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Effect of Corrosion on Rebar Mechanical Properties on Bond Strength and Interlock

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ABSTRACT

Indeed, the manifestation of corrosion is a long-term process that takes decades to fully work, but the introduction of sodium chloride causes the appearance of corrosion in a short period. This research work evaluated the behavioral characteristics of non-coated and coated reinforcing steel inserted in concrete and immersed in corrosive media.

The experimental work represented a suitable high-salt sea media and the possible use of daniellia oliveri exudate/resin extract as a barrier to prevent corrosion and the risk of corrosion impact in a reinforced concrete structure exposed or built within this harsh region. The experimental were results obtained from 36 concrete cube samples as explained in experimental procedures for 12 controlled, placed in freshwater for 360 days, 12 non-coated, and 12 coated with exudates/resin samples all embedded in concrete cube samples and immersed in 5% sodium chloride (NaCl) aqueous solution for 360 days and investigated their effectiveness by, monitoring, testing for three months in 90 days, 180 days, 270 days, and 360 days. Obtained results showed lower bond strength recorded in corroded and reduced/decreased value compared to controlled and coated samples, indications showed that coated materials increased the interaction between concrete and reinforcing steel.The maximum slip obtained peak comparative values are controlled 74.35% as against corroded -37.947% and coated 24.273%, The obtained results showed lower slippage and decrease value from the corroded sample as against controlled and coated samples with higher slippage to failure and increase values resulting from coating materials. The presence of corrosion reduces the efficiency of the material corroded thereby reduces the original mechanical properties of reinforcing steel.From the results obtained and given in Figures 3-6b, it can be seen that the diameter of uncoated decreased by the maximum value of (-0.97% and coated increased by 0.98%, for the cross-sectional area, corroded has maximum reduction value of -12.706% and coated increased by 42.617%%, weight loss and gain are corroded -22.623% decreased (loss) and coated 34.06% increase (gain). The indication analyzed from the test work was that the effect of corrosion on the non-coated concrete cube samples has a reduction in diameter and cross-sectional area and in rebar unit weight reduction, the increase in diameter of the coated concrete cube samples and the cross-sectional area increase resulting from varying thicknesses of the coating exudates /resins.while coated concrete cubes have 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 products result when there is a chemical reaction between the metal and its environment. The area of reinforcing bars and weakening the bond between reinforcement and concrete seriously affects the durability and service life of structures (Almusallam et al. [1], Cabrera [2], Rashid et al. [3]). The bond strength originates primarily from weak chemical bonds between steel and concrete, but this resistance is broken at very low pressure, affecting the load transfer between the bonding steel and the concrete at the steel and concrete interface. The reinforcement of corroded (ribbed) steel bars, and the main bearing or mechanical interlock under increasing slip bonding, depends on the ribs rolled on the surface of the bar. Bond strength is the maximum bonding stress created by the friction between reinforcement and concrete, which can easily be considered as shear stress on the bar surface (Cairns and Abdullah, [4]), interlock mechanism concrete with surrounding reinforcing bar interfaces.

Charles et al. [5] Investigated and evaluated the effect of corrosion on the bond between the reinforcing steel and concrete interface of corroded and resins/exudates coated reinforcement with ficus glumosa extracts from trees. The test samples were subjected to tensile and pullout bond strength and the results obtained were 33.50%, 62.40%, 84.20%, with failure load, bond strength, and coated maximum slip values. For corroded cube concrete members, the values were 21.30%, 38.80%, and 32.00% lower in failure load, bond strength, and maximum slip for those obtained by corrugated and non-corrugated members. The entire results showed good binding characterization and efficiency in the use of ficus glumosa resins/exudates as protective materials against corrosion.

Charles et al. [6] Explored the primary reasons for decreasing service life, integrity, and the effectiveness of reinforced concrete structures in the marine environment of saline. The results obtained for comparison showed that the failure bond load, bond strength, and maximum slip decreased by 21.30%, 38.80%, and 32.00%, respectively, in the coated samples with 51.69%; 66.90%, 74.65%, for the uncorrected sample, 27.08%, 55.90%,, and 47.14%. The full results showed a lower percentage of corporations and a higher percentage of coated members. This justifies the effect of corrosion on the strength of the corrugated and coated members.

Otunyo and Kennedy [7] investigated the effectiveness of natural resin resins in preventing reinforcement in reinforced concrete cubes. The obtained results indicate that the failure bond strength, bond strength, and maximum slip of the adhesive coated reinforced cubes are high (19%), (84%), and (112%). Similar results were obtained for the maximum slip (resin-coated and non-corrugated steel members) steel reinforcements had higher values of the maximum slip compared to the decomposed cubes. For corroded beam members, the maximum slip (22%), (32%), and (32%) of the failure bond strength, bond strength, and adhesive coated reinforcements were low.

Charles et al. [8] Stated that the bond strength exhibited by reinforcement embedded in concrete is controlled by corrosion effects. The results showed the corrosion potential of the samples not associated with cracking, scattering, and cavity. The pullout bond results of failure load, bond strength, and maximum slip for dacryodes edulis are 75.25%, 85.30%, 97.80%, moringa oleifera lam; 64.90%, 66.39%, 85.57%, magnifera indica; 36.49%, 66.30% and 85.57%, 27.08%, 5590% and 47.14%, that of corroded samples was 21.30%, 36.80% and 32.00%, for the non-corrosive. The entire results showed lower values in the corroded samples compared to the coated samples; the coated members showed high bonding properties variation from dacryodes edulis edulis (max), moringa oleifera lam (high) and magnifera indica (high), and acts as a resistance and protective membrane against the coated corrosion effects.

Han-Seung Lee et al. [9] evaluated the degree of corrosion of reinforcement as a function of the bonding properties between concrete and reinforcement. Pull-out testing was conducted and evaluated to determine the effects of reinforcement corrosion on the bonding behavior between corrugated reinforcement and concrete. The reagents were corroded with the accelerated erosion method to the desired extent inside the pull-out test specimen.

Cairns and Plizzari [10] confirmed that the splitting force from the surrounding concrete was the result of the action of the ribs producing explosive forces, resulting in the compressive force exerted by the ribs on the concrete at an angle to the bar axis. The concrete cover around the bar is made up of radial components of a ring tension force. When the tensile strength of the ring is violated during the development of the bonding action, a split failure occurs by breaking the concrete cover around the reinforcement. If the concrete imprisonment is sufficient to restore the force generated by the bond.

Chung et al. [11] experimentally investigated the effects of corrosion on bond strength and growth length. Different levels of corrosion were used to reduce reinforcement, concrete slab models with a steel reinforcement bar were used to evaluate the effect of corrosion level on bond stress and the length of growth of the flexural tension members. The average bond pressure increases before the erosion level reach 2% and then begins to decrease after the 2% erosion level.

Toscanini et al. [12] studied chloride and carbonation contamination presence in marine zones of the Niger Delta of Nigeria to assess the causes of poor bonding between steel reinforcement and concrete that has led to the premature deterioration in reinforced concrete structures in harsh environments. Reinforcing steel bars were coated with varying thicknesses of 150µm, 300µm, and 450µm against non-coated and embedded in concrete cubes, cured in accelerated corrosive media, and investigated pull-out bond strength parameters. Relatively, results of corroded specimens decreased while control and cola acuminata exudates/ resins steel bar coated specimens increased which resulted due to layered bonding agent properties of exudate specimens. The entire results showed that natural exudates/resins should be explored as inhibitors to corrosion effects in steel reinforcement in a concrete structure in chloride expected regions.

Charles et al [13] 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 -43.622% against 77.3771% and 79.6743% percentage of corroded and coated exudates/resins members. The declined mean percentile bond strength load varied from 57.0631% to 36.331% and 106.576% 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 members.

Charles et al [14] examined the use of acacia Senegal exudates/resins as paste materials in reinforcing steel at 150µm, 300µm, and 450µm thickness. Experimental studies have investigated coated and uncoated samples embedded in concrete cubes and accelerated for 178 days by immersing in sodium chloride. In comparison, corrosion on the mechanical properties of reinforcing steel decreases the value of the non-coated specimens but increased corroded and exudates/resins coated members, indicating the efficiency of acacia Senegal exudates/resins in steel reinforcement coating operations. Overall results showed high values of pull-out bond strength and low failure load in control and coated over corroded specimens.

Charles et al. [15]) assessed the characteristics of coated and non-coated reinforcing steel embedded members in concrete and exposed to a harsh environment. Collective results show that corroded models with weak maximum slip during split separation testing and high failure load have lower bond strength. Non-corroded and exudates/resins coated models have high bond strength and low failure load. Exudates/resin designs show high protective properties against corrosion effects, thereby acting as inhibitors. Exudates/resins coated models exhibited high-performance resistance properties for bond strength and maximum slip with minimal failure compared to corroded models.

Terence et al. [16] explored the impact of reinforced steel coated inhibitors under a rapid process test of embedded steel failure bond strength for 150 days. The overall results showed high values of the control drag-binding strength and the exudates / adhesive coating for the corrugated samples.

Gede et al. [17] investigated the bond strength between the reduction of concrete and reinforcement capacity due to the effect of the corrosion on the steel reinforcement resulting from saltwater presence. The application of exudates/resins extract of Artocarpus altilis was used to enhance reinforcing steel coating with 150µm, 300µm, and 450µm thickness, with an embedment of non-coated and coated reinforcing steel into concrete cubes and saturated in sodium chloride for 150 days to assess the corrosion effects. The overall results showed high values of bond strength from coated samples over non-coated samples, these results showed the negative effects of corrosion attack on the mechanical properties of reinforcing steel.

Charles et al. [18] explored the effect of olibanum exudates/resins in reinforcing steel corrosion in coastal zones under the influence of saltwater on concrete structures. To evaluate the effects of corrosion, non-coated and exudates / resin-coated steel were embedded in concrete cubes and pooled in the corrosive medium. The tests showed that the value of the non-coated specimens decreased due to the reduction of corrosion attacks. The average percentage bond strength load was 33.1347% and coating members 45.66004% and 71.84448% compared to the control differential. The mean maximum slip values were 0.083567 mm and mean 33.87847% and 75.30913%, respectively, compared to control and end -25.3054%. Experimental results show that reduced samples have lower bond strength and higher failure bond load and lower maximum slip, whereas exudates/resins coated samples have lower test samples and higher percentage values compared to corrosive samples.

2.0 Test Program

The research examined the coating of the exudates/resin paste extracted from plant trunks called inhibitors directly on the reinforcing steel. Acceleration of corrosive media with the introduction of sodium chloride (NaCl) and into the environment with a view to determining the potency of the use of environmentally friendly and widely available materials in controlling the negative impact of corrosion attacks of steel reinforcement embedded in concrete structures. Experimental specimens reflect severe acid levels, which indicate the level of sea salt concentration in the marine environment in reinforced concrete structures. The embedded reinforcement steel is completely submerged and samples for the corrosion acceleration process are maintained in the pooling tank. These samples were designed with 36 reinforced concrete cubes of dimensions 150 mm × 150 mm x 150 mm, with 12 mm in diameter for all controlled, non-coated, and coated samples, centered for pullout bond testing and immersed in sodium chloride for 360 days after 28 days initial cube curing. Acid media samples were changed monthly and samples were reviewed for high performance.

2.1 Materials and methods for testing

2.1.5 Aggregates

Aggregates (fine and coarse) were purchased. Both met the requirements of BS882;[19]

2.1.5 Cement

Portland lime cement grade 42.5 is the most common type of cement in the Nigerian market. It was used for all concrete mixes in this test. It meets cement requirements (BS EN 196-6)[20]

2.1.3 Water

The water samples were clean and free from contaminants. Freshwater was obtained from the Civil Engineering Laboratory, Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State. Water filling (BS 3148)[21] requirements

2.1.4 Structural steel reinforcement

Reinforcements are obtained directly from the market at Port Harcourt, (BS4449: 2005 + A3)[22]

2.1.5 Corrosion Inhibitors (Resins / Exudates) Daniellia oliveri

The exudates / resins were obtained by tapping from the tree trunk. The trees are abundantly found in south eastern Nigeria. Exudates are gotten from Uli, Ihiala Local Government of Anambra 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, coated with 150μm, 300μm, 450μm, and 600μm coatings before corrosion testing. The test cubes were coated with 150 mm x 150 mm x 150 mm metal mold and removed after 72 hours. Samples were treated at room temperature in tanks 28 days prior to the initial treatment period, after which a rapid accelerated corrosion test and a test regime allowed a monthly routine monitoring of 360 days. Cubes for corrosion-acceleration samples were taken at 90 days, 180 days, 270 days, and 360 days approximately 3 months apart, and failure bond loads, bond strength, maximum slip, reduction/increase of cross-sectional area, and weight loss/steel reinforcement are examined.

2.3 Accelerated Corrosion Setting and Testing Method

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

2.4 Pull-Out Bond Strength Test

The tensile-binding strength test of concrete cubes was carried out on a total of 36 specimens in each of the 12 specimens with controlled, unpainted, and coated members, and subjected to a 50 kN universal testing machine according to BSEN12390. 2.[23] Total numbers of 36 cubes measuring 150 mm × 150 mm × 150 mm embedded in the center of a single 12 mm diameter concrete cube.

2.5 Tensile Strength of Reinforcement bars

To determine the yield and tensile strength of the bar, a 12 mm diameter reinforced, non-coated, and coated reinforced steel strip was tested under pressure at the Universal Test Machine (UTM) and subjected to direct pressure until the failure load was recorded. To ensure stability, the remaining cut pieces were used in subsequent bond testing of and failure bond loads, bond strength, maximum slip, reduction/increase of cross-sectional area, and weight loss/steel reinforcement.

3.1 Experimental Discussion

The bond ensures that there is little or no slip of steel-related bars and pressure transfer mechanisms across the steel concrete (Hadi [24]; Warner et al., [25]). Bond resistance is formed by chemical adhesion, friction, and mechanical connection between the bar and the surrounding concrete. To avoid the adhesion of solid concrete and construction forms, oil is widely used these days in site construction. This effective method can affect the bond between concrete and steel due to the contamination of the steel bars with oil before the concrete. Based on this defective approach, the introduction of extracts of tree origin known as exudate/resin is introduced to increase the bonding characteristics between concrete and steel and thereby acts as anti-corrosion materials to curb the scourge effect of corrosion on reinforcing steel exposed to corrosive media.

The experimental data presented in Tables 3.1, 3.2, and 3.3, summarized in Tables 3.4 and 3.5 were results obtained on 36 concrete cube samples as explained in experimental procedures for 12 controlled, placed in freshwater for 360 days, 12 non-coated, and 12 coated with exudates/resin samples all embedded in concrete cube samples and immersed in 5% sodium chloride (NaCl) aqueous solution for 360 days and investigated their effectiveness by, monitoring, testing for three months in 90 days, 180 days, 270 days, and 360 days. Indeed, the manifestation of corrosion is a long-term process that takes decades to fully work, but the introduction of sodium chloride causes the appearance of corrosion in a short period. The experimental work represented a suitable high-salt sea media and the possible use of daniellia oliveri exudates/resin extract as a barrier to prevent corrosion and the risk of corrosion impact in a reinforced concrete structure exposed or built within this harsh region.

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

Sample Numbers	DOC	DOC1	DOC2	DOC3	DOC4	DOC5	DOC6	DOC7	DOC8	DOC9	DOC10	DOC11
	Time Interval after 28 days curing											
Samplin g and Durations	**Samples 1 (28 days)**			**Samples 2 (28 Days)**			**Samples 3 (28 Days)**			**Samples 4 (28 Days)**		
Failure Bond Loads (kN)	29.428	27.339	27.903	28.499	29.314	29.015	29.539	29.356	29.421	31.232	30.356	30.558
Bond strength (MPa)	10.531	11.423	9.921	10.851	11.224	12.147	12.241	11.571	11.605	12.311	11.622	12.169
Max. slip (mm)	0.101	0.106	0.100	0.101	0.116	0.110	0.103	0.104	0.108	0.115	0.119	0.104
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)	11.952	11.951	11.961	11.960	11.951	11.960	11.961	11.957	11.960	11.951	11.960	11.961
Rebar Diamete r- at 28 Days Nominal(mm)	11.952	11.951	11.961	11.960	11.951	11.960	11.961	11.957	11.960	11.951	11.960	11.961
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rebar Weights- Before Test(Kg)	0.586	0.584	0.587	0.587	0.587	0.593	0.585	0.585	0.587	0.586	0.585	0.589
Rebar Weights- at 28 Days Nominal(Kg)	0.586	0.584	0.587	0.587	0.587	0.593	0.585	0.585	0.587	0.586	0.585	0.589
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

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

Samplin g and Durations	**Samples 1 (90 days)**			**Samples 2 (180 Days)**			**Samples 3 (270 Days)**			**Samples 4 (360 Days)**		
Failure Bond Loads (kN)	17.276	16.588	16.878	16.321	15.569	16.436	16.015	16.323	16.021	17.256	16.135	16.869
Bond strength (MPa)	7.861	7.871	7.636	7.858	7.624	7.597	7.395	8.084	7.059	7.547	7.395	7.707
Max. slip (mm)	0.080	0.083	0.084	0.093	0.084	0.087	0.086	0.076	0.082	0.083	0.084	0.075
Nominal Rebar Diameter	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
Measured Rebar Diameter Before Test(mm)	11.960	11.970	11.961	11.960	11.950	11.970	11.961	11.957	11.960	11.952	11.950	11.961
Rebar Diamete r- After Corrosion(mm)	11.902	11.901	11.911	11.911	11.901	11.911	11.911	11.908	11.911	11.901	11.910	11.912
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.058	0.069	0.050	0.050	0.049	0.060	0.050	0.050	0.050	0.050	0.040	0.050
Rebar Weights- Before Test(Kg)	0.593	0.587	0.587	0.587	0.585	0.593	0.585	0.586	0.587	0.586	0.585	0.589
Rebar Weights- After Corrosion(Kg)	0.528	0.529	0.528	0.529	0.527	0.528	0.527	0.529	0.528	0.528	0.526	0.530
Weight Loss /Gain of Steel (Kg)	0.065	0.058	0.059	0.058	0.059	0.058	0.061	0.059	0.061	0.059	0.060	0.063

Table 3.3: Results of Pull-out Bond Strength Test (τu) (MPa) of Daniellia oliveri 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)	31.965	29.876	30.440	31.036	31.851	31.552	32.076	31.893	31.958	33.769	32.893	33.095
Bond strength (MPa)	13.068	13.960	12.458	13.388	13.761	14.684	14.778	14.108	14.142	14.848	14.159	14.706
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)	11.952	11.950	11.961	11.951	11.951	11.970	11.961	11.957	11.960	11.960	11.951	11.961
Rebar Diameter- After Corrosion(mm)	12.019	12.018	12.028	12.027	12.018	12.027	12.028	12.024	12.027	12.018	12.027	12.025
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.067	0.068	0.067	0.077	0.067	0.057	0.067	0.067	0.067	0.058	0.076	0.064
Rebar Weights- Before Test(Kg)	0.587	0.587	0.586	0.587	0.585	0.586	0.585	0.587	0.586	0.586	0.584	0.589
Rebar Weights- After Corrosion(Kg)	0.669	0.663	0.663	0.663	0.661	0.669	0.661	0.662	0.663	0.662	0.661	0.664
Weight Loss /Gain of Steel (Kg)	0.085	0.076	0.076	0.076	0.075	0.083	0.076	0.077	0.077	0.662	0.074	0.076

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

Sample	Non-Corroded Specimens Average Values				Corroded Specimens Average Values				Coated Specimens Average Values of 150µm, 300µm, 450µm, 6000µm)			
Failure load (KN)	28.223	27.914	28.572	28.943	16.914	16.596	16.256	16.108	30.760	30.451	31.109	31.480
Bond strength (MPa)	10.625	10.732	10.665	11.408	7.789	7.788	7.706	7.693	13.162	13.269	13.202	13.945
Max. slip (mm)	0.102	0.102	0.106	0.105	0.082	0.087	0.087	0.088	0.144	0.143	0.141	0.142
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)	11.954	11.957	11.957	11.957	11.964	11.964	11.957	11.960	11.954	11.954	11.954	11.957
Rebar Diameter- After Corrosion(mm)	11.954	11.957	11.957	11.957	11.905	11.908	11.908	11.908	12.022	12.024	12.024	12.024
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.059	0.056	0.049	0.053	0.067	0.071	0.070	0.067
Rebar Weights- Before Test(Kg)	0.586	0.586	0.587	0.589	0.589	0.587	0.586	0.589	0.587	0.587	0.586	0.586
Rebar Weights- After Corrosion(Kg)	0.586	0.586	0.587	0.589	0.528	0.528	0.528	0.528	0.665	0.663	0.662	0.664
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.061	0.058	0.059	0.058	0.079	0.076	0.076	0.078

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

	Non-corroded Control Cube				Corroded Cube Specimens				Exudate / Resin steel bar coated specimens			
Failure load (KN)	66.864	68.199	75.766	79.677	-45.014	-45.500	-47.746	-48.830	81.863	83.486	91.373	95.427
Bond strength (MPa)	36.404	37.795	38.404	48.281	-40.819	-41.304	-41.632	-44.830	68.974	70.369	71.327	81.259
Max. slip (mm)	24.273	18.102	21.605	19.728	-42.644	-39.162	-38.246	-37.947	74.350	64.371	61.933	61.152
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)	0.079	0.084	0.083	0.079	0.080	0.084	0.084	0.074	0.080	0.084	0.084	0.084
Rebar Diamete r- After Corrosion(mm)	0.417	0.417	0.417	0.417	-0.971	-0.970	-0.970	-0.970	0.980	0.980	0.980	0.980
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	-12.706	-20.537	-29.882	-21.416	14.555	25.845	42.617	27.252
Rebar Weights- Before Test(Kg)	0.371	0.470	0.035	0.045	0.398	0.428	0.429	0.404	0.396	0.428	0.429	0.402
Rebar Weights- After Corrosion(Kg)	10.901	10.935	11.233	11.651	-20.579	-20.314	-20.334	-20.599	25.910	25.492	25.525	25.943
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	-23.356	-23.400	-22.623	-25.406	30.474	30.549	29.237	34.060

3.2 Failure load, Bond Strength, and Maximum slip

The results of the failure bond load, bond strength, and maximum slip carried out on 36 concrete cubes, as shown in Table 3.1. 3.2 and 3.3 and averagely and percentiles summarized in 3.4 - 3.5 and shown graphically in figures 1 - 6b. The results obtained refer to 12 controlled, 12 corroded and 12 coated samples tested for failure using Instron Universal Testing Machines at 50kN as described in the test procedure.

The average and minimum and maximum calculated percentiles obtained from the failure bond load of controlled samples are 27.914kN and 28.943kN and presented in percentile as 66.864% and 79.677%, the corroded values are 16.108kN and 16.914kN having percentile range of -48.83% and -45,014% and the exudates/resin coated samples are 30.451kN and 31.48kN representing percentile values of 81.863% and 95.427%.

The bond strength values to controlled were 10.625MPa and 11.408MPa and valued at percentiles of 36.404% and 48.281%, the corroded samples are of 7.693MPa and 7.789MPa, and valued at 44.83% and -40.819% percentile, and the coated values are 13.162MPa and 13.945MPa percentiles at 68.974% and 81.259%.

The maximum slip results were examined and data obtained are 0.102mm and 0.106 mm valued at 18.102% and 24.273% percentile, the corroded samples are 0.082 mm and 0.088 mm representing -42.644% and -37.947%), while the coated samples with 0.141 mm and 0.144mm having percentile values of 61.152%) and 74.35%.

From the results shown in Table 3.4 the average values of Tables 3.1, 3.2, and 3.3 which are derived from 3.4 to 3.5, for the difference in percentage values, the comparative maximum obtained values are failure bond load of controlled is 79.677% as against corroded-45.014% and coated 95.427%. This result showed lower failure bond load application, decreased value as compared to the controlled samples as a reference point. Controlled and coated samples recorded increased and higher failure bond loads. It can be judged from the reference point that coated recorded closed value range to that of controlled.

Comparatively, the bond strength samples' maximum obtained controlled value for controlled is 81.259% as against the corroded value of -40.819% and coated value of 48.281%. Obtained results showed lower bond strength recorded in corroded and reduced/decreased value compared to controlled and coated samples, indications showed that coated materials increased the interaction between concrete and reinforcing steel.

The maximum slip obtained peak comparative values are controlled 74.35% as against corroded -37.947% and coated 24.273%, The obtained results showed lower slippage and decrease value from the corroded sample as against controlled and coated samples with higher slippage to failure and increase values resulting from coating materials.

The results showed an indication of the effect of corrosion on failure bond load, bond strength, and maximum slip recorded from corroded samples resulting from damages of the ribs and severe modifications of the surface area as stated in the studies of (Cairns and Abdullah, [4]; Charles et al., [5]; Otunyo and Kennedy, [7]; Han-Seung Lee et al., [9]; Cairns and Plizzari, [12]; Toscanini et al., [12]; Gede et al., [17]; Terence et al., [16]; Charles et al., [215]).The presence of corrosion reduces the efficiency of the material corroded thereby reduces the original mechanical properties of reinforcing steel.

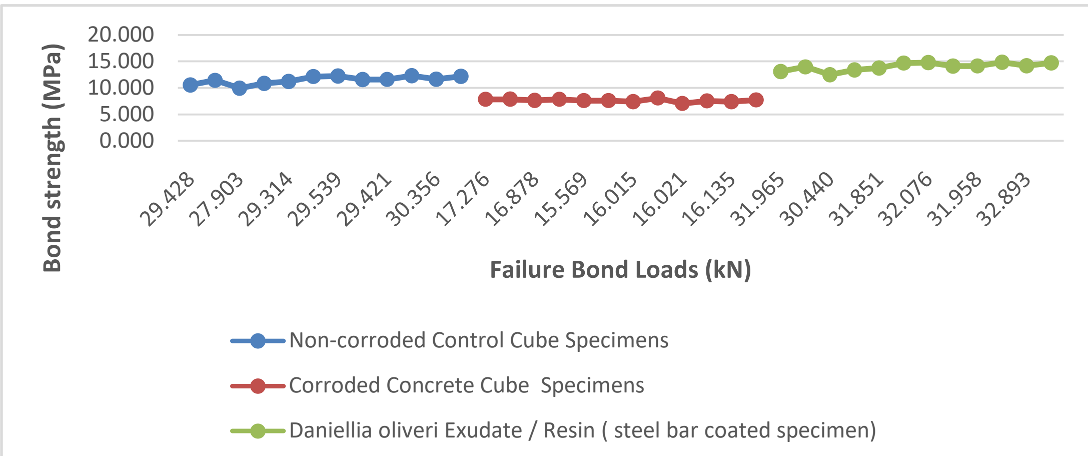

Figure 1: Failure Bond loads versus Bond Strengths

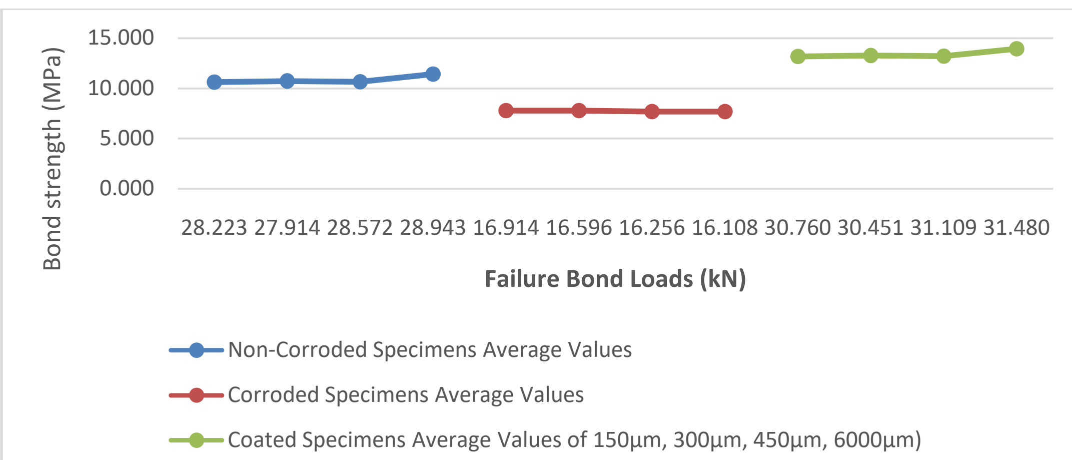

Figure 1a: Average Failure Bond loads versus Bond Strengths

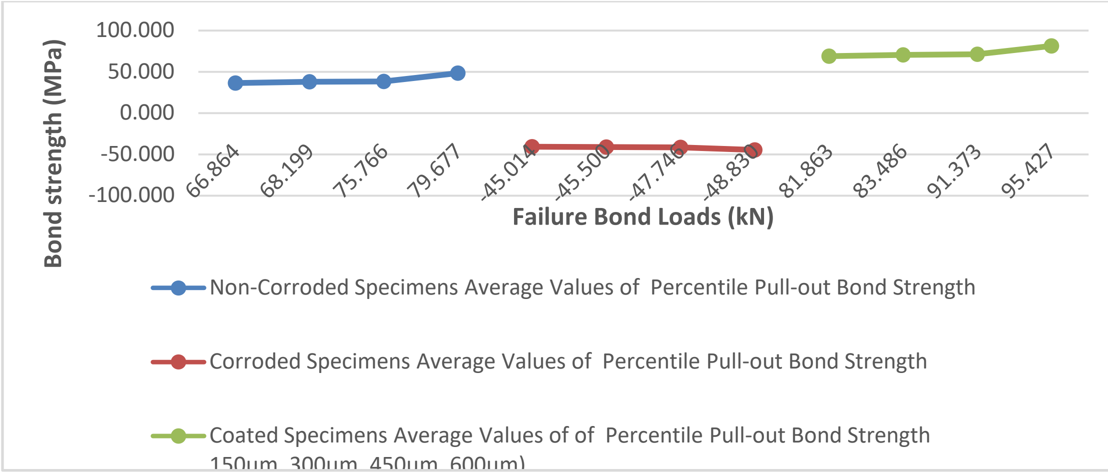

Figure 1b: Average Percentile Failure Bond loads versus Bond Strengths

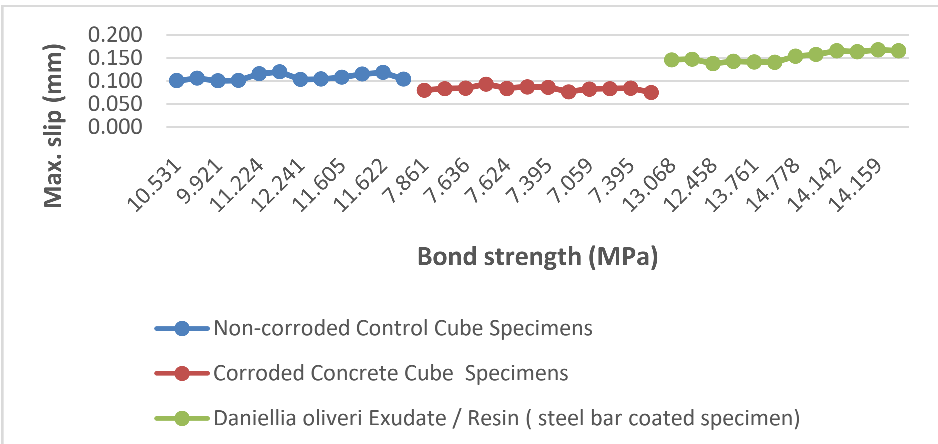

Figure 2: Bond Strengths versus Maximum Slip

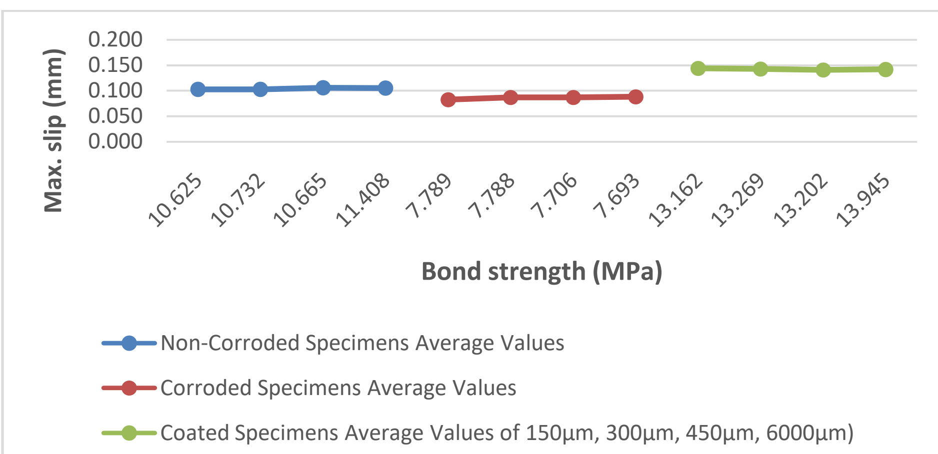

Figure 2a: Average Bond Strengths versus Maximum Slip

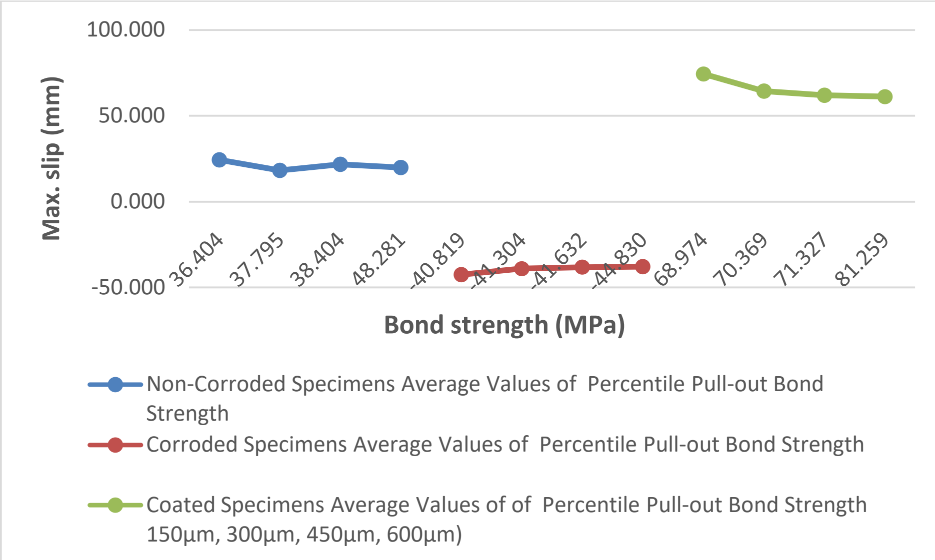

Figure 2b: Average Percentile Bond Strengths versus Maximum Slip

3.3 Mechanical Properties of Reinforcing Bars

The use of anti-corrosion, improved concrete features, and additional concrete cover are used to increase the protection provided by concrete in the reinforcement. Without these measures, structural cracks in operation and environmental hazards reduce the effectiveness of these measures. Ultimately, these factors will cause the structures to suffer from corrosion, affecting their strength and durability. While the reduction of energy is not directly related to the reduction of the cross-sectional area of the bars, the effects of stiffness and fatigue are associated with complex processes, one of which is the collapse of the bond. This research introduced the use of exudates/resins to curb the menace of corrosion effect suffered by reinforcing steel embedded in concrete and exposed to corrosive media by proving resistive membrane through coatings.

The data presented in Tables 3.1, 3.2, and 3.3 and collapsed in Table 3.4 of the average values, and (finally) summarized to 3.5 percentile values, are the behavioral characteristics of the controlled, corroded, and coated concrete cube members subjected to failure using Instron Universal Testing Machine after accelerated corrosion induction process for 360 days and detected the specific performance of the samples at 3-month intervals as scheduled and projected in figures 1 - 6b. The results of the controlled samples are 100% values because they are concentrated in the freshwater tank according to the requirements of (BS3148).

The results are summarized in Tables 3.4 and 3.5 for minimum and maximum values obtained, the nominal diameter steel rebar of all models are 100%, and the minimum and maximum diameters of steel rebar measured before the test are in the range of 11.954mm and 11.95mm (0.079% and 0.084%), respectively.

The diameters of non-coated specimens after corrosion testing were 11.905mm and 11.908mm (-0.971% and -0.97%) and coated samples are 12.022mm and 12.024mm (0.98% and 0.98%), respectively. The results for the non-coated-cross-sectional area were 0.049mm and 0.059 mm (-29.882% and -12.706%), while the coated samples were 0.06 mm and 0.067mm (14.555% and 42.617%).

The pre-test weight results for all samples were 0.587kg and 0.589kg (0.035% and 0.47%), respectively.

Weight after corrosion testing for non-coated was 0.528 kg and 0.528 kg (-20.599% and -20.314%), coated 0.662 kg and 0.665kg (25.492% and 25.943%), and non-coated samples steel weight loss / increase are 0.058. Kg and 0.061Kg (-25.406% and -22.623%) and coated values were 0.076Kg and 0.079Kg (29.237% and 34.06%) after corrosion tests. From the results obtained and given in Figures 3-6b, it can be seen that the diameter of uncoated decreased by the maximum value of (-0.97% and coated increased by 0.98%, for the cross-sectional area, corroded has maximum reduction value of -12.706% and coated increased by 42.617%%, weight loss and gain are corroded -22.623% decreased (loss) and coated 34.06% increase (gain) as stated in the studies of (Cairns and Abdullah, [4];

Charles et al., [5]; Otunyo and Kennedy, [7]; Han-Seung Lee et al., [9]; Cairns and Plizzari, [12]; Toscanini et al., [12]; Gede et al., [17]; Terence et al., [16]; Charles et al., [215]).

The indication analyzed from the test work was that the effect of corrosion on the non-coated concrete cube samples has a reduction in diameter and cross-sectional area and in rebar unit weight reduction, the increase in diameter of the coated concrete cube samples and the cross-sectional area increase resulting from varying thicknesses of the coating exudates /resins.while coated concrete cubes have diameter and cross – sectional area increases and weight gain resulting from the varying thickness coated to reinforcing steel.

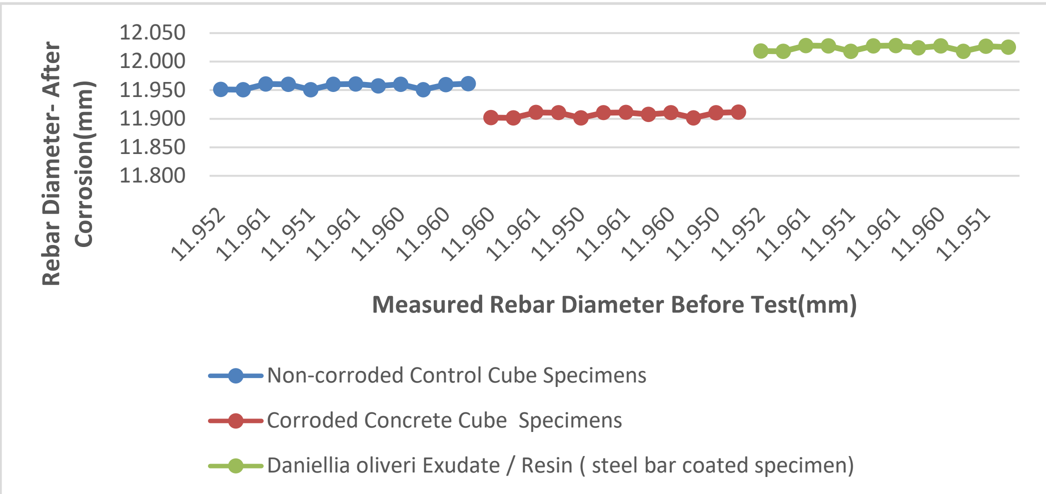

Figure 3: Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

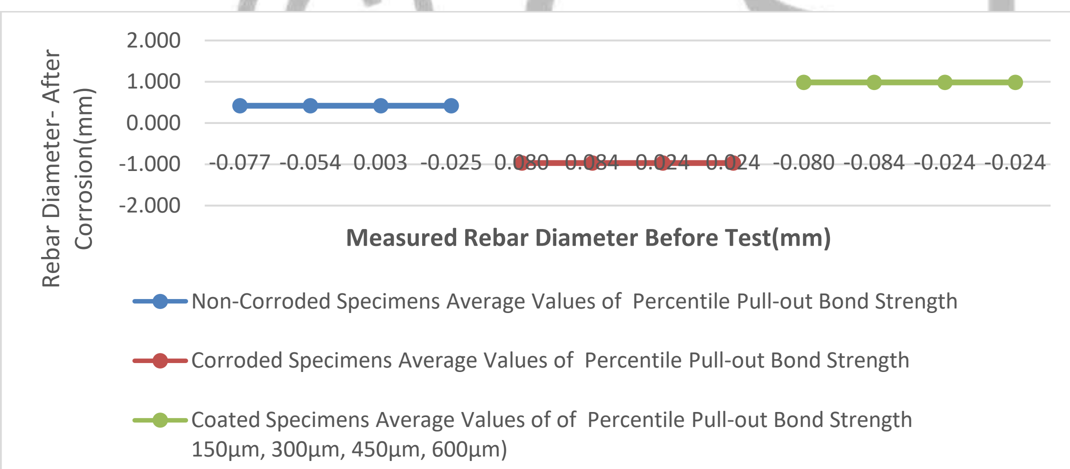

Figure 3a: Average Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion

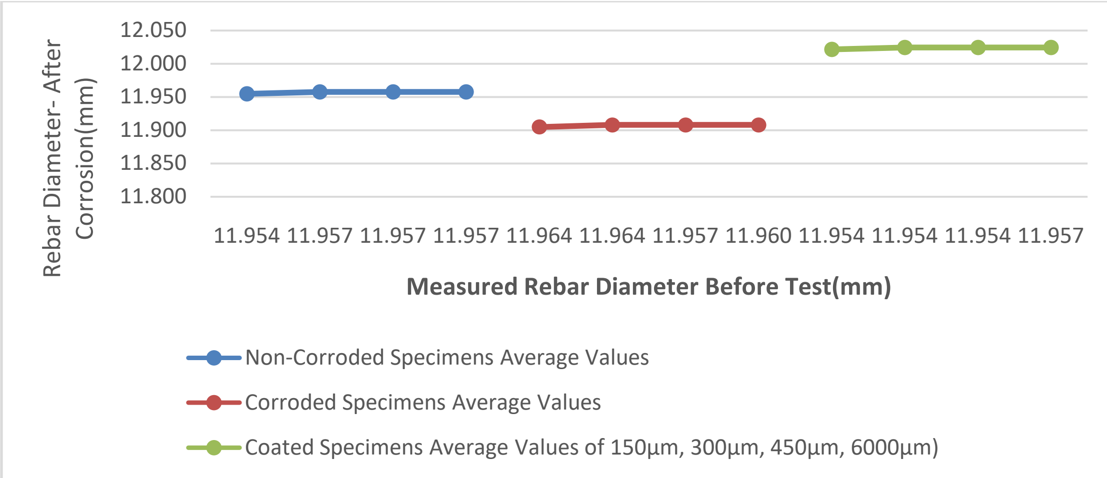

Figure 3b: Average Percentile Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion

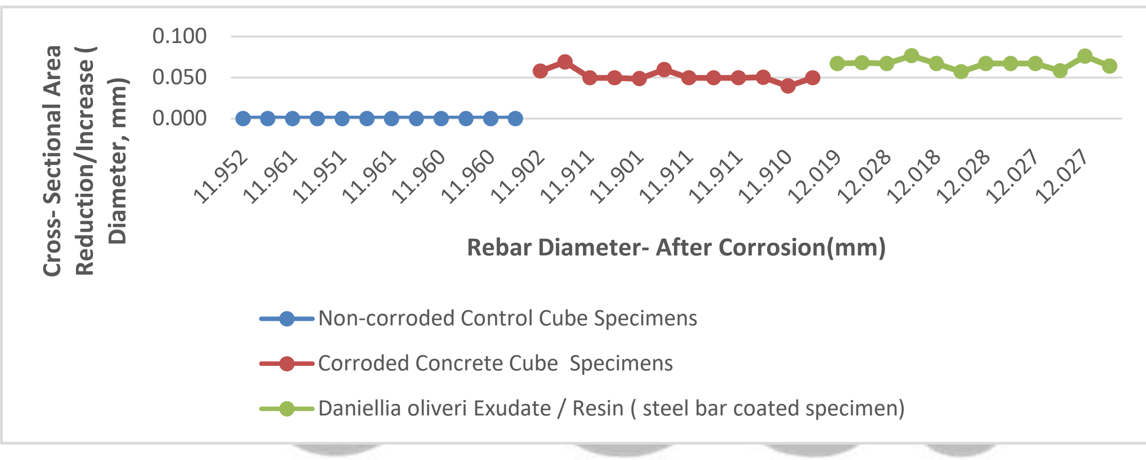

Figure 4: Rebar Diameter- After Corrosion versus Cross - Sectional Area Reduction/Increase

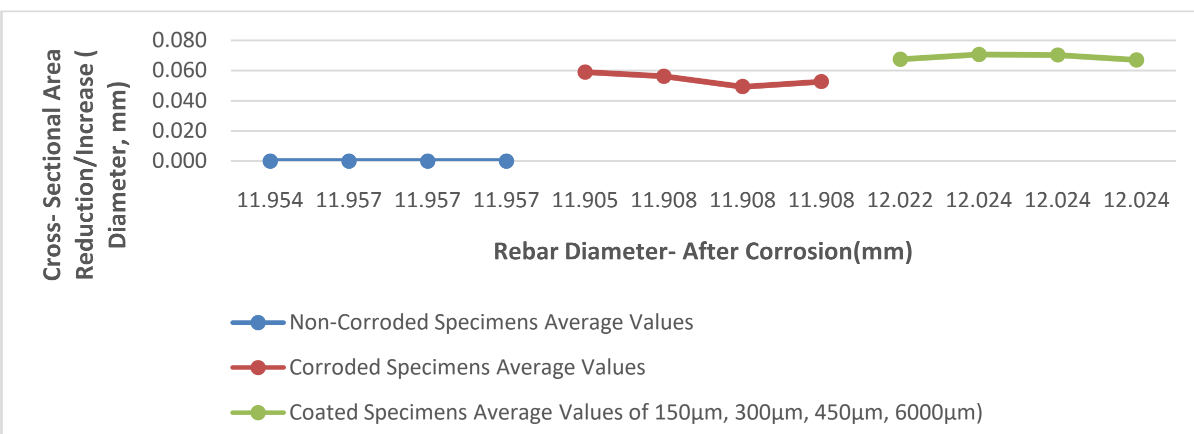

Figure 4a: Average Rebar Diameter- after Corrosion versus Cross – Sectional Area Reduction/Increase

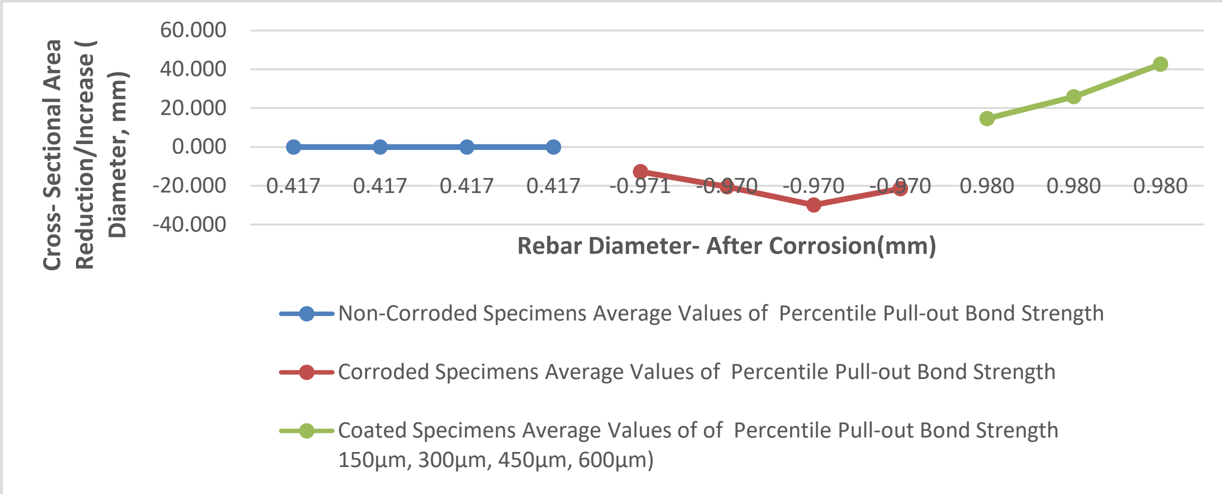

Figure 4b: Average percentile Rebar Diameter- after Corrosion versus Cross - sectional Area Reduction/Increase

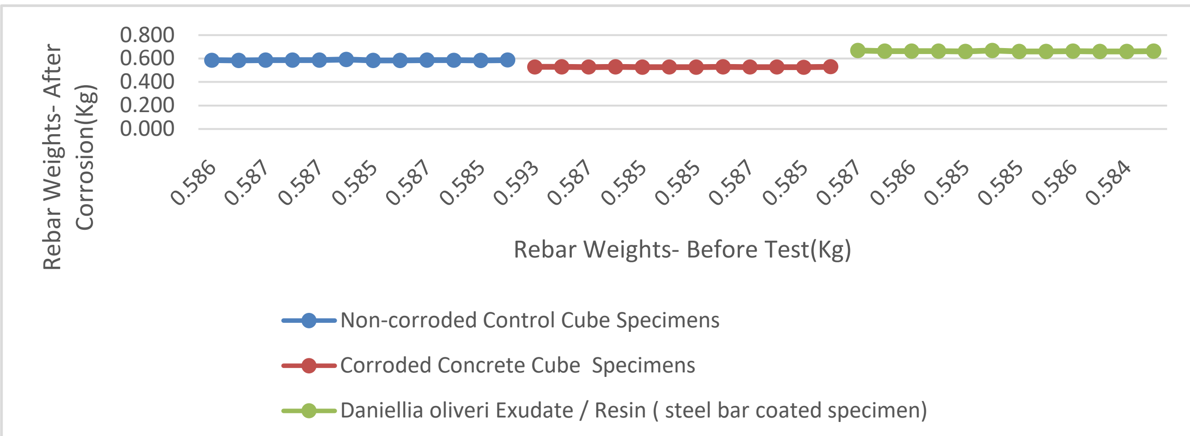

Figure 5: Rebar Weights- before Test versus Rebar Weights- after Corrosion

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

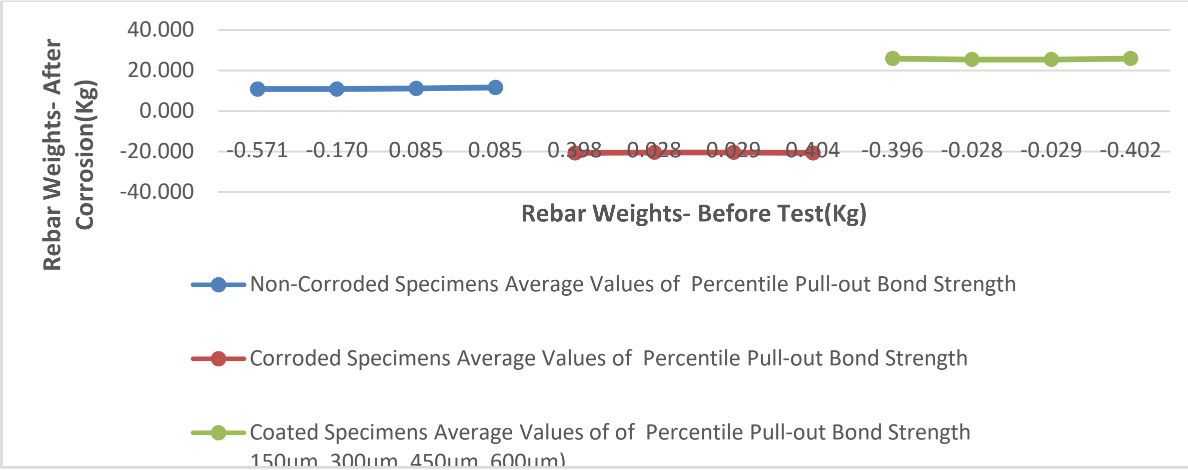

Figure 5b: Average Percentile Rebar Weights- before Test versus Rebar Weights- after Corrosion

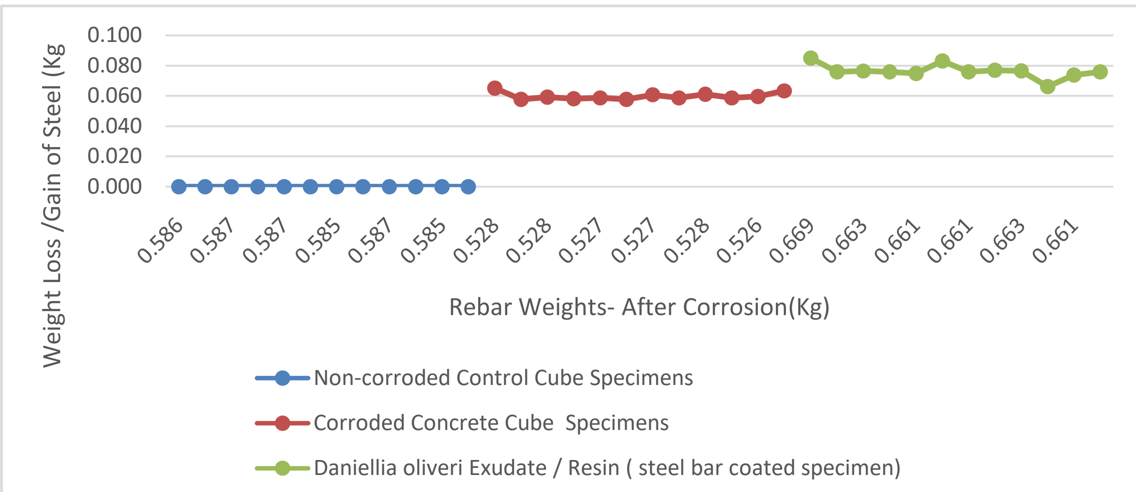

Figure 6: Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

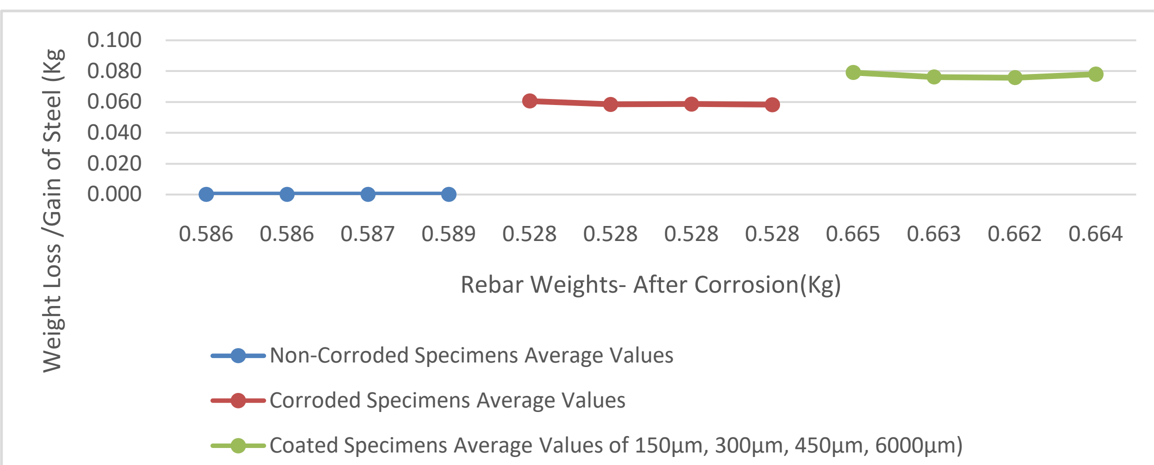

Figure 6a: Average Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

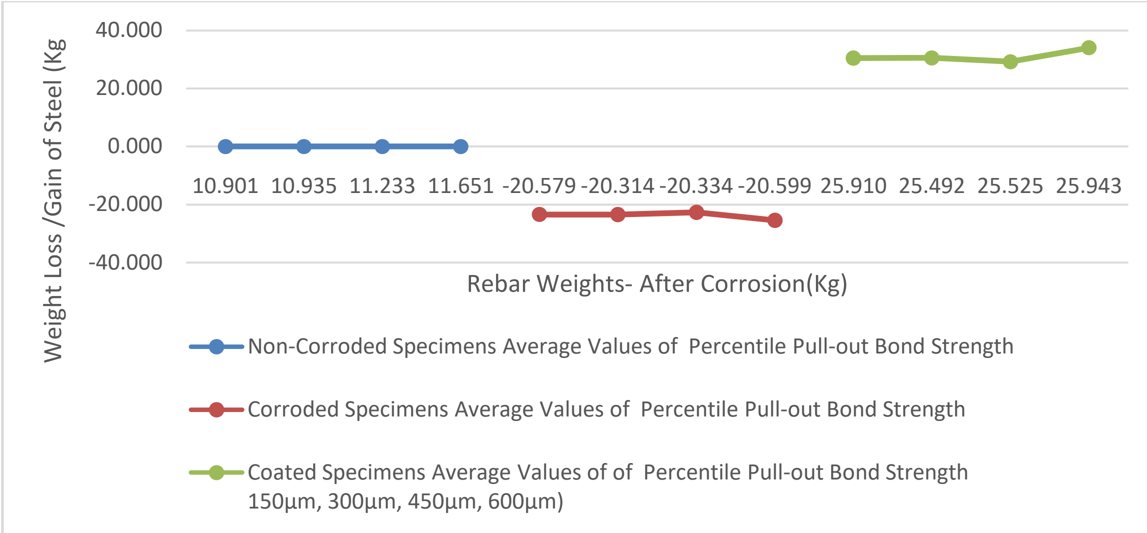

Figure 6b: Average percentile Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

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

For comparison, data from Tables 3.1, 3.2 and 3.3 and 3.4, 3.5 are 36 concrete cube samples subdivided into 3 sections of 12 controlled samples pooled in a freshwater tank for 360 days, 12 non-coated and 12 coated samples pooled in accelerated in 5% sodium chloride (NaCl) aqueous corrosive media tank for 360 days as described in experimental procedures and presented in tables 3.1 - 3.3, summarized into average and percentile in tables 3.4 - 3.5 and represented in figures 3a, 3b, 4a, 4b, 5a, 5b, 6a and 6b of failure bond loads, bond strength and maximum slip, cross-sectional reduction/increase, the diameter of rebar before /after corrosion, weight loss/gain. The results obtained by comparison showed that the controlled and coated failure bond load maintains close values, while the corroded members resulted in lower load application; similar factors are present in bond strength and maximum slip. Among the mechanical properties of reinforced steel, the impact of corrosion on reinforced steel revealed a cross-sectional reduction in the diameter of the bar compared to the nominal diameter before the test, the weight loss is observed and the cross-sectional area of the coated members is increased, with an increase in the diameter and weight of the coating material compared to the nominal resilience.

The indication analyzed from the experiment is that the effect of corrosion on non-coated concrete cube specimens decreases in diameter and cross-sectional area. Whereas the diameter and cross-sectional area of the coated concrete cubes increases and the weight increases as a result of the different thickness of the coated steel reinforcement. The exudate/resin studied showed the potency of the inhibitory properties against corrosion attack and can be concluded that it can be used as an inhibitor for corrosion.

4.0 Conclusion

In the experiment, the result obtained is drawn as follows:

i. Exudate/resin has a preventive effect on corrosion because of its waterproofing resistance to corrosion penetration and attacks.

ii. The contact between the concrete and steel in the coated components is greater than in the embossed specimens

iii. The properties of the bonds in the coated and controlled components are much higher than in the corroded

iv. Less failed bond load, bond strength, and maximum slip were recorded in the corroded member

v. The coating and control model recorded high values of bond load and bond strength.

vi. Weight loss and cross-sectional reduction are mainly recorded in corroded coatings and controlled models

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