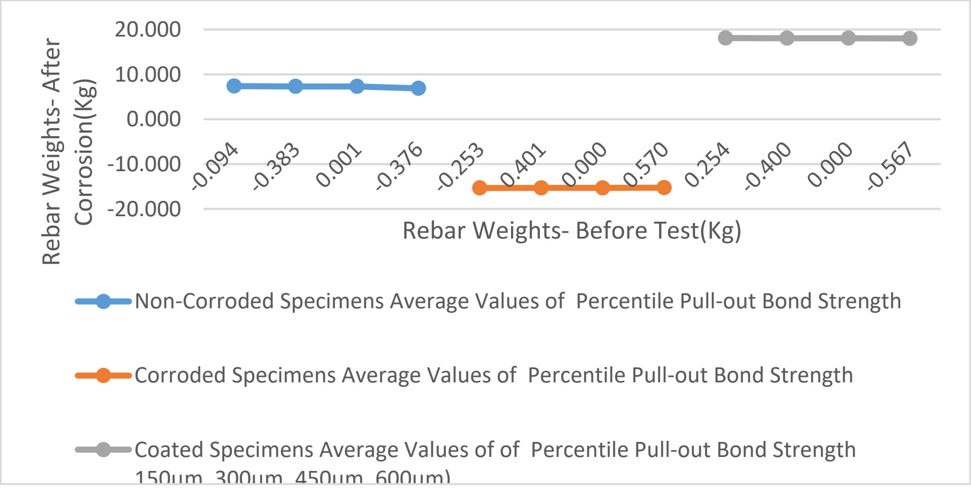

Figure 5b. Average Percentile Rebar Weights- Before Test versus Rebar Weights- After Corrosion

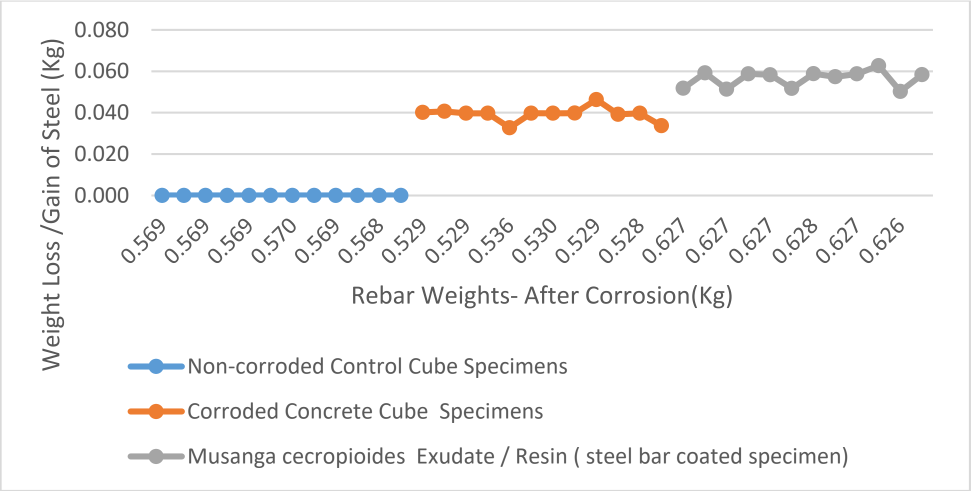

Figure 6. Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

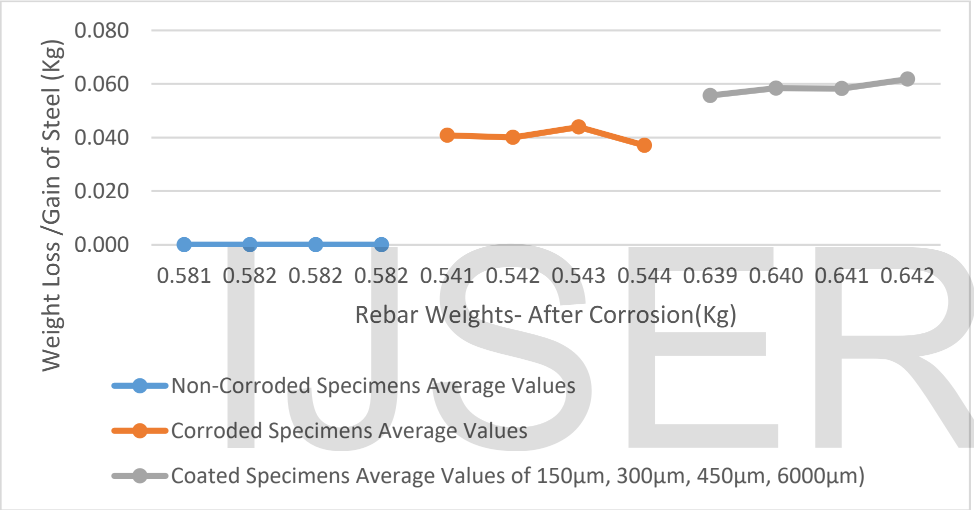

Figure 6a. Average Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

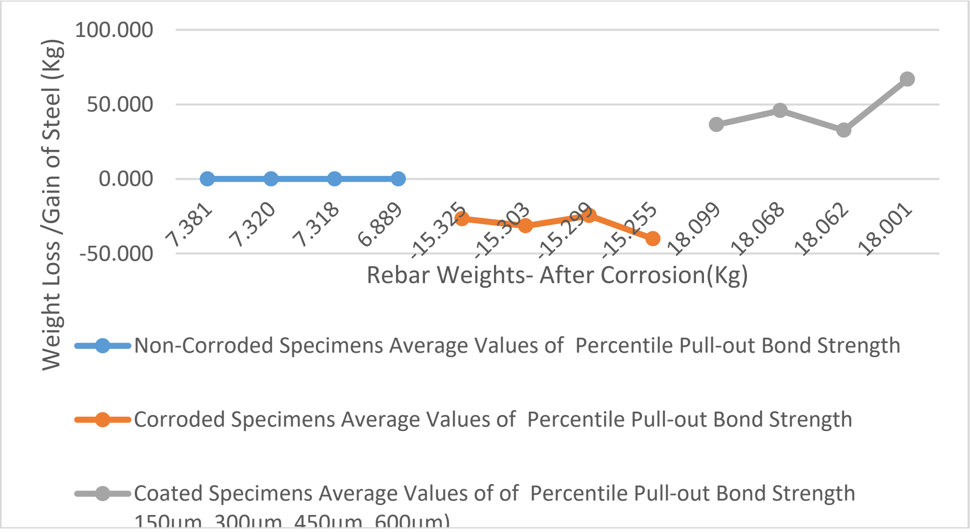

Figure 6b. Average percentile Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

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

The data in tables 3.1, 3.2 and 3.3 and figures 3, 4, 5 and 6 are the results of 36 concrete cubes from pull-out bond test conducted on 12 controlled samples immersed in a fresh water tank for 360 days, also 12 uncoated and 12 coated samples immersed in 5% aqueous sodium chloride (NaCl) solution for 360 days as 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 values and percentage of failure bond loads, bond strength and maximum slip, reduction / increase of the cross-section, diameter of reinforcement before / after corrosion, weight loss / weight gain. The results obtained for comparison showed that the failure bond load maintains a lean range of values for controlled and coated sample values, whereas the corroded elements provided the same factors for bond strength and maximum slip at lower loads. Regarding the mechanical properties of reinforcing steel, the effect of corrosion on reinforcing steel shows a decrease in the cross section of the rebar diameter compared to the nominal diameter before testing, weight reduction is also observed, while the reinforcing steel element has decreased. An increase in the cross-sectional area, an increase in the diameter and an increase in weight in the area compared with the nominal reinforcement, which is due to a difference in the thickness of the coating material. It can be concluded that the exudates / resin studied has shown effective inhibiting properties against corrosion attack and can be used as a corrosion inhibitor as validated by the studies of (Toscanini et al.[27], Charles et al.[28], Charles et al.,[29], Terence et al., [30]; Gede et al. [31]).

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 registered in the corroded elements
v. The coverage and control patterns show higher bond load values and bond strength, weight loss and area reduction were recorded mainly in the corroded layers and in controlled samples

References

1. U. M. Angst, M. R.Geiker, A. Michel, C. Gehlen, H.Wong, B. Isgor, B. Elsener, C. M. Hansson, R. François, K. Hornbostel, R. Polder, M. C. Alonso, M. Sanchez, M. J. Correia, M. Criando, A. Sagues, N. Buenfeld, “The Steel-concrete interface”, Materials and Structures, no.50, pp.143, 2017.
2. H. Lin, Y. Zhao, P. Feng, “State-of-the-art review on the bond properties of corroded reinforcing steel bar,” Construction and Building Materials, vol. 213, pp. 216–233, 2019.
3. G. Rehm, “The Basic Principles of the Bond between Steel and Concrete. C&CA Library Translation n.134 (Uber die Grundlagem des Verbundes Zwischen Stahl und Beton. Deutscher Ausschuss Fur Stahlbeton, Heft 138, pp.59, 1968.
4. D. Watstein, “Bond stress in concrete pull-out specimens,” ACI Journal, Proc. vol. 38, pp. 37-50, 1941.
5. R. Mains, “Measurement of distribution of tensile and bond stress along reinforcing bars”, Journal of ACI, pp. 225-252, 1951.

6. P. M. Ferguson, R. D. Turpin, J. N. Thompson, “Minimum bar spacing as a function of bond and shear strength,” ACI Journal. Proc. vol. 50, pp. 869-887, 1954
7. E. S. Perry, J. N. Thompson, “Bond stress distribution on reinforcing steel in beams and pull-out specimens,” ACI Journal. Proc. vol. 63, pp. 865-875, 1966.
8. Y. Goto, “Cracks Formed in Concrete around Deformed Tension Bars,” Journal of the ACI, pp. 244-251, 1971.
9. S. M. Mirza, J. Houde, “Study bond stress-slip relationship in reinforced concrete,” Journal of the ACI. vol. 76, no. 1, pp. 19-46, 1979.
10. E. L. Kemp, “Bond in reinforced concrete: behavior and design criteria,” ACI Journal. Proc. vol. 83, pp. 50-57, 1986.
11. D. H. Jiang, S. P. Shah, A. T. Andonian, “Study of the transfer of tensile forces by bond,” ACI Journal, 1984.
12. Barbosa, Maria Teresa Gomes , “Avaliação do Comportamento da Aderência em Concretos de Diferentes Classes de Resistência [Evaluation of the Bonding Behavior of Concretes],” 144 f. Thesis (Doctor of Science in Civil Engineering) - Rio de Janeiro, 2001 [in portuguese].
13. Barbosa, Mônica Pinto; Costa, Odair José; Silva, Leonardo Moisés; Salles, Flavio Moreira , “Concreto Auto-Adensável: Avaliação da Aderência Aço-Concreto Através dos Ensaios de Determinação do Coeficiente de Conformação Superficial de Barras de Aço. [Self-Compacting Concrete: Evaluation of Steel-Concrete Bonding Through Tests to Determine the Surface Conformation Coefficient of Steel Rebars] 46º Congresso Brasileiro do Concreto - IBRACON - Volume II - Construções em Concreto - Trabalho CBC0167 - pg. II.484 - II.497. Florianópolis,[in portuguese], 2004.
14. F. M. Almeida Filho, M. K. El Debs, A. L. El Debs, “ Bond-Slip behavior of self-compacting concrete and vibrated concrete using pull-out and beam tests,” Materials and Structures, vol. 41, pp. 1073-1089, 2008.
15. D. L. Araujo, A. R. Danin, M. B. Melo, P. F. Rodrigues, “Influence of steel fibers on the reinforcement bond of straight steel bars,” IBRACON Structures and Materials Journal. Vol. 6, no. 2, pp. 307-338, 2003.
16. I. K. Michael, G. P. and G. P. Catherine, “Bond behavior of reinforcement in lightweight aggregate self-compacting concrete,” Construction and Building Materials, vol.113, pp. 641-652. 2016.
17. H. Binici and O. Aksogan, “'The use of ground blast furnace slag, chrome slag and corn stem ash mixture as a coating against corrosion,” Construction and Building Materials, vol. 25, no. 11, pp. 4197–4201, 2011.
18. O. Kayali and B. Zhu, “Corrosion performance of medium strength and silica fume high-strength reinforced concrete in a chloride solution,” Cement and Concrete Composites, vol. 27, no. 1, pp. 117–124, 2005.
19. B.V. Silva, M. P. Barbosa, L. C. P. Silva Filho, M. S. Lorrain, “ Experimental investigation on the use of steel concrete bond tests for estimating axial compressive strength of concrete,” Part 1. IBRACON Structures and Materials Journal. vol. 6, no.5. pp. 715-736, 2013.
20. Lorrain, Michel; Barbosa, Mônica Pinto; Silva Filho, Luiz Carlos, “Estimation of compressive strength based on Pull-Out bond test results for on-site concrete quality control,” Ibracon Structures and Materials Journal, vol. 4, no. 4 pp. 582-591, 2011.
21. A. E. P. G. Jacintho, L. L. De Avila, M. P. Pimentel, P. S. P. Barbosa, Fontanini, “Steel and concrete bond stress: a contribution to the study of Apulot tests using concrete with rubber addition. IBRACON Structures and Materials Journal. vol. 7, no 5.pp. 817-844, 2014.
22. Caetano, Luciane Fonseca, “Estudo do Comportamento da Aderência de Elementos de Concreto Armado em Condições Extremas [Study of the Behavior of Reinforced-Concrete Elements in Extreme Conditions]. Dissertation (Masters in Engineering), Porto Alegre [in portuguese].
23. Márquez, J.F.C., Matin L.M.G., Ruiz, M.A.F., Montes E.H. (2016) Procedure for the assessment of the residual capacity of corroded B-regions in RC structures, Construction and Building Materials, v.121, pp. 519-534.
24. Elshami, A. & Ali, A. (2014). Using New Coating Materials for Corrosion Prevention of Reinforced Concrete, *MATEC Web of Conferences*, 11th October, 2014
25. N. M. Ahmed, M. G. Mohamed, M. R. Mabrouk, and A. A. Elshami, “Novel anticorrosive pigments based on waste material for corrosion protection of reinforced concrete steel,” Construction and Building Materials, vol. 98, pp. 388–396, 2015.
26. N. M. Ahmed, M. G. Mohamed, R. H. Tammam, and M. R. Mabrouk, “Performance of coatings containing treated silica fume in the corrosion protection of reinforced concrete,” Pigment & Resin Technology, vol. 47, no. 4, pp. 350–359, 2018.
27. D. S. Toscanini, T. E. Gede, K. Charles, **“**Pullout Bond Failure Load of Corroded and Coated Members in Corrosive Media,” International Journal of Advanced Scientific and Technical Research, Vol 5, no 9, pp. 38-46, 2019
28. E. N. Charles, K. Charles, T. T. W. Terence, “Corrosion Degree on the Mechanical Properties of Reinforcing Steel Embedded in Concrete,” Global Scientific Journal, vol. 7, no. 10, pp, 688 -696, 2019.
29. K. Charles, B. Geofrey, T. E. Gede, “ Corrosion Effect on Reinforcement Pull-Out Bond Strength Characteristics of Corroded and Coated Members in Concrete, ”American Journal of Sustainable Cities and Society, vol. 1, no.8, pp. 61-69, 2019.
30. T. T. W. Terence, K. Charles, F. Y. Branly, ” Bond Strength Characteristics of Reinforcements Embedded in Reinforced Concrete Structures in Corrosive Marine Environment, “American Journal of Engineering Research, vol. 8, no.10, pp.128-134, 2019.
31. T. E. Gede, K. Charles, B. Geofrey, “Reinforcement Bond Strength Interface Behavior of Corroded and Coated in Concrete Members, ” European Academic Research , vol.77, pp. 3399 – 3412, 2019.
32. BS. 882; 1992- Specification for Aggregates from Natural Sources for Concrete. British Standards Institute. London, United Kingdom.
33. BS EN 196-6; 2010- Methods of Testing Cement. Determination of fineness, British Standards Institute. London, United Kingdom, 2010.
34. BS 3148; 1980 – Methods of test for Water for Making Concrete. British Standards Institute. London, United Kingdom.
35. BS 4449:2005+A3; 2010 – Steel for Reinforcement of Concrete. British Standards Institute. London, United Kingdom.
36. BS EN 12390-2; 2005 – Testing Hardened Concrete: Flexural Strength Test of Specimens, British Standards Institute. London, United Kingdom
37. L. Amleh, and S. Mirza, “Corrosion influence on bond between steel and concrete,” ACI Structural Journal, vol. 96, no.3, 415-423, 1999.
38. Y. Auyeung, P. Balaguru, and L. Chung, “Bond behavior of corroded reinforcement bars,” ACI Materials Journal, vol. 97 , no. 2, 214-220, 2000.