Corrosion Effects on Cross-Sectional Area Reduction of Reinforcing Steel Embedded in Concrete and Exposed to Saline Media

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***Abstract*—The study investigated the potential application of boswellia dalzielii burseraceae exudate/resin on reinforcing steel by direct coating as an inhibitory material against the effect of corrosion on reinforced concrete structures exposed to the harsh marine region and assessed the surface modifications and the mechanical properties of steel bars. The obtained results of summarized maximum values of failure bond load of corroded concrete cube sample are -48.702% against controlled 85.763% and coated 94.941%, the results in comparison as represented in figure 1-1b showed failure load at low application and with high yield, this is attributed to the effect of corrosion on the reinforcing steel. The bond strength maximum values are corroded -34.962% against 59.161% and 81.31% for controlled and coated, results implied that the corroded failure at low load and as well as decreased in values when as compared with controlled and coated. The results of maximum slip values are corroded -27.647% against 57.894% and 80.978%. The low failure to slippage and splitting was attributed to the effect of corrosion on the mechanical properties of reinforcing steel with the rib affected by corrosion presence which in turn reduced the bonding characteristics between concrete and steel. The introduction of exudates/resins has improved the interlock between concrete and steel and stress reduction in the surrounding of the concrete cubes. The effect of corrosion on the uncoated and coated reinforced steel is calculated and in Figures 3 and 6b on the back diameter, the uncoated (corroded) diameter decreases by a maximum value of 0.845% while the coated volume increased by 0.859%, for the cross-sectional area the maximum reduction value of corroded decreased by -9.611% and the coating increased by 14.764%, the weight loss and gain decreased by -13.19% (loss) and the coated 17.623% increase (gain) the change in mild weight resulted to volumetric and expansive nature of exudates/resin. Effect of corrosion on coated concrete cubes reduction in diameter and cross-sectional area reduction and weight reduction, while coated concrete cubes increase in diameter and cross-sectional area of reinforced steel with increasing weight due to varying thicknesses resulting from volumetric actions.**

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

INTRODUCTION

Collapses and failures of reinforced concrete structures in the coastal sea of the extreme and severe environment with high salinity levels are caused by corrosion of reinforcing steel. The corrosion of reinforcement embedded in concrete reduces the lifetime and intended purpose, its integrity, and the efficiency of the structures. Chloride-induced corrosion of reinforced concrete structures built in the marine environment is at risk due to high chloride concentrations and moisture or saturation conditions. Corrosion is one of the main reasons for the limited durability of reinforced concrete [1].

Summary of bonding in a reinforced concrete member is the mechanical interlock between the concrete and reinforcement and the deformation characteristic of the reinforcement ribs.

[2] Improved bond zone area for the interaction between the steel bar and concrete, and the concrete surrounding it, as illustrated by a physical law showing the unique bond-zone properties [3]. Bond strength is influenced by bar geometries, concrete

structures, the presence of confinement around the bar, and bar conditions [4].

[5] Studied the bond behavior of reinforced bars and found that the weight loss of reinforcement due to corrosion reaches about 2%, the concrete cracks along the line. A small amount of corrosion increases the bond strength but the slip to failure decreases so much. However, they concluded that if the weight loss is more than 2%, the bond strength decreases significantly.

[6] Investigated the effect of the diameter of the steel bar, the rate of corrosion that occurs due to the thickness of the coating of the thin reinforcing steel. They found that there was an important effect of rebar diameter, cover thickness, and specimen size on corrosion intensity.

[7] Studied and evaluated the effect of corrosion on the bond between the steel and concrete interface of corroded and resins/exudates coated members. Experimental members were subjected to tensile and pull-out bond strength. Overall results showed a good bonding feature and effectiveness in the use of exudates as protective substances against corrosion.

[8] investigated the main causes from the short service life, integrity, and strength of reinforced concrete structures in the marine environment of the sine origin is rust. The obtained results showed a reduction in the bond yield failure and the maximum slip of the molded species to 21.30%, 38.80%, and 32.00%, respectively, while accounting for 51.69%, 66.90%, 74.65%, in the control specimen, 27.08%, 55.90%, and 47.14%. Overall results showed lower percentages noticed and higher for coated members. This justifies the effect of corrosion on the strength of the composite and bonded members.

[10] Showed that the cover over the reinforcement has a significant effect on the width of the carban ion regeneration.

[11] Investigated the effects of composite and curved stiffness on the stresses generated by the controlling bond separator, deformed with resins/exudates paste to the galvanized steel bar. In comparison, the failure load of symphonia globulifera linn, ficus glumosa, acardium occidentale l is 36.47%, 32.50% and 29.59% compared to 21.30% damaged, bond strength is 64.00%, 62.40%, 66.90 versus 38.88% and total penetration is 89.30%, 84.20%, 74.65% compared to 32.00% built. Full results showed increased values in the coated compared with the corroded specimens that resulted in the adhesion properties from the resins/exudates.

[12] Investigated the effect of corrosion reinforcement and inhibitor on the bond and extracts the volume of collapsed and barred steel reinforcement and monitors significant changes in the

[13] Studied of bond strength shown by reinforced concrete reinforced by corrosion effects. The results indicate that the uncoated corrosion strength is not characterized by cracking, cracking, and bending characteristics. All results showed lower values in the damaged systems as compared to the implanted instruments, the camera-shaped members showed high affinity for bonding dacryode edulis (high), moringa oleifera lam (high) and magnifera indica (high), and coated serve as antitumor and wound protection.

[14]Terence et al (2019) examined the effect of inhibitors on coated reinforcing steel under accelerated process examination of failure bond strength of embedded steel for 150days. Comparatively, the results of the corroded samples are reduced and the coated samples exudate when under control increased, these are ribbed reinforcement and exudates due to the adhesive properties of the controlled specimens. The overall results showed higher values of pull-out bond strength in the control and exudates/resin Coating for corroded samples.

[15]Charles et al. (2019) Experimental work evaluated the bond strength of non-corroded, corroded, and exudates/resins coated samples with varying coating thicknesses, immersed in a corrosive medium for 150 days. The combined results showed that the corroded samples were weakened during the

separation test with a high failure load with low bond strength. Non-corroded and exudates/resin members have a higher bond strength and lower failure load. Exudate/resin designs show high protective properties against the effects of corrosion, acting as inhibitors. The exudates/resins coated specimens show a higher resistance to bond strength properties, and higher flow with less failure compared to the composite members.

[16]Toscanini et al (2019) examined the use of eco-friendly corrosion inhibitors in a natural source exudates/resins to steel bars with a coating of 150µm, 300µm, and 450µm thicknesses and embedded into reinforced concrete cubes, cured in rapid corrosive media, and the pull-out bond strength parameters are investigated against non-coating. Comparatively, the results of the corroded models decreased while the control and cola acuminate exudates/resins increased in the steel bar coated specimens. Overall results showed that natural exudates/resins should be investigated as inhibitors for corrosion effects in steel reinforcement in concrete construction in areas where chloride is expected.

[17] Gede et al (2019) studied the factors that led to a reduction in the bonding between reinforcing steel and concrete within the saline environment of the Niger Delta region. An examination of non-coated and exudates/resin extracts from artocarpus altilis with a coating thickness of 150µm, 300µm, and 450µm to reinforcing steel and were embedded in a concrete cube, pooled for 150 days in corrosive media to ascertain their effects. Comparative results showed that the values of the non-coated (corroded) specimens decreased and the exudates/resin coating samples increased. Overall results showed high values of controlled pull-out bond strength and coated exudates/resin over corroded specimens.

[18]Charles et al. (2019) investigated the impact of olibanum exudates/resins in reinforcing steel corrosion in coastal zones with the impact of saltwater on concrete structures. The effects of corrosion on the coating and non-coated steel inserted in concrete cubes and exposed to corrosive accelerated media and evaluated corrosion effects on samples. The average percentage bond strength load was 33.13% and coated members 45.66% and 71.84% compared to the control difference. The mean maximum slip values were 0.08 mm and the mean and plated -25.30% were 33.87% and 75.30%, respectively. Experimental results showed that corroded samples have reduced samples have lower bond strength and higher failure bond load and lower maximum slip, whereas exudates/resin coated samples have lower test specimens and higher percentage values compared to corrosive samples.

[19] Charles et al. (2019) investigated the impact of corrosion attack on Acacia Senegal exudates/resins paste coated and non-coated reinforcing steel embedded in concrete cubes and immersed in aggressive media for 178 days. The obtained results show that non-coated members corroded and failed in the bond loading percentage value of 56.61% and 59.15% against the controlled and exudates/resins coated members. Bond strength loads showed 83.04% and 94.92% and -45.36%, respectively, percentage values decreased against corroded and exudates/resins coated members. In comparison, the values of corroded specimens decreased but controlled and the exudates/resins coated members increased, indicating the potential of Acacia Senegal as inhibitors.

[20] Charles et al. (2019) investigated the pull-out bond strength of reinforcing steel and concrete with non-corroded, corroded, and khaya senegalensis exudates/resins coated specimens. The results of the failure bond load showed a difference of -43.62% against 77.37% and 79.67% percentage of corroded and coated exudates/resin members. The declined mean percentile bond strength load varied from 57.06% to 36.33% and 106.57% percent of the corroded and coated specimens. The obtained results clearly showed that the failure bond loads are higher for corroded over exudates/resin coated

members in non-corrosive samples. The bond strength of the non-corroded and coated specimens exhibited a greater affinity for strain compared to the corroded ones.

2.0 Test Program

This research involves the direct application of extracted exudates/resins paste of plants origin known as inhibitors. The research work utilizes the effectiveness of eco-friendly extracted exudates/resins in curbing the effect of corrosion attacks on reinforcing steel embedded in concrete structures and immersed in sodium chloride (NaCl) solution by coating the steel reinforcement with varying thicknesses and experimentally tested in the laboratory. The test samples reflecting the severe acidic levels that indicate sea salt concentration levels in the reinforced concrete cubes. The embedded reinforcement steel is completely immersed in water and the samples are maintained in the pooling tank for the corrosion accelerated process. The samples were designed with 36 numbers of reinforced concrete cubes measuring 150 mm × 150 mm × 150 mm, with 12 mm diameter reinforcement embedded in the center for pullout bond test for all controlled, uncoated, and coated specimens and immersed in sodium chloride (NaCl) solution between 1 - 360 days after the initial 28 days of concrete cubes curing. Samples of acid media were updated monthly and samples were monitored for high-efficiency performance.

2.1 Materials and Methods for Testing

2.1.1 Aggregates

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

2.1.2 Cement

Portland lime cement grade 42.5 is the most common type of cement in the Nigerian market. It was used for all concrete mixes in this test. Meets Cement Requirements (BS EN 196-6)

2.1.3 Water

The water samples were clean and free from contaminants. Freshwater was obtained from a tap in the state of the Civil Engineering Laboratory, Kenule Beason Polytechnic, Bori, Rivers. Water (BS 3148) met the requirements'

2.1.4 Structural steel reinforcement

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

2.1.5 Corrosion Inhibitors (Resins / Exudates) Boswellia dalzielii (Burseraceae)

The natural gum exudates were obtained from the tree bark by tapping in Isanlu Isin or Isanlusin is an ancient town in Isin LGA of Kwara State, Nigeria. Isin LGA of Kwara State

2.2 Test Procedures

Corrosion acceleration was tested on high-yielding steel (reinforcement) with a diameter of 12 mm and a length of 650 mm. Pastes with 150µm, 300µm, 450µm and 600µm coatings before corrosion testing. The test cubes were cast with a 150 mm x 150 mm x 150 mm metal mold and demolished after 72 hours. Samples were treated at room temperature in tanks for 28 days before the initial curing period, followed by rapid accelerated corrosion testing and a trial procedure allowing 360 days of regular monthly monitoring. For corrosion-accelerated samples the cubes were taken every 3 months for 90 days, 180 days, 270 days, and 360 days, and the gain of failure bond loads, bond strength, maximum slip, reduction/increase of cross-sectional area, and weight loss/steel reinforcement.

2.3 Accelerated Corrosion System and Test Method

In real and natural phenomena, the manifestation of corrosion effects on reinforcement embedded in concrete members is very slow and can take many years to achieve; But the laboratory accelerated process will take less and less time to unravel by introducing accelerated media that represent the saltwater of the sea area. The samples were immersed in 5% NaCl solution for 360 days to test the surface and mechanical properties of the changes and effects and to test both unlimited and exudate/resin coated specimens.

2.4 Pull-Out Bond Strength Test

The tensile-bond strength test of concrete cubes was carried out on a total of 36 samples of 12 samples each with filtered water, non-coating and coated members, and subjected to a 50kN universal testing machine according to BSEN12390-2. A total of 36 cubes with dimensions of 150 mm × 150 mm × 150 mm, embedded in the center of a single 12 mm diameter concrete cube.

2.5 Tensile Strength of Reinforcing bars

To determine the yield and tensile strength of the bars, reinforcing steel bar of diameter of 12 mm of controlled, non-coated (corroded) and and coated were tested under tension in a Universal Test Machine (UTM) and subjected to direct tension until failure and and failure loads are recorded. To ensure stability, the remaining cut pieces were used in the subsequent bonding test.

3.1 Experimental Discussion

The contact between the concrete and the reinforcing steel is expected to be optimal for the implementation of the maximum bond exhibit in ambient concrete structures. The increase in deformed (rib) reinforcing bars and slip joints mainly depends on the bearings or mechanical gaps between the concrete surrounding the ribs on the bar surface. The detrimental effect of corrosion attack is that many structures become unmanageable and the designed lifetime is reduced. Hence, the use of Boswellia dalzielii (Burseraceae) as an inhibitive material was introduced, the assessment of its potential and efficacy was monitored, and as well as its performance.

The test data presented in Tables 3.1., 3.2, and 3.3 are summarized in Tables 3.4 and 3.5, with 12 controlled trials concrete cubes placed in freshwater for 360 days as the standard for comparison and 12 uncoated and 12 exudates/resin coated samples containing all single embedded steel bars are immersed in 5% sodium chloride (NaCl) for 360 days and on a three (3) month intervals of routine tests for 90 days, 180 days, 270 days and 360 days assessing the surface modifications and first crack appearance. Corrosion exposure is a long-term process that takes decades to fully function, but the introduction of synthetic sodium chloride triggers the manifestation and occurrence of corrosion with minimal time. Experimental work results revealed the potential use for Boswellia dalzielii **(**Burseraceae**)** as a resin adhesive, and it controls the corrosion effect on reinforced concrete structures exposed to the harsh marine region.

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

Sample Numbers	BDC	BDC1	BDC2	BDC3	BDC4	BDC5	BDC6	BDC7	BDC8	BDC9	BDC10	BDC11
	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)	27.429	25.339	25.903	26.500	27.315	27.016	27.539	27.357	27.421	29.232	28.357	28.558
Bond strength (MPa)	8.762	9.655	8.152	9.083	9.456	10.379	10.472	9.802	9.837	10.542	9.854	10.400
Max. slip (mm)	0.105	0.107	0.097	0.102	0.101	0.100	0.113	0.117	0.125	0.123	0.127	0.125
Nominal Rebar Diameter	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
Measured Rebar Diameter Before Test(mm)	11.958	11.950	11.959	11.959	11.949	11.969	11.959	11.948	11.958	11.955	11.949	11.959
Rebar Diameter- at 28 Days Nominal(mm)	11.958	11.950	11.959	11.959	11.949	11.969	11.959	11.948	11.958	11.955	11.949	11.959
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)	0.578	0.578	0.576	0.578	0.578	0.579	0.579	0.578	0.580	0.577	0.577	0.585
Rebar Weights- at 28 Days Nominal(Kg)	0.578	0.578	0.576	0.578	0.578	0.579	0.579	0.578	0.580	0.577	0.577	0.585
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3.2: Results of Pull-out Bond Strength Test (τu) (MPa) of **Corroded Concrete Cube Specimen**

Sampling and Durations	**Samples 1 (90 days)**			**Samples 2 (180 Days)**			**Samples 3 (270 Days)**			**Samples 4 (360 Days)**		
Failure Bond Loads (kN)	15.980	15.293	15.583	15.025	14.273	15.141	14.720	15.028	14.726	15.961	14.840	15.574
Bond strength (MPa)	6.761	6.771	6.535	6.758	6.524	6.497	6.295	6.984	5.959	6.447	6.295	6.607
Max. slip (mm)	0.078	0.082	0.083	0.091	0.082	0.086	0.085	0.075	0.081	0.082	0.083	0.073
Nominal Rebar Diameter	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
Measured Rebar Diameter Before Test(mm)	11.958	11.950	11.959	11.959	11.949	11.969	11.959	11.948	11.958	11.956	11.949	11.960
Rebar Diamete r- After Corrosion(mm)	11.909	11.900	11.910	11.911	11.900	11.921	11.910	11.899	11.909	11.906	11.900	11.910
Cross- section Area Reduction/Increase (Diameter, mm)	0.049	0.050	0.049	0.048	0.050	0.048	0.049	0.049	0.050	0.049	0.049	0.050
Rebar Weights- Before Test(Kg)	0.579	0.580	0.577	0.580	0.580	0.580	0.580	0.579	0.582	0.578	0.578	0.586
Rebar Weights- After Corrosion(Kg)	0.527	0.528	0.526	0.528	0.528	0.528	0.528	0.527	0.530	0.526	0.526	0.535
Weight Loss /Gain of Steel (Kg)	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052

Table 3.3: Results of Pull-out Bond Strength Test (τu) (MPa) of Boswellia dalzielii 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)	28.848	26.758	27.322	27.919	28.734	28.435	28.958	28.775	28.840	30.651	29.776	29.977
Bond strength (MPa)	10.191	11.083	9.581	10.511	10.884	11.807	11.901	11.231	11.265	11.971	11.282	11.829
Max. slip (mm)	0.124	0.125	0.116	0.120	0.119	0.118	0.131	0.135	0.143	0.141	0.146	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)	11.956	11.948	11.957	11.957	11.947	11.967	11.957	11.946	11.956	11.953	11.947	11.957
Rebar Diameter- After Corrosion(mm)	12.011	12.003	12.012	12.014	12.002	12.020	12.011	12.001	12.012	12.008	12.002	12.012
Cross- section Area Reduction/Increase (Diameter, mm)	0.055	0.055	0.055	0.057	0.055	0.054	0.054	0.055	0.056	0.055	0.055	0.055
Rebar Weights- Before Test(Kg)	0.579	0.580	0.578	0.580	0.580	0.581	0.581	0.580	0.582	0.578	0.579	0.587
Rebar Weights- After Corrosion(Kg)	0.640	0.640	0.638	0.641	0.641	0.641	0.641	0.640	0.643	0.639	0.639	0.647
Weight Loss /Gain of Steel (Kg)	0.062	0.061	0.061	0.061	0.062	0.059	0.061	0.060	0.062	0.639	0.059	0.061

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

	Control, Corroded and Resin Steel bar Coated											
Sample	Non-Corroded Specimens Average Values				Corroded Specimens Average Values				Coated Specimens Average Values of 150µm, 300µm, 450µm, 6000µm)			
Failure load (KN)	26.224	26.943	27.439	28.716	15.619	14.813	14.825	15.458	27.643	28.362	28.858	30.135
Bond strength (MPa)	8.856	9.639	10.037	10.265	6.689	6.593	6.413	6.450	10.285	11.068	11.466	11.694
Max. slip (mm)	0.103	0.101	0.118	0.125	0.081	0.086	0.080	0.079	0.121	0.119	0.137	0.143
Nominal Rebar Diameter	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
Measured Rebar Diameter Before Test(mm)	11.956	11.959	11.955	11.955	11.956	11.959	11.955	11.955	11.954	11.957	11.953	11.953
Rebar Diameter- After Corrosion(mm)	11.956	11.959	11.955	11.955	11.906	11.911	11.906	11.905	12.009	12.012	12.008	12.007
Cross- section Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.049	0.048	0.049	0.050	0.055	0.055	0.055	0.055
Rebar Weights- Before Test(Kg)	0.577	0.579	0.579	0.580	0.579	0.580	0.581	0.581	0.579	0.580	0.581	0.581
Rebar Weights- After Corrosion(Kg)	0.577	0.579	0.579	0.580	0.527	0.528	0.529	0.529	0.640	0.641	0.641	0.642
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.052	0.052	0.052	0.052	0.061	0.061	0.061	0.060

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

	Table 3.5: Results of Average Percentile Pull-out Bond Strength Test (τu) (MPa)											
	Non-corroded Control Cube				Corroded Cube Specimens				Exudate / Resin steel bar coated specimens			
Failure load (KN)	67.900	81.890	85.092	85.763	-43.498	-47.772	-48.629	-48.702	76.984	91.468	94.662	94.941
Bond strength (MPa)	32.399	46.200	56.518	59.161	-34.962	-40.429	-44.070	-44.846	53.756	67.868	78.796	81.310
Max. slip (mm)	27.488	17.027	47.999	57.894	-33.379	-27.647	-41.475	-44.745	50.102	38.210	70.867	80.978
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)	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
Rebar Diamete r- After Corrosion(mm)	0.413	0.404	0.414	0.415	-0.850	-0.845	-0.849	-0.851	0.858	0.853	0.856	0.859
Cross- section Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	-10.200	-12.864	-9.750	-9.611	11.359	14.764	10.803	10.633
Rebar Weights- Before Test(Kg)	0.247	0.247	0.246	0.246	0.017	-.017	0.017	.017	0.017	0.017	0.017	0.017
Rebar Weights- After Corrosion(Kg)	9.591	9.568	9.560	9.549	-17.643	-17.607	-17.595	-17.579	21.423	21.370	21.352	21.329
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	-14.983	-14.863	-14.938	-13.190	17.623	17.458	17.562	15.194

3.2 Failure load, bond strength, and maximum slip

Results of failure bond load, bond strength, and maximum slip conducted on 36 concrete cubes as given in Tables 3.1. 3.2, and 3.3 and represented graphically and plotted in Figures 3.4- 2.5 and 1 - 6b. Test Results obtained for controlled, 12 corrugated and 12 coated 12 samples that were tested for failure using Instron universal testing machines with 50kN as described.

The minimum and maximum calculated average and percentage results of the failure bond load are controlled samples, 26.224kN and 28.716kN (67.9% and 85.763%), corroded 14.813kN, and 15.619kN (-48.702% and -43.498%), coated 27.643kN and 30.135kN (76.984% and 94.941%). The controlled bond strength values are 8.856MPa and 10.265MPa (32.399% and 59.161%), corroded 6.413MPa and 6.689MPa (-44.846% and -34.962%), coated 10.285MPa and 11.694MPa (53.756% and 81.31%). The Maximum slip results are controlled 0.101mm and 0.125mm (17.027% and 57.894%), corroded 0.079mm and 0.086mm (-44.745% and -27.647%), coated 0.19 mm and 0.143mm (38.21% and 80.978%).

The obtained results as shown from tables 3.1., 3.2 and 3.3 to 3.4 and 3.5, is the summarized maximum values of failure bond load of corroded concrete cube sample of -48.702% against controlled 85.763% and coated 94.941%, the results in comparison as represented in figures 1-1b showed failure load at low load application and with high yield, this is attributed to the effect of corrosion on the reinforcing steel. The bond strength maximum values are corroded -34.962% against 59.161% and 81.31% for controlled and coated, results implied that the corroded failure at low load and as well as decreased in values when as compared with controlled and coated. The results of maximum slip values are corroded -27.647% against 57.894% and 80.978%. The low failure to slippage and splitting was attributed to the effect of corrosion on the mechanical properties of reinforcing steel with the rib affected by corrosion presence which in turn reduced the bonding characteristic between concrete and steel (Fu and Chung, 1997: Gede et al., 2019; Toscanini et al., 2019; Charles et al., 2019; Charles et al., 2019; Terence et al., 2019; De Groot et al., 1981., ACI Committee 408., 2003, and Auyeung et al., 2000). The introduction of exudates/resins has improved the interlock between concrete and steel and stress reduction in the surrounding of the concrete cubes.

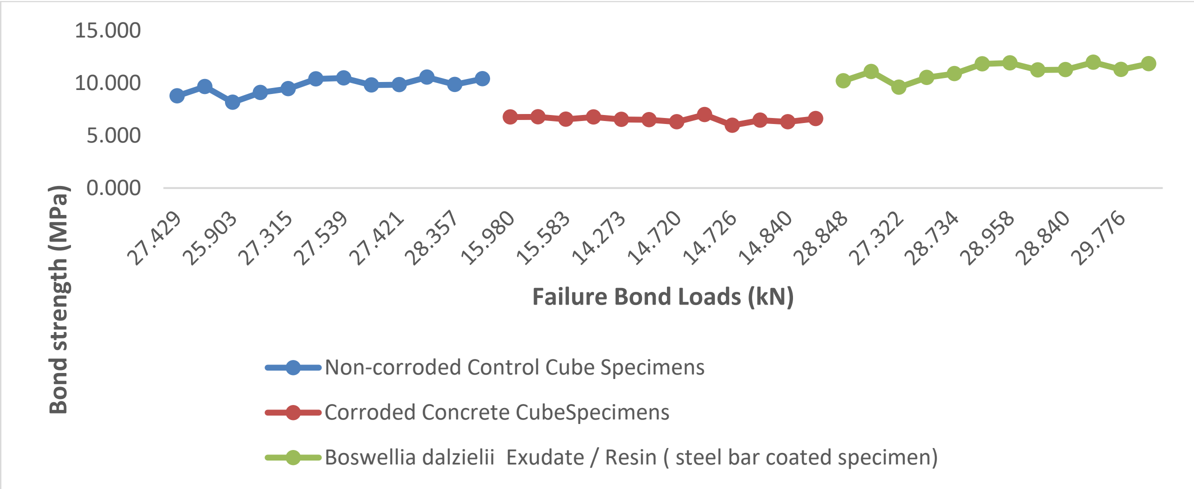

Figure 1: Failure Bond loads versus Bond Strengths

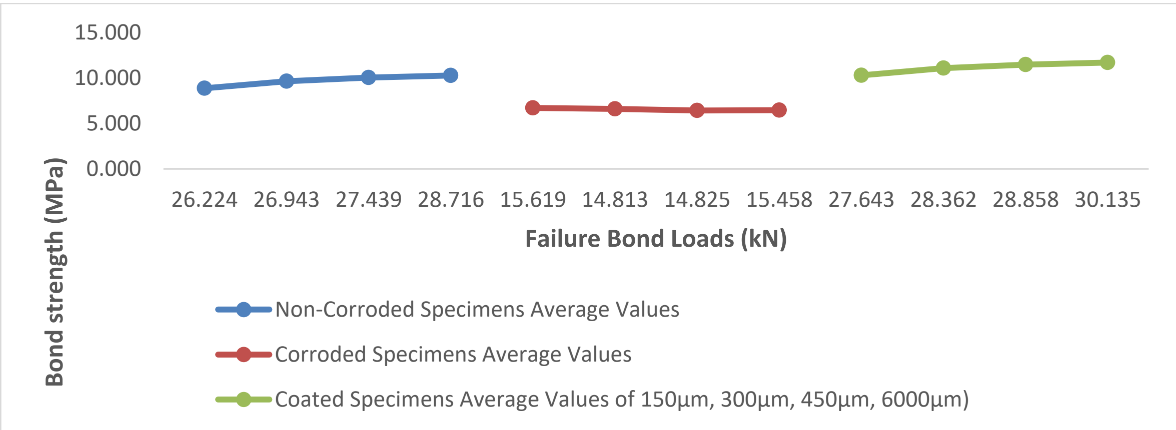

Figure 1a: Average Failure Bond loads versus Bond Strengths

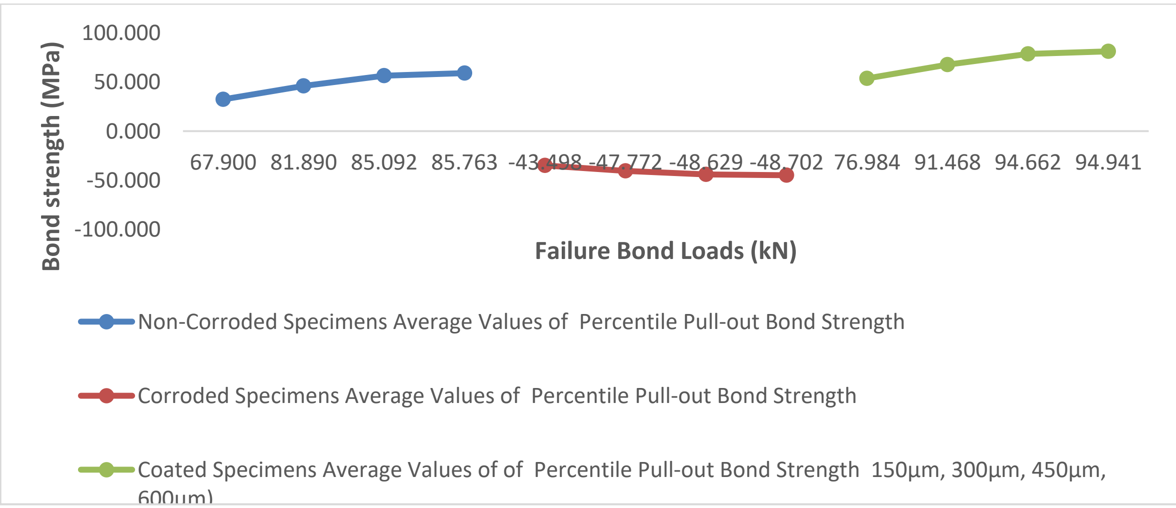

Figure 1b: Average Percentile Failure Bond loads versus Bond Strengths

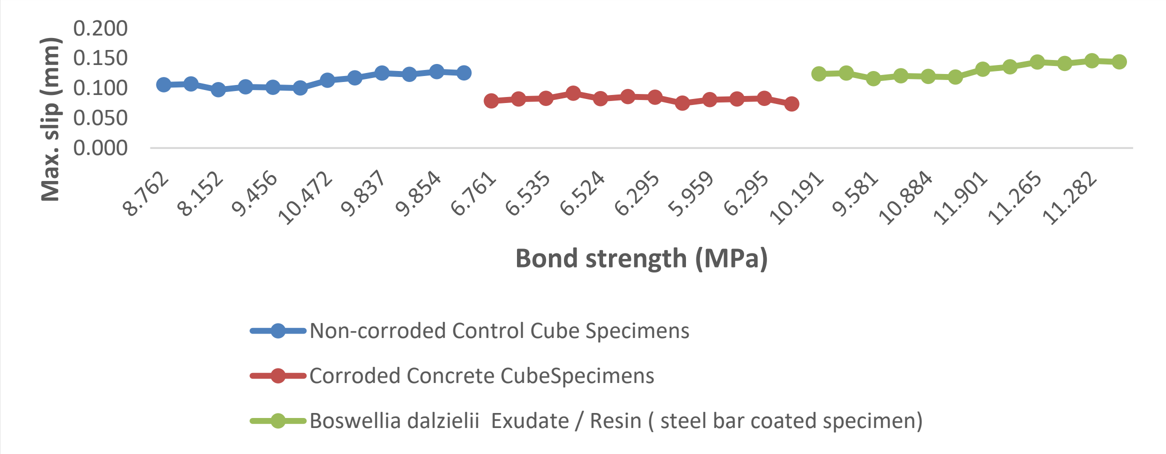

Figure 2: Bond Strengths versus Maximum Slip

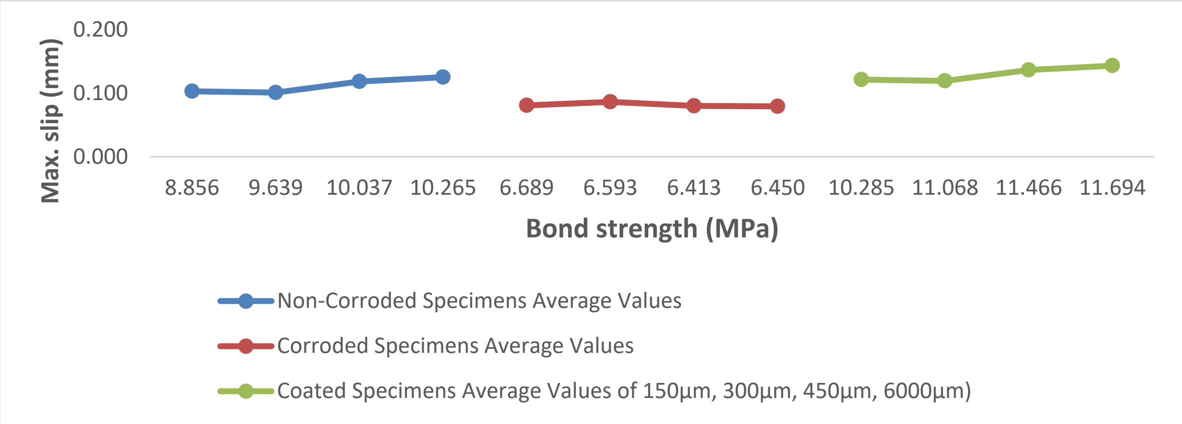

Figure 2a: Average Bond Strengths versus Maximum Slip

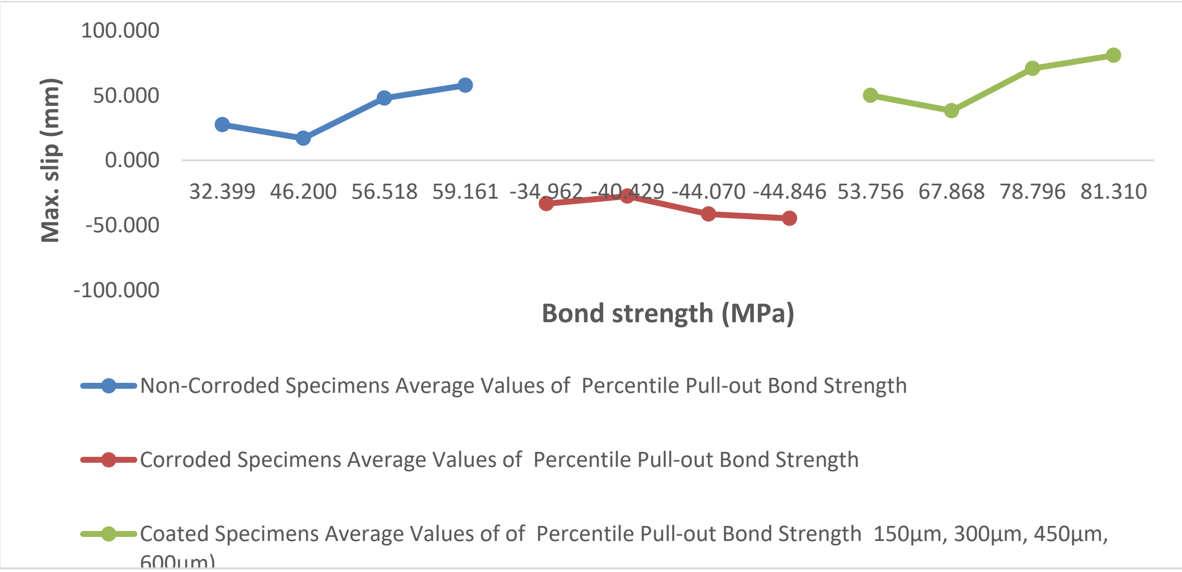

Figure 2b: Average Percentile Bond Strengths versus Maximum Slip

3.3 Mechanical Properties of Reinforcing Bars

The mechanical properties of reinforcing steel results in tables 3.1,3.2 and 3.3 are summarized in tables 3.4 and 3.5, also presented graphically plotted in figures 3-6b. The results of the 36 concrete cubes were investigated for 360 days after the initial 28 days standard procedure; the cubes were tested to failure state in 50KN Instron Universal Testing Machine. The resulting concrete cubes under freshwater and induced accelerated corrosion test have the following; nominal diameter steel rods of all models are 100%, and the minimum and maximum diameters of steel rods measured before the tests are in the range of 11.955mm and 11.959mm (0.018% and 0.018%). The diameters (corroded) of non-coated specimens after corrosion were 11.905mm and 11.911mm (-0.851% and -0.845%), 12.007mm and 12.012mm (0.853% and 0.859), respectively, after coating.

The results for the corroded cross-sectional area 0.048mm and 0.05mm (-12.864% and -9.611%), and the coated are 0.058mm and 0.055mm (10.633% and 14.764%) respectively.

The results of rebar weights before corrosion test, all sampled cubes weight are 0.577kg and 0.58kg (0.048% and 0.05%), corroded samples weights are 0.527kg and 0.529kg (-17.643% and -17.579%), ad coated are 0.64.Kg and 0.642Kg (21.329% and 21.423%), ad steel weight loss / increase 0.052Kg and 0.052Kg (-14.983% and -13.19%) and coated values 0.06Kg and 0.061Kg (15.194% and 17.623%)). From the results obtained and presented in the figures, the effect of corrosion on the uncoated and coated reinforced steel are calculated and in Figures 3 and 6b on the bar diameter, the uncoated (corroded) diameter decreases by a maximum value of 0.845% while the coated volume increased by 0.859%, for the cross-sectional area the maximum reduction value of corroded decreased by -9.611% and the coating increased by 14.764%, the weight loss and gain corroded decreased by -13.19% (loss) and the coated 17.623% increase (gain) the change in mild weight resulted to volumetric and expansive nature of exudates/resin. Effect of corrosion on coated concrete cubes reduction in diameter and cross-sectional area reduction and weight reduction, while coated concrete cubes increases in diameter and cross-sectional area of reinforced steel with increasing weight due to varying thicknesses resulting from volumetric actions (Fu and Chung, 1997: Gede et al., 2019; Toscanini et al., 2019; Charles et al., 2019; Charles et al., 2019; Terence et al., 2019; De Groot et al., 1981., ACI Committee 408., 2003, and Auyeung et al., 2000).

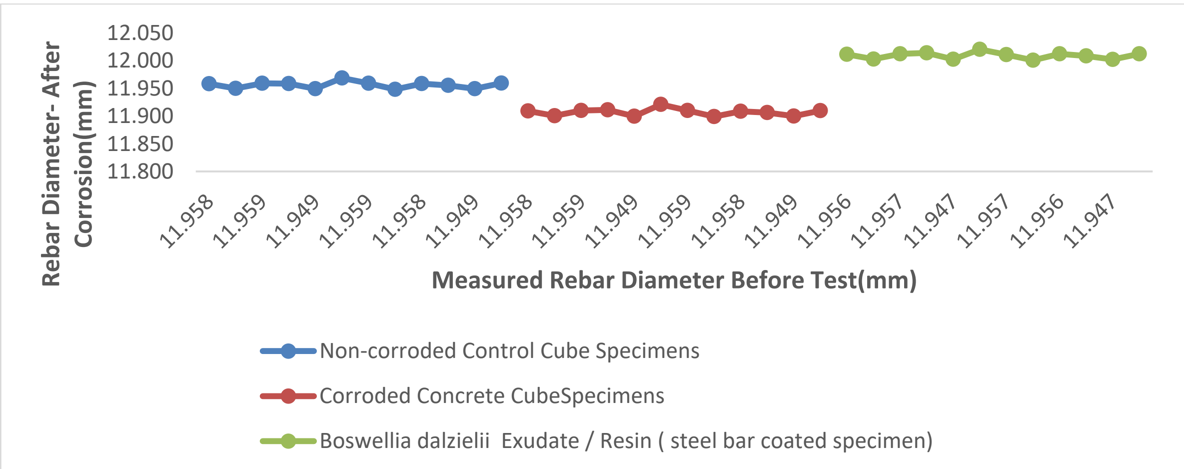

Figure 3: Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

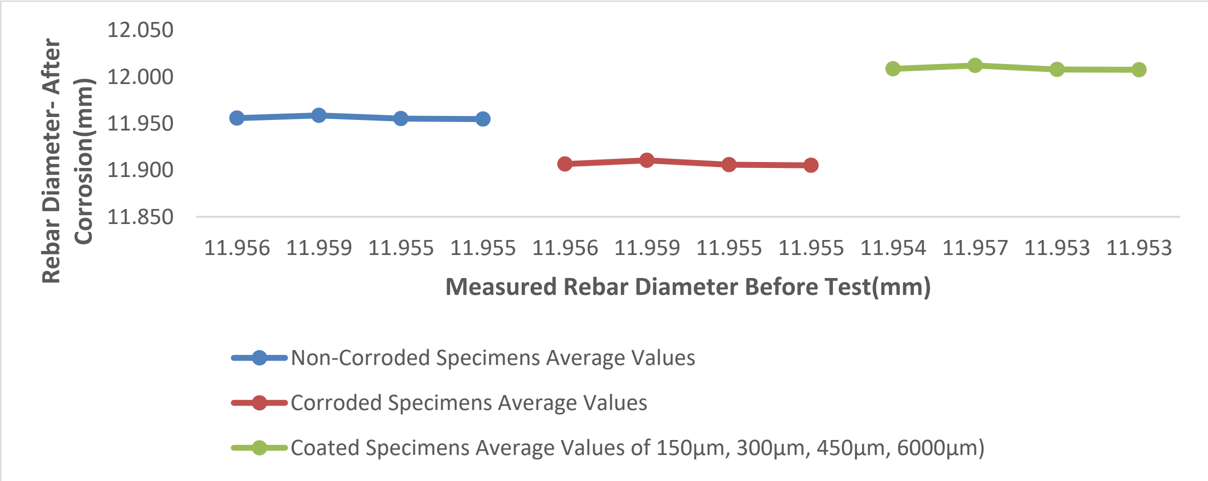

Figure 3a: Average Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

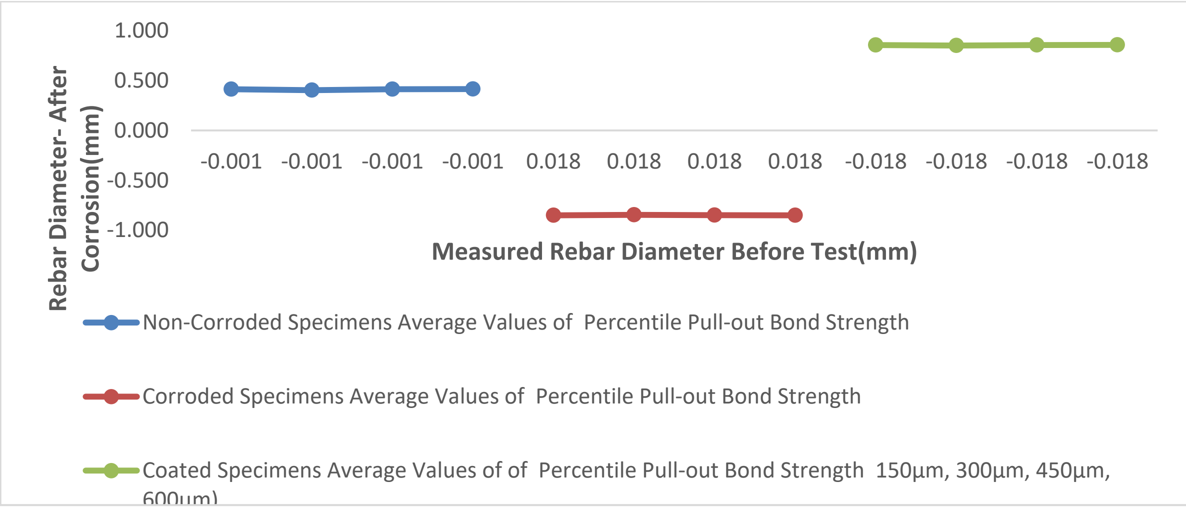

Figure 3b: Average Percentile Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

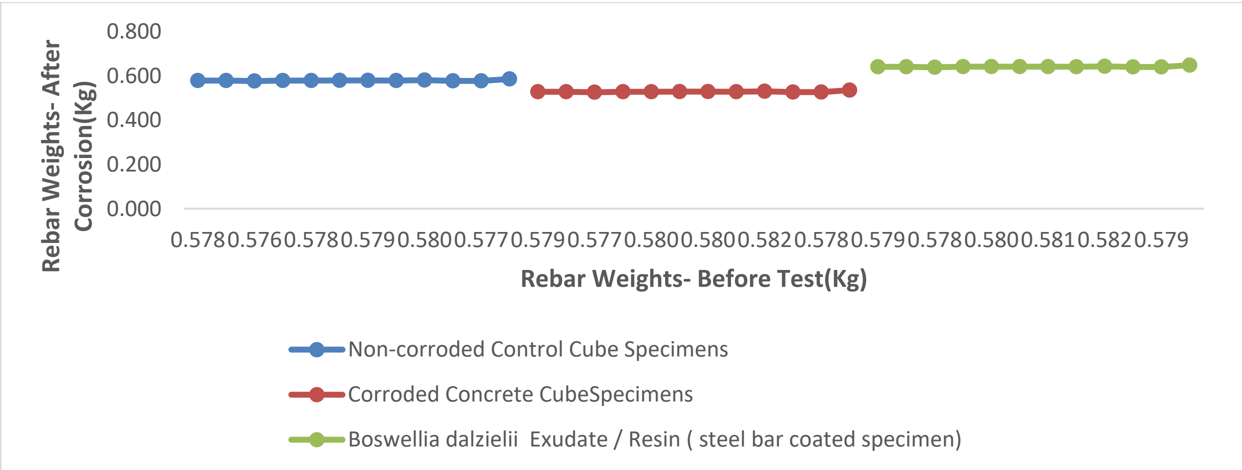

Figure 4: Rebar Diameter- after Corrosion versus Cross - Sectional Area Reduction/Increase

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

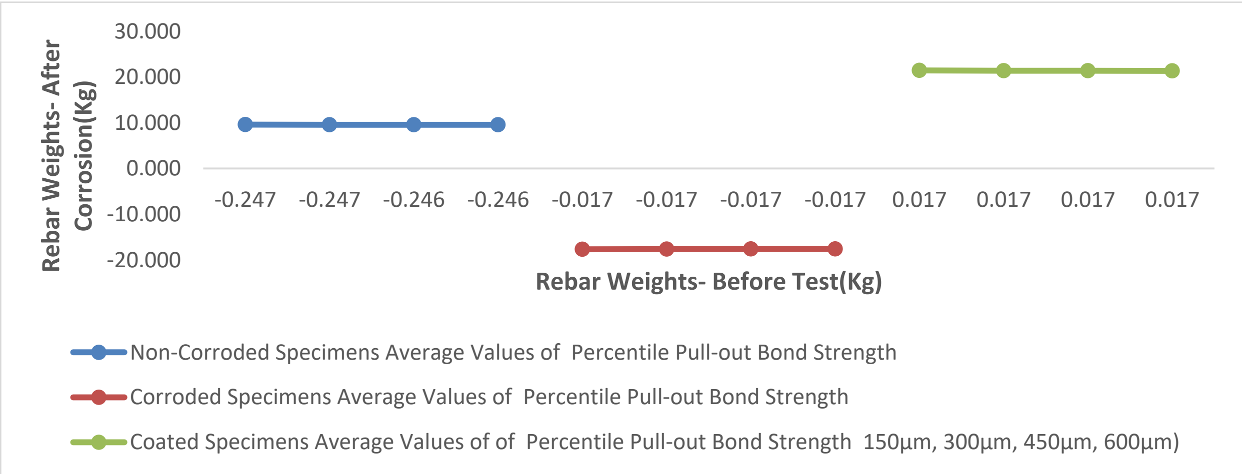

Figure 4b: Average percentile Rebar Diameter- after Corrosion versus Cross - sectional Area Reduction/Increase

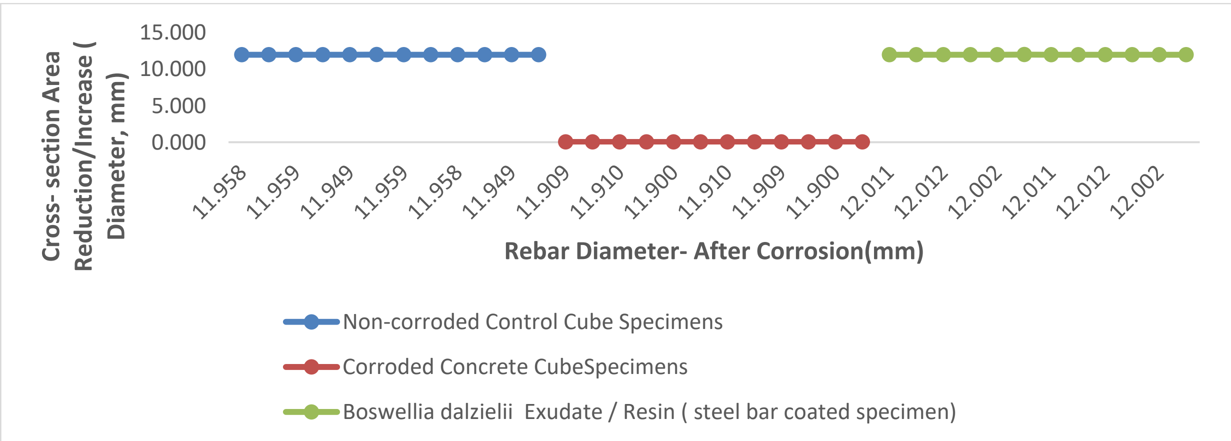

Figure 5. Rebar Weights- Before Test versus Rebar Weights- After Corrosion

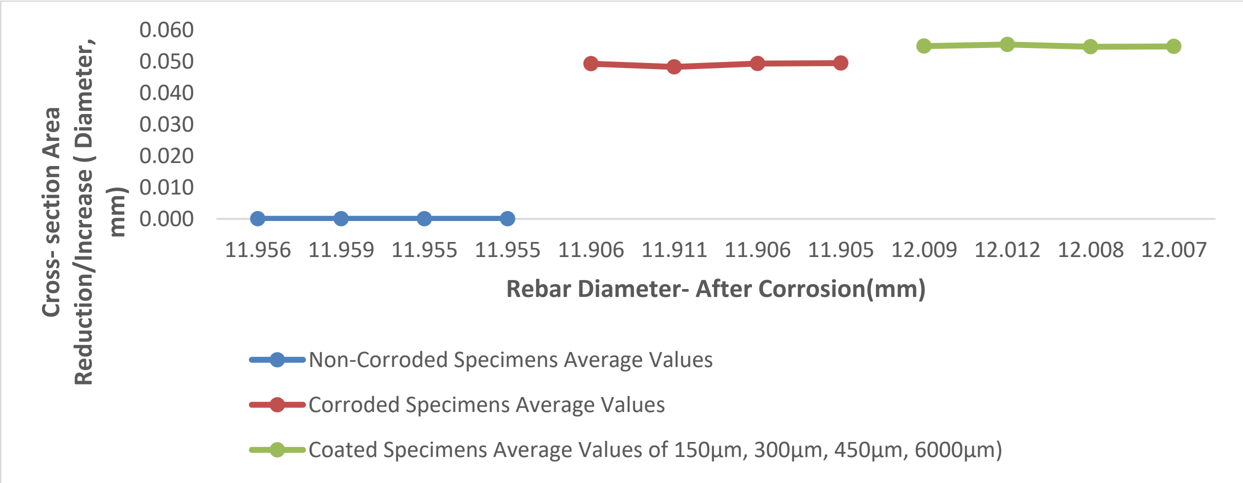

Figure 5a: Average Rebar Weights- Before Test versus Rebar Weights- after Corrosion

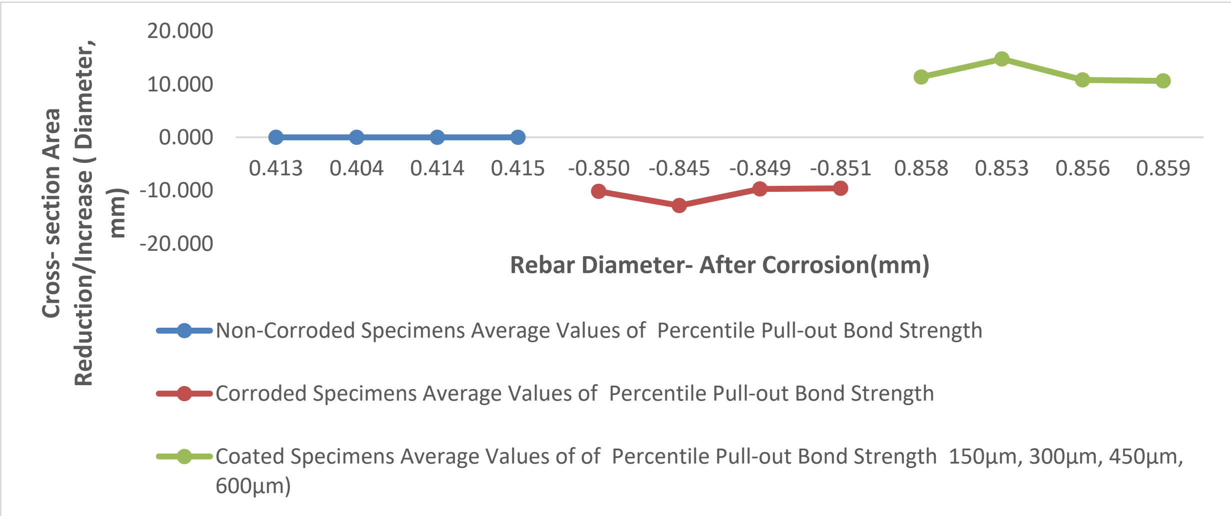

Figure 5b: Average Percentile Rebar Weights- before Test versus Rebar Weights- after Corrosion

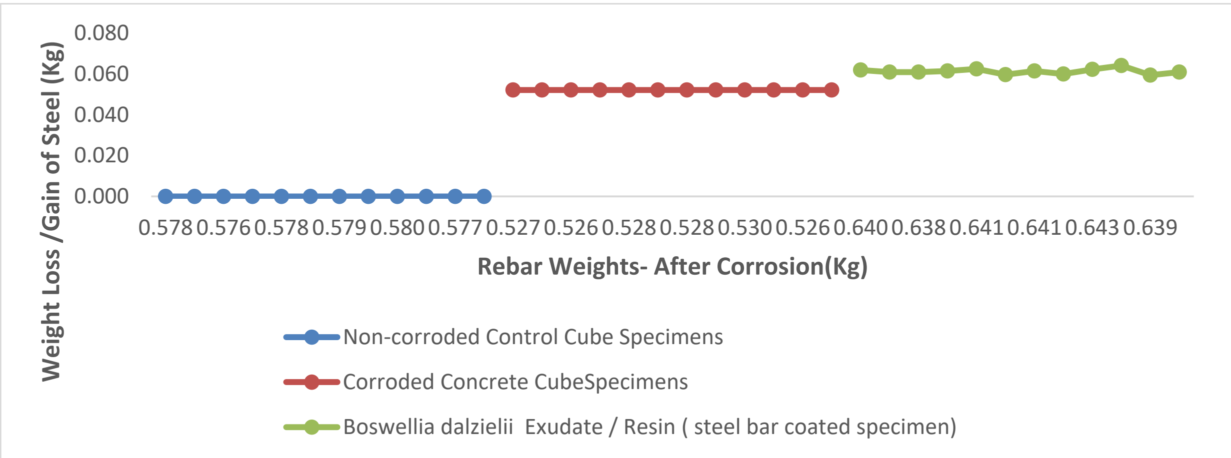

Figure 6: Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

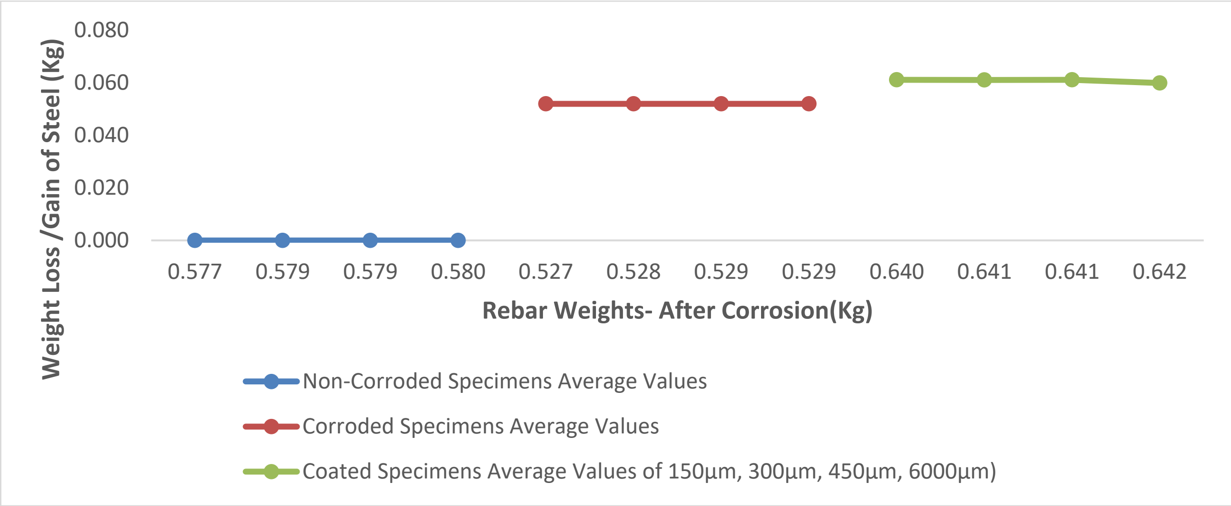

Figure 6a: Average Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

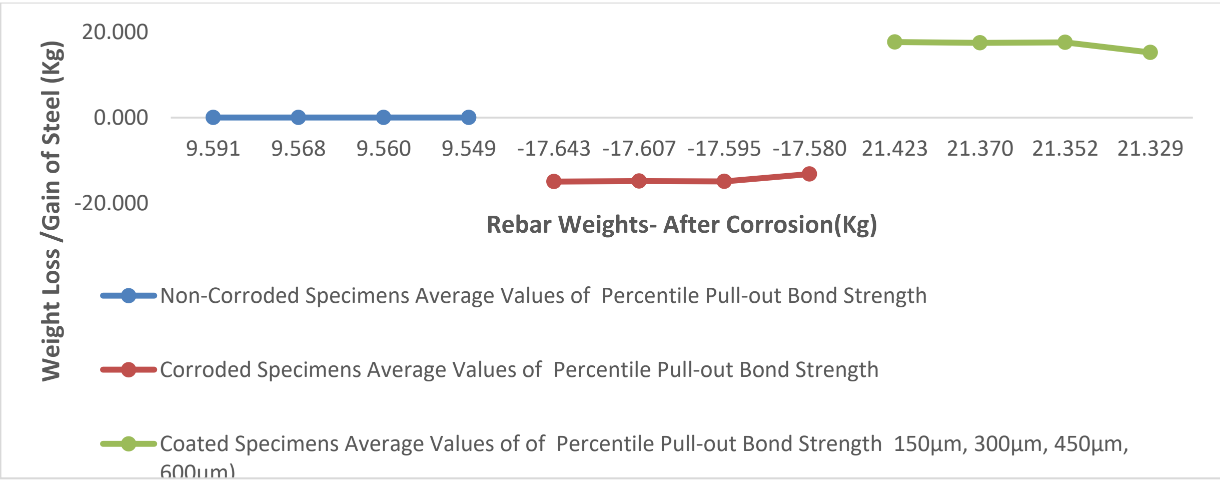

Figure 6b: Average percentile Rebar Weights- after Corrosion versus Weight Loss / Gain of Steel

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

The data in tables 3.1, 3.2, and 3.3 and figures 3, 4, 5, and 6 are the results of 12 controlled samples cured in a freshwater tank for 360 days and 12 uncoated and 12 coated samples in 5% aqueous sodium chloride (NaCl) solution 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 loads, maximum adhesive strength and slip, reduction/increase of the cross-section, diameter of reinforcement before/after corrosion, weight loss/weight gain. The results obtained by comparison show that the failure loads from controlled and coated maintain a closed range of values, whereas the corroded elements produce at lower loads, the same factors for adhesive strength and maximum slip apply. Regarding the mechanical properties of reinforcing steel, the effect of corrosion on reinforcing steel shows a decrease in the cross-section of the rod 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-section in the 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 roofing material. It can be concluded that the exudate/resin studied has shown effective inhibiting properties against corrosion attack and can be used as a corrosion inhibitor.

4.0 Conclusion

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

i. The exudate/resin has a corrosion-inhibiting effect, as the seal is resistant to corrosion 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, connection breakage and maximum slippage are listed in the corroded elements
v. The coverage and control patterns show higher bond load values and bond strength.
vi. Weight loss and area reduction were recorded mainly in the corroded layers and in controlled samples

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