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Corrosion Influence on Bond Reduction of Steel Reinforcement Embedded in Reinforced Concrete Structures Exposed to Corrosive Media

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ABSTRACT

The main assumption in reinforced concrete structures is that there is a perfect bond between the reinforcement and the surrounding concrete to accommodate this difficulty posed by corrosion attacks. The experimental work represented the high-salt ocean media and the possible use of boswellia dalzielii hutch exudate/resin extract as a barrier to prevent corrosion and the risk of corrosion impact on the reinforced concrete structure exposed or built within this severe corrosive coastal region. Corrosion acceleration was tested on high-yielding steel (reinforcement) with a diameter of 12 mm and a length of 650 mm. The cubes for the corrosion-acceleration samples were taken at 90 days, 180 days, 270 days, and 360 days at approximately 3 months intervals, and the failure bond loads, bond strength, maximum slip, reduction/increase of cross-section area, and weight loss/steel reinforcement are explored.. Results showed lower slippage in the corroded sample as against controlled and coated samples with higher slippage force before failure, this factors showed the effect of corrosion on the mechanical properties of reinforcing steel showing the interactive relationship of concrete and steel to slippage and as well as the negative effect of corrosion on the mechanical properties of reinforcing steel. Comparative results of differential values for the maximum rebar diameter of uncoated decreases to -0.623% while coated sample increases by 0.722%, for the maximum corroded cross-sectional area, the value of reduction is -23.296%, and the coated sample increase by 33.218 %%, the weight loss of corroded sample decreases by -21.643% showing weight reduction (loss), and the coated sample increased by 35.916%.

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

1.0 INTRODUCTION

The most causes of reinforced steel corrosion are carbon dioxide and chloride ions entering the concrete and migrating to the steel surface. De-icing salts destroy the passive layer of iron oxide around the reinforcement, leading to rapid corrosion. The corrosion of reinforced steel reduces the cross-sectional area of the steel bar and increases the corrosion products, which reduces the ductility and strength of the steel. Products of corrosion occupy 2 to 6 time's larger volumes than the original reinforced steel (Liu and Weyers, [1]). Early corrosion products around the steel bar surface create longitudinal cracks, spills, and delamination of the concrete cover. Loss of the concrete cover results in a loss of bonding as the bond strength decreases at the interfacial zone between the steel bar and the concrete. The soft layer produced by the corrosion products collected on the bar surface successfully reduces the frictional fraction of the bond strength. Therefore, the rib degradation of the deformation bars reduces the interlocking forces between the ribs of the bars and the surrounding concrete structure. This degrades the main mechanism of bond strength between deformation bars and concrete, which significantly reduces bonding in the process.

Ichinose et al. [2] provided experimental evidence that the effect of rod size on bond strength depends on the degree of retention. In their tests it was found that the bond strength of samples with low retention rates and disintegration decreased with increasing rod size, but this effect was negligible for samples with high retention rates and tensile damage.

Turk and Yildirim [3] reported that the diameter of the steel bar has a very important influence on bond strength. Other researchers such as De Larrard et al. [4] reported that the bond strength of reinforcement with a diameter of 10 mm was higher than that of steel with a large diameter, indicating that the bond strength decreased with increasing diameter of the steel reinforcement.

Charles et al. [5] examined the use of acacia senegal exudates/resins as paste materials in reinforcing steel with a thickness of 150µm, 300µm and 450µm, embedded in the concrete cube and immersed in sodium chloride and accelerated for 178 days. In comparison, the values of corroded specimens are reduced, but non-corroded and exudates/resins coated members increased, indicating the potential of acacia senegal exudates/resins in steel reinforcing coating operations. Overall results showed high values of pull-out bond strength and low failure load in the control and were coated for corroded specimens.

Al-sulaimani et al. [6] studied the effect of corrosion and bond strength on steel reinforcement was found to be approximately 1% of the corrosion level because of the hardness of the reinforced bar surface in the early stages of a firm adhesive layer of corrosion. This is in agreement with the experimental results obtained from the reinforced concrete member tests, which showed that the increase in radial stress caused by the expansion of the corrosion product increased the bond strength when the corrosion rate increased to 4% (Mangat and Elgarf, [7]).

Almusallam et al. [8] demonstrated that the bond strength increased during the pre-rupture phase, but that the slip of the ultimate bond strength decreases with the increase of the corrosion level. Experimental studies have shown that bond strength increases by about 2% at the initial corrosion level.

Cabrera [9], Amleh and Mirza. [10] Stated that the increase in bond strength was attributed to the production of a stable layer. The rust around the reinforcing steel bar will increase the bond strength as a result. The bond strength is dramatically reduced after the development of longitudinal corrosion cracks. The loss of the bearing components is the result of a reduction in the strength of the bearing as a result of the corrosion of the steel ribs. In addition, with a higher corrosion level, tensile ring stress on the surrounding concrete exceeds the tensile strength, which led to the separation of the concrete cover, which reduced in turn reduced bonding.

Charles et al. [11] explored the primary reasons for the reduction of service life, the integrity, and efficiency of reinforced concrete structures in saline marine environments. The results obtained for comparison of non-coated and coated reinforcing steel with resins/exudates showed that the failure bond load, bond strength, and maximum slip decreased by 21.30%, 38.80%, and 32.00% in the non-coated (corroded) samples respectively. The coated samples were 51.69%, 66.90%, 74.65%, for the control samples, 27.08%, 55.90% and 47.14%. The full results showed a lower percentage of corroded and a higher percentage of coated members. This justifies the effect of corrosion on the strength of the corroded and coated members.

Charles et al. [12] discovered the corrosion of steel reinforcement in concrete as one of the main factors that caused the failure of steel and concrete, and the use of epoxy, resin/exudate utilization has been implored to trend corrosion effect on reinforcing steel. The results obtained showed the presence of corrosion potential in non-coated members. The tensile strength test results of the failure bond load, bond strength, and maximum slip were 21.30%, 36.80% and 32.00% for the deformed members, 36.47%, 64.00% and 49.30% for the values of corroded members were lower compared to the coated members. The results showed that the resins/exudates improve strength for reinforcement and acts as a protection line against corrosion.

Otunyo and Kennedy [13] explored the effect of resin/exudate in preventing reinforcement in reinforced concrete cubes. Failure bond strength, bond strength, and the maximum slip of adhesive-coated reinforced cubes were higher. Similar results were obtained for the maximum slip (adhesive coating and control steel members) which had higher values of maximum slip compared to corroded steel reinforcement.

Toscanini et al. [14] investigated the effect of chloride and carbonate contamination in the marine regions of the Niger Delta, Nigeria on the poor bond characteristics between steel reinforcement and concrete that has led to the premature deterioration of reinforced concrete structures. The reinforced steel was coated with 150µm, 300µm, and 450µm thick and embedded in concrete cubes, cured in accelerated corrosive media, and analyzed for pull-out bond strength parameters. Comparatively, the results of the deformed samples decreased while control and cola acuminata exudates/resins coated samples increased. Full results showed that natural exudates/resins showed resistance to corrosion effects on steel reinforcement in concrete structures.

Charles et al. [15] Evaluated the effect of the bond strength reduction and the interaction between reinforcing steel and reinforced concrete structures in the marine environment of saltwater using non-coated steel and khaya senegalensis. The results of the failure bond loads showed a difference of -43.622% and 77.3771% and 79.6743% for corrosive and coated exudates/resin members. The reduced average percentage bond strength load ranges from 57.0631% to 36.331% and 106.576% in stained and coated samples. The obtained results clearly showed that corrosive bond loads are higher for corroded than for exudates / adhesive coating members of the corrosion model. The combined strength of corroded and coated specimens showed a greater affinity for coated compared to corroded specimens.

Charles et al [16] investigated the effect of exudates/resins in preventing corrosion attack on bond strength between steel and concrete. The coated samples of non-coated and exudates/resins were embedded in different thicknesses of concrete and pooled for a 178-day corrosion acceleration process. Comparative results have shown that the values of corrosive samples have decreased but increased in corrosion and exudates/resins coated members, indicating the ability of Acacia Senegal exudates/resins to strengthen the steel coating. Overall results showed high values of pull-out bond strength and low failure load in the control and were coated on depleted samples.

Terence et al. [17] investigated the effect of inhibitors on reinforced steel coating in an accelerated experimental process of embedded steel failure bond strength over 150 days. Overall results showed high values of control and exudates/adhesive coating pull-out bond strength against corroded specimens.

Gede et al. [18] investigated the strength of the bond between the concrete and the reinforcement elasticity due to the effect of the reduction of the steel reinforcement on the saltwater presence. Artocarpus altilis exudates/resins extract enhanced reinforcing steel by 150µm, 300µm and 450µm thickness and non-coated were placed in concrete and saturated in sodium chloride for 150 days. Comparable results showed that the values of the applied load are reduced in non-coated (corroded) and coated samples increased. The overall results showed high values of the strength of the controlled binding bonds and the coating exudates/resins over corroded samples due to fibre and diameter reduction from the effect of corrosion.

2.0 Test Program

The research investigated the coating of exudates/resins paste extracted from plant trunks on reinforcing steel. Varying coating thickness was introduced to the reinforcing steel, embedded into concrete cubes.

Corrosion acceleration process of the introduction of sodium chloride (NaCl) as corrosive media into the environment with a view to determining the potential of the use of environmentally friendly and widely available materials in controlling the modification effects usually encountered by reinforcing concrete structures in the marine and coastal environment. The test sample represents the level of harsh acidic, which indicates 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 specimens were designed with 36 reinforced concrete cubes of dimensions 150 mm × 150 mm x 150 mm, with the embedment of 12 mm in diameter centrally for all controlled, uncoated, and coated specimens for pullout bond testing and are immersed in sodium chloride for 360 days after initial cube curing for 28 days. Acidic corrosive media solutions were changed monthly and concrete samples were reviewed for high performance and examination on modifications.

2.1 Materials and methods for testing

2.1.1 Aggregates

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

2.1.2 Cement

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

2.1.3 Water

The water samples were clean and free from contaminants. Freshwater was obtained from Bori, Civil Engineering Laboratory, Kenule Beeson Saro-Wiwa Polytechnic. Water fulfills (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) Boswellia dalzielii Hutch

The tree barks yielded whitish gummy Exudates / Resins. They are gotten from tree trunks by tapping from Ardo-Kola Village in Ardo Kola Local Government of Taraba State, Nigeria

2.2 Test Procedures

Corrosion acceleration was tested on high-yielding steel (reinforcement) with a diameter of 12 mm and a length of 650 mm. Coated with 150µm, 300µm, 450µm, and 600µm 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 trial regime allowed 360 days of monthly routine monitoring. The cubes for the corrosion-acceleration samples were taken at 90 days, 180 days, 270 days, and 360 days at approximately 3 months intervals, and the failure bond loads, bond strength, maximum slip, reduction/increase of cross-section area, and weight loss/steel reinforcement are explored.

2.3 Accelerated corrosion setting and testing method

In real and natural phenomena, the manifestation of corrosion effects on reinforcement embedded in concrete members is very slow and can take many years to achieve; but the laboratory-accelerated process will take less time to accelerate marine media. Immerse 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/resins coated samples.

2.4 Pull-out bond strength test

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

2.5 Tensile strength of reinforcement bars

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

3.1 Experimental Discussion

The main assumption in reinforced concrete structures is that there is a perfect bond between the reinforcement and the surrounding concrete to accommodate this difficulty posed by corrosion attacks. The full relationship does not exist and this further reduces the effectiveness of the relationship due to the deterioration that kicks against this assumption, the effects of which are not fully understood. Reinforced concrete structures deteriorate during their lifetime. This is especially evident in buildings that are submerged in uneven terrain leading to heavy metal reinforcement. Corrosion protection, improved concrete properties, and additional concrete coatings increase the protection of the concrete in the reinforcement. Based on this innovative approach, the introduction of extracts known as exudate/resin was introduced to enhance the bonding properties between concrete and steel and thus act as anti-corrosion agents to prevent the impact of corrosion reinforcing metal exposed to media spread.

The experimental data as presented in Tables 3.1, 3.2, and 3.3, summarized in Tables 3.4 and 3.5 were the results obtained from 36 concrete cube samples as described in the experimental procedures, 12 controlled concrete cube samples were immersed in freshwater that fulfills (BS 3148[21]) requirements for 360 days, and the second parts are 12 uncoated and 12 coated reinforcing steel with exudates/resin samples all immersed in 5% aqueous sodium chloride (NaCl) solution for 360 days and carefully monitored their performance, with a three-month spaced test of 90 days, 180 days, 270 days, and 360 Days. Indeed, the manifestation of corrosion is a long-term process that takes decades to fully function, but the introduction of sodium chloride causes the appearance of corrosion in the short term. The experimental work represented the high-salt ocean media and the possible use of boswellia dalzielii hutch exudate/resin extract as a barrier to prevent corrosion and the risk of corrosion impact on the reinforced concrete structure exposed or built within this severe corrosive coastal region.

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

Sample Numbers	BDHC	BDHC1	BDHC2	BDHC3	BDHC4	BDHC5	BDHC6	BDHC7	BDHC8	BDHC9	BDHC10	BDHC11
	Time Interval after 28 days curing											
Samplings and Durations	**Samples 1 (28 days)**			**Samples 2 (28 Days)**			**Samples 3 (28 Days)**			**Samples 4 (28 Days)**		
Failure Bond Loads (kN)	29.685	27.596	28.160	28.756	29.571	29.272	29.795	29.613	29.678	31.489	30.613	30.814
Bond strength (MPa)	10.668	11.560	10.058	10.988	11.361	12.284	12.378	11.707	11.742	12.448	11.759	12.306
Max. slip (mm)	0.102	0.107	0.101	0.102	0.117	0.120	0.104	0.105	0.109	0.116	0.120	0.105
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)	11.994	11.993	12.004	12.003	11.993	12.003	12.003	12.000	12.003	11.993	12.002	12.004
Rebar Diameter- at 28 Days Nominal(mm)	11.994	11.993	12.004	12.003	11.993	12.003	12.003	12.000	12.003	11.993	12.002	12.004
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)	0.585	0.583	0.585	0.586	0.585	0.592	0.584	0.584	0.585	0.585	0.584	0.587
Rebar Weights- at 28 Days Nominal(Kg)	0.585	0.583	0.585	0.586	0.585	0.592	0.584	0.584	0.585	0.585	0.584	0.587
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3.2: Results of Pull-out Bond Strength Test (τu) (MPa) 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)	16.218	15.530	15.820	15.263	14.511	15.378	14.957	15.265	14.963	16.198	15.077	15.811
Bond strength (MPa)	7.867	7.878	7.642	7.864	7.631	7.603	7.402	8.090	7.065	7.554	7.401	7.714
Max. slip (mm)	0.082	0.085	0.086	0.095	0.085	0.089	0.088	0.078	0.084	0.085	0.086	0.077
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)	11.994	12.005	11.996	11.995	11.984	12.005	11.995	11.992	11.995	11.986	11.984	11.996
Rebar Diameter- After Corrosion(mm)	11.945	11.956	11.946	11.946	11.935	11.956	11.946	11.943	11.946	11.937	11.935	11.947
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049
Rebar Weights- Before Test(Kg)	0.594	0.587	0.587	0.587	0.586	0.586	0.588	0.588	0.589	0.587	0.585	0.594
Rebar Weights- After Corrosion(Kg)	0.526	0.525	0.526	0.524	0.525	0.524	0.526	0.525	0.525	0.523	0.528	0.526
Weight Loss /Gain of Steel (Kg)	0.067	0.061	0.061	0.063	0.060	0.061	0.061	0.062	0.064	0.063	0.058	0.068

Table 3.3: Results of Pull-out Bond Strength Test (τu) (MPa) of Boswellia Dalzielii Hutch Exudate / Resin (Steel Bar Coated Ppecimen)

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)	30.706	28.617	29.181	29.777	30.592	30.293	30.817	30.634	30.699	32.510	31.634	31.836
Bond strength (MPa)	12.521	13.413	11.911	12.841	13.214	14.137	14.231	13.561	13.595	14.301	13.612	14.159
Max. slip (mm)	0.123	0.125	0.115	0.120	0.119	0.118	0.131	0.135	0.143	0.141	0.145	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	11.954	11.966	11.955	11.955	11.975	11.965	11.962	11.965	11.964	11.955	11.966
Rebar Diameter- After Corrosion(mm)	12.021	12.021	12.031	12.030	12.021	12.030	12.031	12.027	12.030	12.021	12.030	12.028
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.065	0.066	0.065	0.075	0.065	0.055	0.065	0.065	0.065	0.056	0.074	0.062
Rebar Weights- Before Test(Kg)	0.587	0.588	0.587	0.588	0.586	0.586	0.585	0.588	0.586	0.587	0.585	0.589
Rebar Weights- After Corrosion(Kg)	0.672	0.666	0.665	0.666	0.664	0.672	0.664	0.665	0.665	0.665	0.663	0.667
Weight Loss /Gain of Steel (Kg)	0.087	0.077	0.078	0.079	0.077	0.085	0.664	0.665	0.665	0.665	0.663	0.667

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)	28.480	29.200	29.695	30.972	15.856	15.050	15.062	15.696	29.501	30.221	30.717	31.993
Bond strength (MPa)	10.762	11.544	11.942	12.171	7.796	7.699	7.519	7.556	12.615	13.398	13.796	14.024
Max. slip (mm)	0.103	0.106	0.106	0.114	0.084	0.090	0.083	0.082	0.121	0.119	0.136	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)	11.997	12.000	12.002	12.000	11.998	11.995	11.994	11.989	11.959	11.962	11.964	11.962
Rebar Diameter- After Corrosion(mm)	11.997	12.000	12.002	12.000	11.949	11.946	11.945	11.940	12.024	12.027	12.029	12.026
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.049	0.049	0.049	0.049	0.065	0.065	0.065	0.064
Rebar Weights- Before Test(Kg)	0.584	0.588	0.584	0.585	0.589	0.586	0.588	0.588	0.587	0.587	0.587	0.587
Rebar Weights- After Corrosion(Kg)	0.584	0.588	0.584	0.585	0.526	0.525	0.526	0.526	0.667	0.667	0.664	0.665
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.063	0.062	0.062	0.063	0.081	0.080	0.664	0.665

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)	79.617	94.014	97.156	97.329	-46.25	-50.19	-50.96	-50.94	86.058	100.799	103.936	103.836
Bond strength (MPa)	38.050	49.938	58.828	61.072	-38.20	-42.53	-45.49	-46.12	61.822	74.008	83.475	85.598
Max. slip (mm)	22.740	33.456	27.275	37.696	-30.54	-24.74	-38.98	-42.38	43.984	32.883	63.899	73.561
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)	0.041	0.042	0.047	0.033	0.331	0.274	0.251	0.225	0.330	0.274	0.250	0.224
Rebar Diameter- After Corrosion(mm)	0.400	0.453	0.478	0.504	-0.623	-0.675	-0.699	-0.717	0.627	0.679	0.704	0.722
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	-24.93	-24.34	-24.53	-23.29	33.218	32.171	32.511	30.372
Rebar Weights- Before Test(Kg)	0.307	0.275	0.327	0.353	0.329	0.291	0.244	0.307	0.328	0.291	0.244	0.306
Rebar Weights- After Corrosion(Kg)	11.096	12.034	11.174	11.364	-21.19	-21.35	-20.89	-20.97	26.902	27.145	26.419	26.535
Weight Loss / Gain of Steel (Kg)	0.000	0.000	0.000	0.000	-21.64	-23.40	-24.60	-24.53	27.620	30.560	34.602	35.916

3.2 Failure load, Bond Strength, and Maximum slip

The bonding process in reinforced concrete structures is offered in two ways; bonding and chemical adhesion to the reinforcing steel interface, and mechanical bonding between the rib cuffs and the concrete (Park and Paulay [24]). Chemical adhesion is a key means of resisting ribless bars, which also withstand limited mechanical interactions due to the size of the bar area. The mechanical connection works to withstand the movement of the bar by providing normal pressure on the surface of the ribs interface in the grip areas. This force is transferred to the surrounding concrete, which then resists the concrete bond, composite bonding, and mechanical bonding strength. The improvement of these factors is been studied in this work with the introduction of exudate/resin extracts from eco-friendly materials of inorganic origin to improve the bonding properties and as well a reduction in corrosion effect of reinforced concrete structures exposed to corrosive media.

The results of failure bond load, bond strength, and maximum slip made on 36 concrete cubes as presented in Tables 3.1, 3.2, and 3.3 and furthered in 3.4- 3.5 and were listed graphically in figures 1 - 6b. The results obtained were 12 controlled, 12 uncoated, and 12 coated samples as described in Test Program in section 2.0. Samples were stressed to failure state on a load of 50kN in Instron Universal Testing Machines as described in the testing process. The minimum and maximum values obtained of average and the percentile results of the failure load are controlled 28.48kN and 30.972kN and percentiles summed to 79.617% and 97.329%, corroded samples are 15.05kN and 15.856kN and percentiles summed to -50.965% and -46.253%) and coated samples are 29.501kN and 31.993kN and percentiles summed to 86.058% and 103.936%. Bond strength values of controlled samples are 10.762MPa and 12.171MPa and percentiles summed to 38.05% and 61.072%, the corroded samples are 7.519MPa and 7.796MPa and percentiles summed to -46.12% and 38.204%) and the coated samples are 12.615MPa and 14.024MPa and percentiles summed to 61.822% and 85.598%. The results of the maximum slip are controlled 0.103mm and 0.106mm and percentiles summed to 22.74% and 37.696%, corroded 0.082mm and 0.09mm and percentiles summed to -42.383% and -24.746%), and 0.119mm and 0.143mm and percentiles summed to 32.883% and 73.561%).

From the result presented in Table 3.4 the average values based on Tables 3.1, 3.2, and 3.3, and finally to 3.5 from 3.4 to percentile differences, bond failure maximum comparative value is controlled 97.329% as against the corroded -46.253% and coated 103.936%. The computed results showed the lower failure load application on the corroded sample with decreased percentile compared to the reference range and of coated samples, while coted has closed value to reference range of controlled samples, both showed higher failure on application. The bond strength maximum values in comparison are controlled 61.072%, corroded -38.204%, and coated 85.598%. Results showed lower failure bond strength in corroded as against controlled and coated samples which higher failure strength, this indication showed the bonding positive effect of exudative materials in concrete - steel interaction.

The maximum slip recorded peak values on comparison for samples controlled is 73.561%, corroded -24.746%, and coated 37.696%. Results showed lower slippage in the corroded sample as against controlled and coated samples with higher slippage force before failure, this factors showed the effect of corrosion on the mechanical properties of reinforcing steel showing the interactive relationship of concrete and steel to slippage and as well as the negative effect of corrosion on the mechanical properties of reinforcing steel as validated by previous works of(Toscanini et al.,[14]; Otunyo and Kennedy, [13]; Gede et al., [18]; Terence et al., [17];Charles et al.,[16]; Charles et al.,[12]). The presence of corrosion reduced the efficiency of the material used by reducing the mechanical properties by the transformation and modification of surface properties of reinforcing steel and thereby affecting the binding and interaction between the concrete and the steel reinforcement.

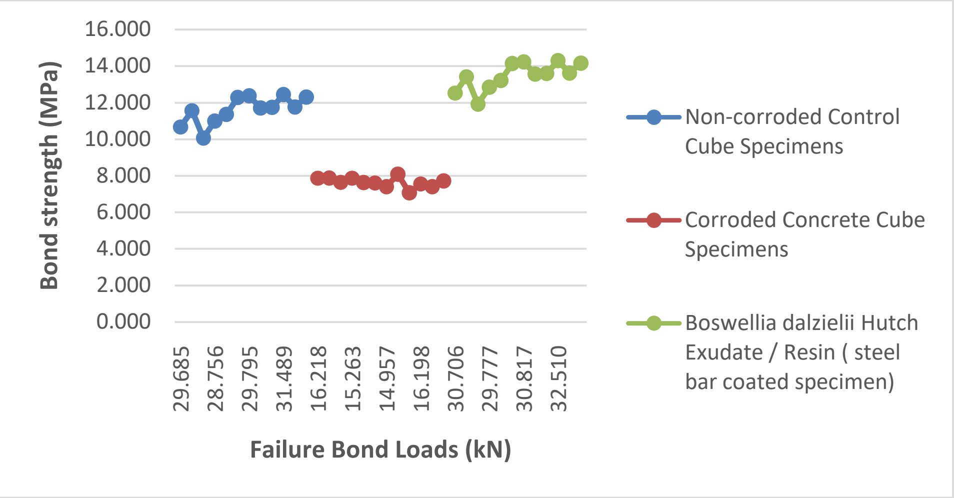

Fig.1. Failure Bond loads versus Bond Strengths

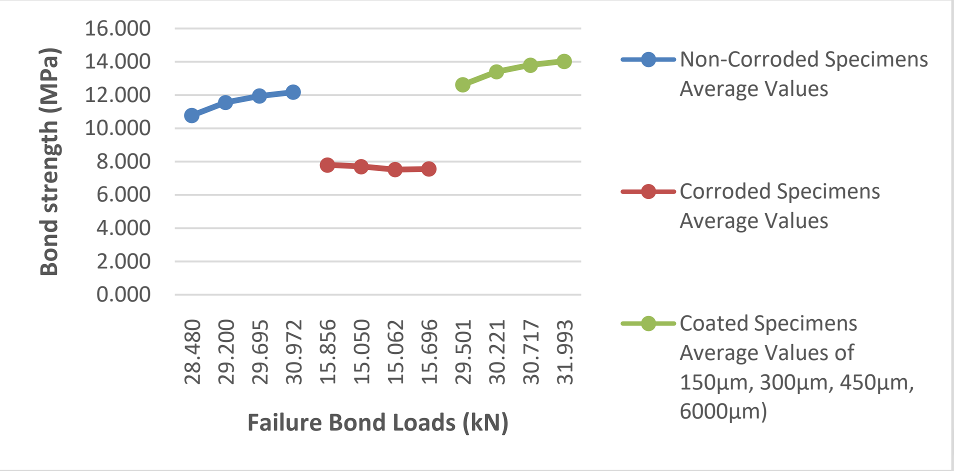

Figure 1a. Average Failure Bond loads versus Bond Strengths

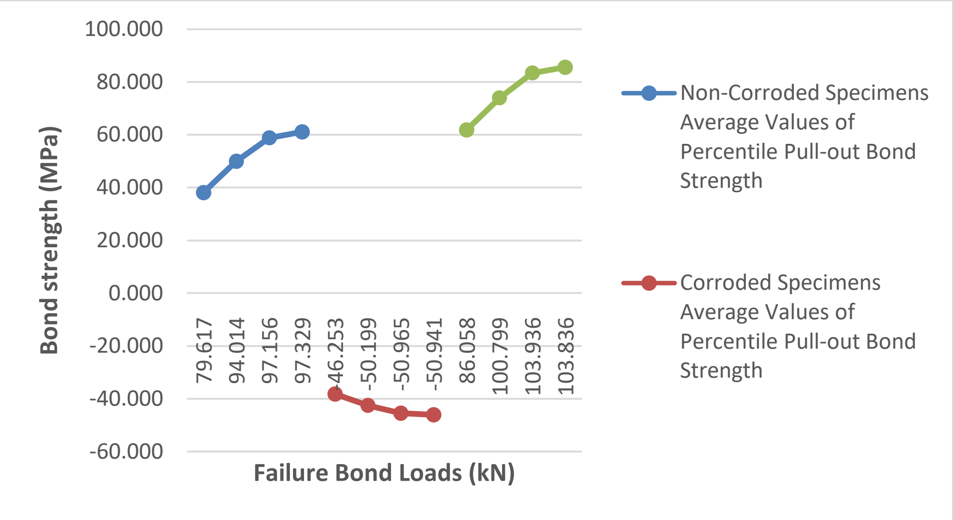

Figure 1b. Average Percentile Failure Bond loads versus Bond Strengths

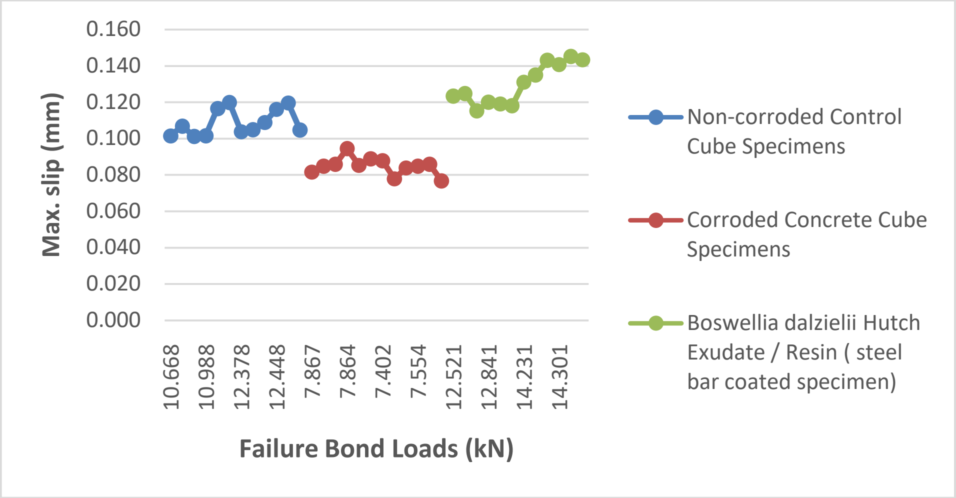

Figure 2. Bond Strengths versus Maximum Slip

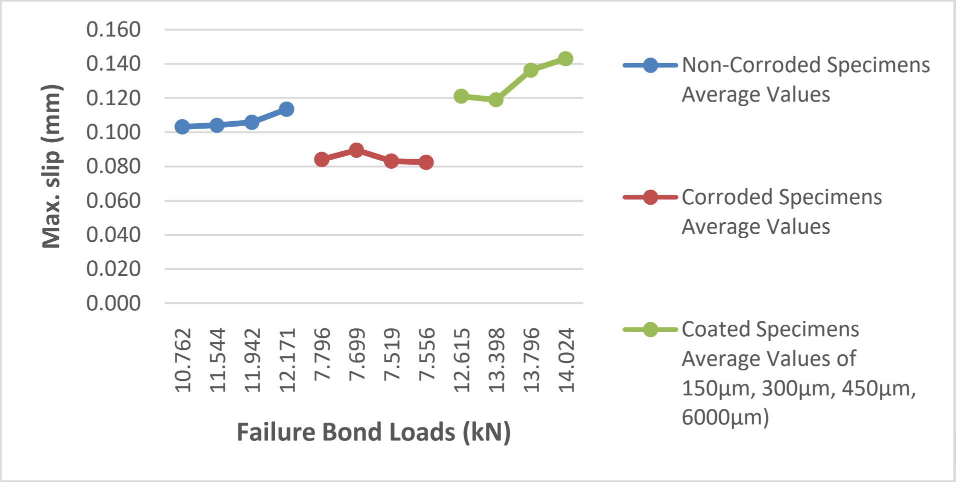

Figure 2a. Average Bond Strengths versus Maximum Slip

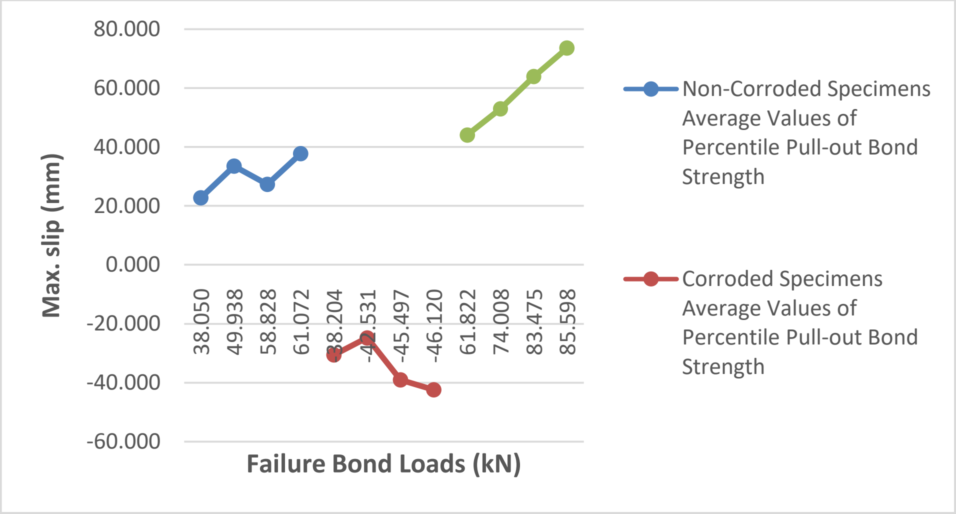

Figure 2b. Average Percentile Bond Strengths versus Maximum Slip

3.3 Mechanical Properties of Reinforcing Bars

The effects of corrosion of the bonding between concrete and reinforcing steel relationship has been widely investigated by several investigators (Almusallam et al. [25]; Lee et al. [26]; Fang et al. [27]; Fang [28]; Fang et al. [29]; Lundgren [30]) and findings recorded the ability of circular and deformed barriers increased under minimal corrosion of cross-sectional by <5% loss. A significant increase in bond strength was seen with round bars compared to the deformed bars and was due to their reliance on slide resistance in contrast to the deformed bars where mechanical ribs provided the main type of resistance. This research tends to fix the gap of low rib and ribless reinforcing steel and to curb the effect of corrosion with the introduction of exudate/resin to improve the bond relationship between concrete and steel interface and the problem of slipperiness encountered with the smooth reinforcing steel.

The data presented in tables 3.1, 3.2, and 3.3 and averaged in table 3.4 and percentile in 3.5 accounted for the behavioral properties of the mechanical properties of the controlled, uncoated (corroded) and coated concrete cube samples exposed to accelerated corrosion-induced process for 360 days and periodic performance settings of samples at 3-month intervals as shown in the tables and plotted in figures 1-6b. The yield of the controlled samples is a value of 100%, as it is pooled in a suitable freshwater tank meeting the requirements of (BS 3148). The nominal diameter of the steel bars of all samples was 100%, and the minimum and maximum steel bar diameters measured before the test were in the range of 11.997 mm and 12.00 mm and percentile values of 0.089% and 0.093% respectively.

The diameter of the uncoated (corroded) reinforcement samples after the corrosion test were 11.94 mm and 11.949 mm and percentile values of -0.717% and -0.623%, after coating 12.024 mm and 12.029 mm and percentile values of 0.627% and 0.722%. The results of the cross-sectional area for uncoated (corroded) are 0.049 mm and 0.049 mm and percentile values of -24.935% and -23.296%), for coatings 0.064 mm and 0.065 mm and percentile values of 30.372% and 33.218%).

The results of the weight of reinforcement before testing for all samples were 0.584 kg and 0.588 kg and percentile values of 0.275% and 0.353%), the weight after the corrosion test for the corroded samples was 0.586 kg and 0.589 kg, and percentile values of 0.244% and 0.329%. The coating was 0.587 kg and 0.587 kg and percentile values of 0.244% and 27.145%) and the loss weight steel was corroded 0.062 kg and 0.063 kg and percentile values of -24.607% and -21.643%) and the coating values were 0.08 kg and 0.665 kg and percentile values of 27.62% and 35.916%). The results obtained and shown in the figure show the corrosion effect of the uncoated and coated reinforcing steel.

Comparative results of differential values for the maximum rebar diameter of uncoated decreases to -0.623% while coated sample increases by 0.722%, for the maximum corroded cross-sectional area, the value of reduction is -23.296%, and the coated sample increase by 33.218 %%, the weight loss of corroded sample decreases by -21.643% showing weight reduction (loss), and the coated sample increased by 35.916%. The data analyzed from experimental work shows that the effect of corrosion on uncoated concrete cubes causes a decrease in diameter and cross-sectional area and the same decrease in rebar unit weight, while coated concrete cubes have a diameter and cross-sectional area increases and weight gain resulting from the varying thickness coated to reinforcing steel as validated by previous works of(Toscanini et al.,[14]; Otunyo and Kennedy, [13]; Gede et al., [18]; Terence et al., [17];Charles et al.,[16]; Charles et al.,[12]).

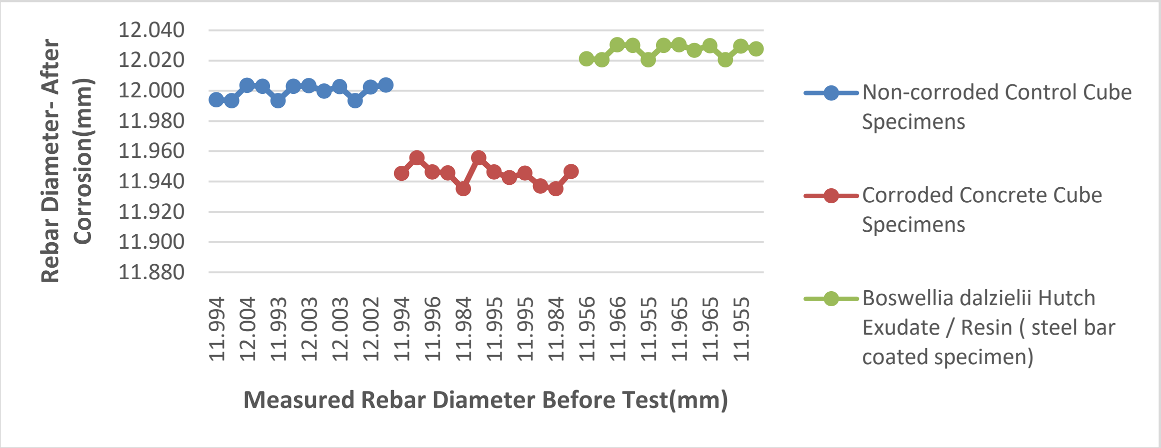

Figure 3. Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

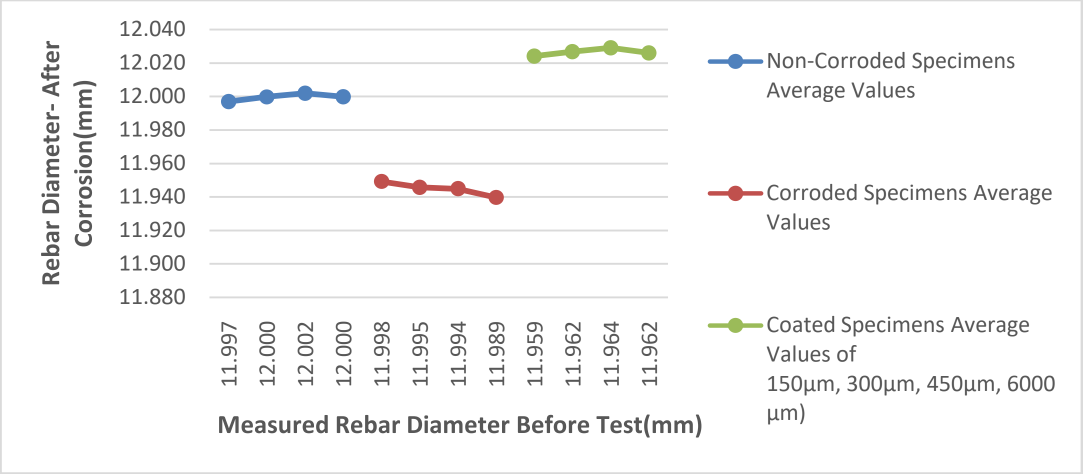

Figure 3a. Average Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion

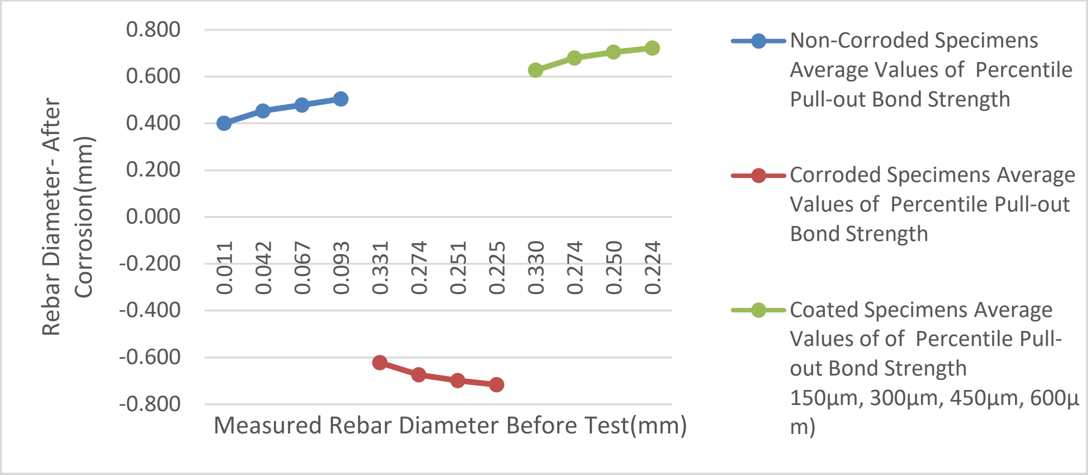

Figure 3b. Average Percentile Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion

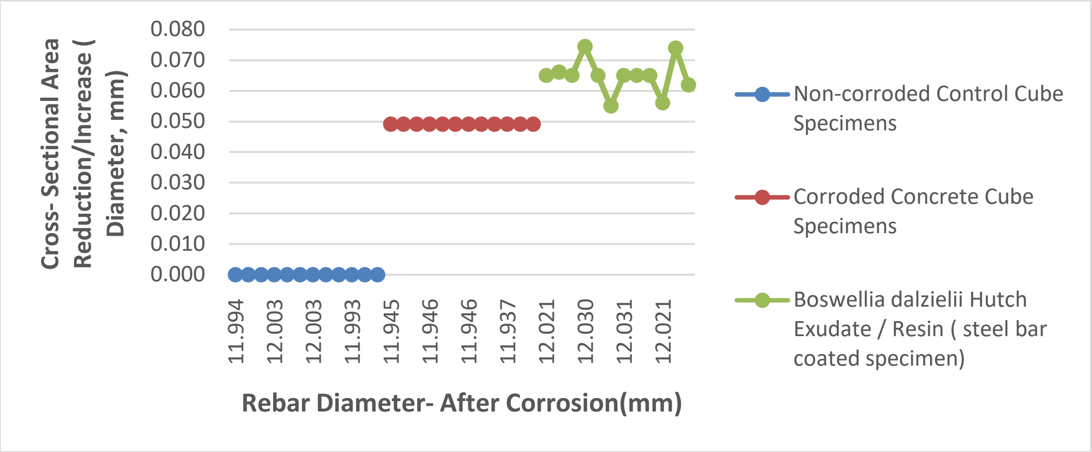

Figure 4. Rebar Diameter- After Corrosion versus Cross - Sectional Area Reduction/Increase

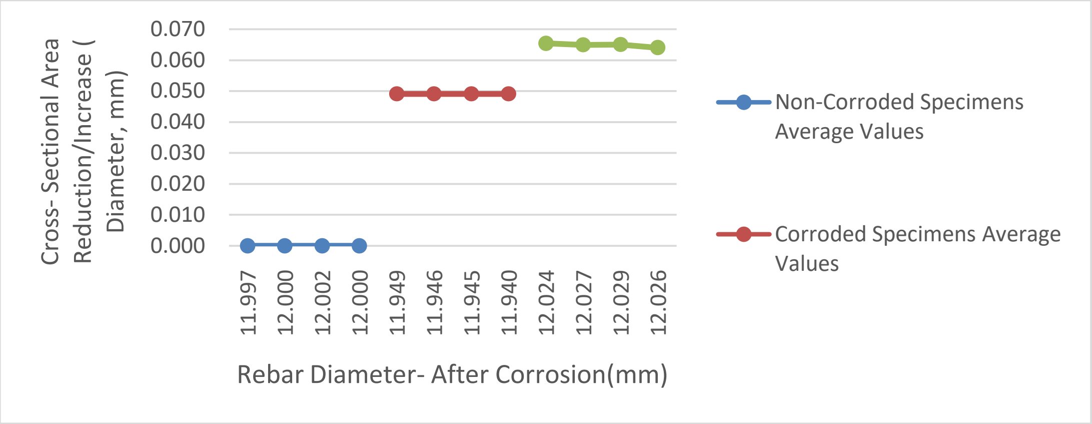

Figure 4a. Average Rebar Diameter- after Corrosion versus Cross – Sectional Area Reduction/Increase

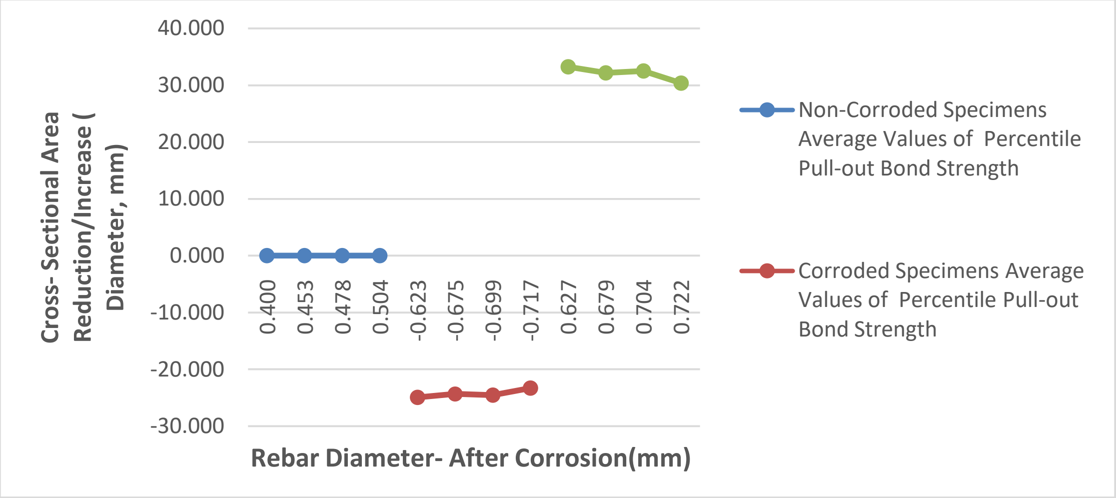

Figure 4b. Average percentile Rebar Diameter- after Corrosion versus Cross - sectional Area Reduction/Increase

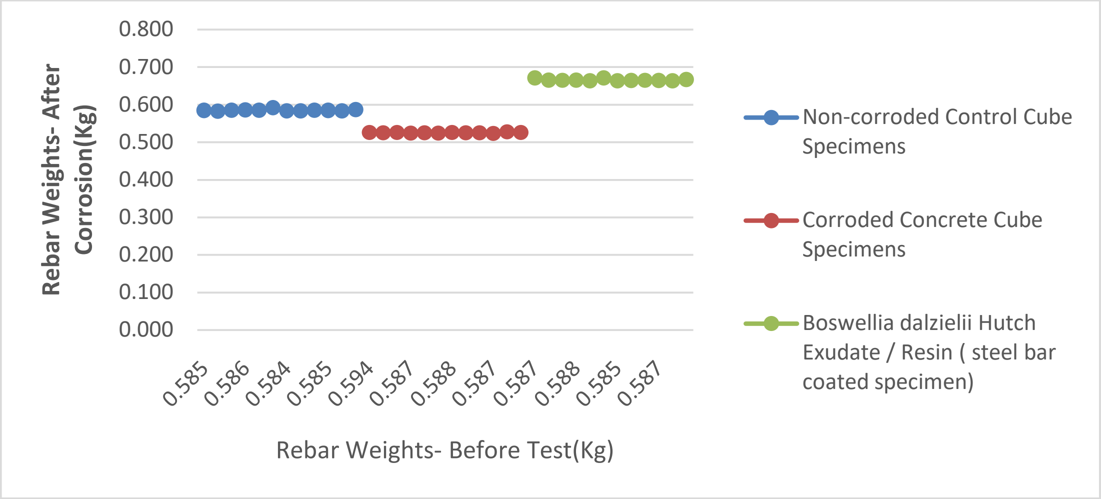

Figure 5. Rebar Weights- before Test versus Rebar Weights- after Corrosion

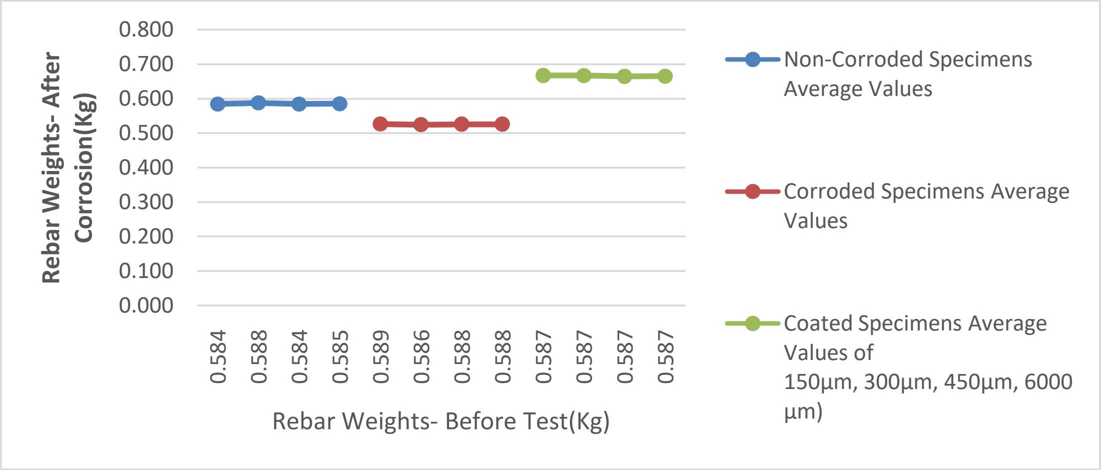

Figure 5a. Average Rebar Weights- before Test versus Rebar Weights- after Corrosion

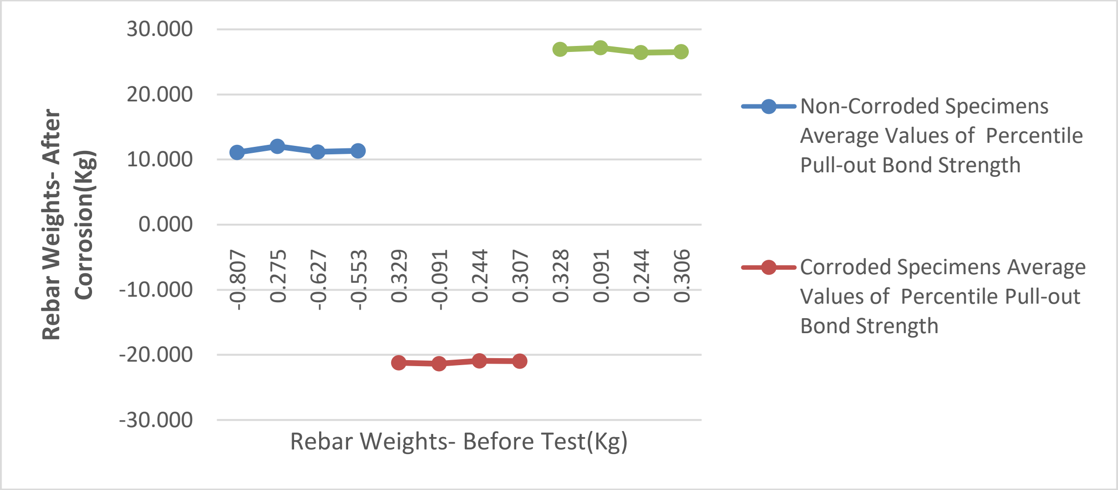

Figure 5b. Average Percentile Rebar Weights- before Test versus Rebar Weights- after Corrosion

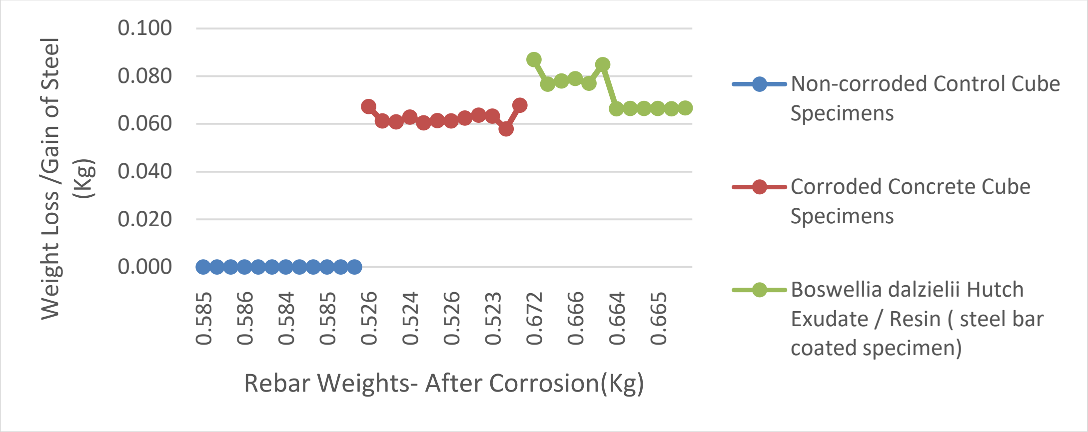

Figure 6. Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

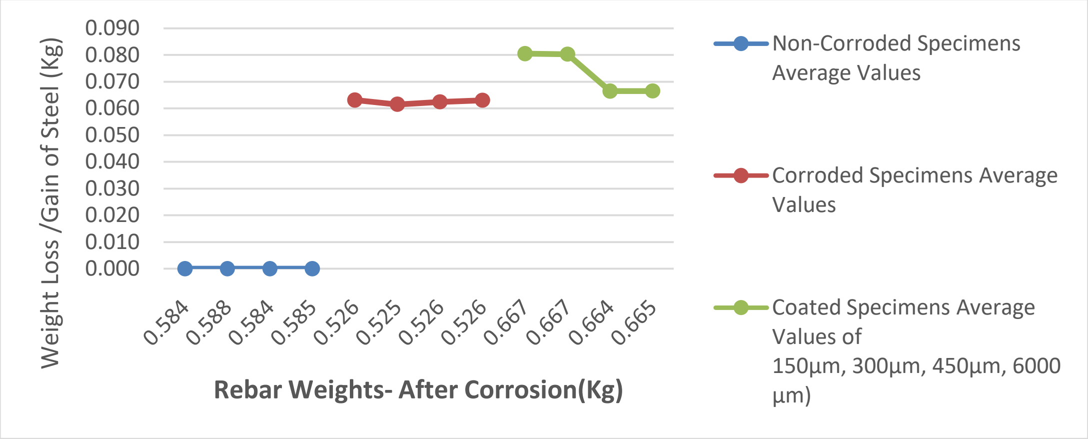

Figure 6a. Average Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

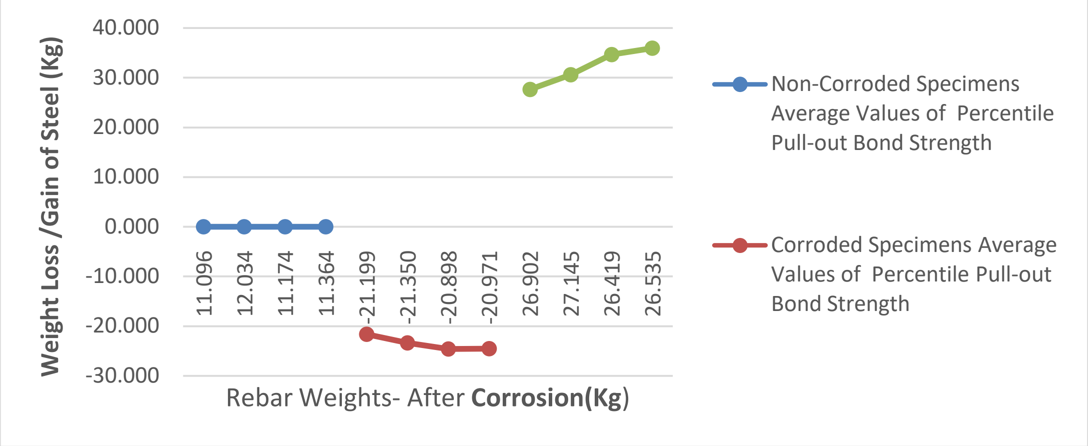

Figure 6b. Average percentile Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

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

By comparison, from the data in tables 3.1, 3.2, and 3.3 and figures 3, 4, 5, and 6, the experimental data of 36 concrete cube samples are subdivided into 3 sections of controlled, uncoated, and coated. Table 3.1 presented 12 controlled samples placed in a freshwater tank for 360 days, table 3.2 is the data for 12 uncoated samples and table 3.3 is 12 coated samples immersed in 5% sodium chloride (NaCl) aqueous solution for 360-days as described in test procedures and summarized in tables 3.4 - 3.5 with figures 3a, 3b, 4a, 4b, 5a, 5b, 6a and 6b presented graphically, The average and percentile failures for bond loads, bond strength and maximum slip, reduction/increase of cross-section, unit weight of rebar before / after corrosion and weight loss/gain. The results obtained by comparison showed that the failure bond load of controlled and coated samples has close values range while the corroded samples expressed a lower loading failure, similar features in bond strength, and a maximum slip. 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 increased values and reference state were observed in both controlled and coated samples. 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 as validated by previous works of(Toscanini et al.,[14]; Otunyo and Kennedy, [13]; Gede et al., [18]; Terence et al., [17];Charles et al.,[16]; Charles et al.,[12]). The presence of corrosion reduces the performance of the material by reducing the mechanical properties of the material by altering the surface properties and thus affecting the binding and interaction between the concrete and the steel reinforcement.

4.0 Conclusion

In experiments, the results obtained are deduced as:

i. Exudate/resin has a corrosion-resistant effect as its waterproofing does not allow for corrosion entry and attack.

ii. The interaction between the concrete and the reinforcing is greater in controlled and coated than that corroded samples.

iii. The binding characteristics of the integrated and controlled components are greater than those used

v. The coated and control sample registered the highest bond values and bond strength.

vi. Weight loss and cross-sectional reduction are mainly recorded on corroded as against in the controlled and coated samples

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