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Determination of Bond Performance Characteristics of Steel Reinforcement Pull-Out and Splitting Failure in Reinforced Concrete Members

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ABSTRACT

The interaction between concrete and reinforcing steel is expected to be cordially perfect to enable the exhibition of maximum bonding in the surrounding concrete structures. The experimental work evaluated the representation of the ideal coastal marine region of high salinity and the potential application of raphia hookeri exudate/resin extract as inhibitory material coated on reinforcing steel, embedded in concrete in curbing the scourge and menace of corrosion effect on reinforced concrete structures exposed or built within the severe and harsh region. Comparatively, an evaluation from the data for 12 controlled samples pooled in a freshwater tank, 12 uncoated and 12 coated pooled in 5% sodium chloride (NaCl) aqueous solutions all for 360 days. The results of average and percentile values for failure bond loads, bond strength, maximum slip, cross–sectional reduction/increase, and weight loss/gain obtained showed that the failure bond load for controlled and coated maintained a close range of values while corroded members yielded on lower load application, similar factors are on bond strength and maximum slip. On the mechanical properties of the reinforcing steel, the effect of corrosion on the reinforcing steel exhibited cross-section reduction on the diameter of the bar as compared to nominal diameter before the test, weight loss also notice while and coated members possess cross-sectional area increased, diameter increase and weight increase as compared to nominal rebar, these increased resulting from the coating materials varying thicknesses. It can be concluded that the studied exudate/resin showed the potency of inhibitory characteristics against corrosion attack and can be used as an inhibitor to corrosion.
Key Words: Corrosion, Corrosion inhibitors, Pull-out Bond Strength, Concrete and Steel Reinforcement

INTRODUCTION

The effect of corrosion on reinforced concrete structures has been greatly influenced by the reduction of tensile strength transfer from concrete to reinforcing steel, bonding interaction between steel reinforcements - the global phenomenon of concrete and structural behavior has been demonstrated by many experimental studies ([1], [2], [3], [4]). Bond strength originates mainly from the weak chemical bonds between steel and hardened cement, but this resistance breaks with very little pressure. Once the slip occurs, friction contributes to bonding. In plain reinforcing steel bars, friction is a major component of strength. Reinforcing the ribbed steel bars and under a growing slip bond mainly depends on the bearing or mechanical interlock between the ribs and the surrounding concrete on the surface. At this stage, the reinforcement bar produces bursting forces that divide the surrounding concrete. Corrosion can cause initial cracking, which creates tensile stress in the steel reinforcement environments in concrete, reduces the overall strength and rigidity of the concrete structures [5].

[6] Studied and evaluated the effect of corrosion of the bond between the reinforcing steel surface and the concrete interface of corroded and exudates inhibited reinforcement with resins. The test samples were subjected to bond strengths that are complex and deductive, and the results obtained showed failure load, bond strength, and high rate of penetration rates. Overall results have shown good bonding and efficiency in the use of ficus glumosa resins/exudates as protective material against corrosion.

[7] Investigated the underlying details for the reduction of service life, integrity, and strength of reinforced concrete structures in the marine environment. Comparable results showed bond yield failure, bond strength and maximum slipping decreased. The overall results showed a low percentage and a large percentage of merged members. This justifies the effect of corrosion on the strength of the composite and bonded joints.

[8] Investigated the effect of resin/exudates on the corrosion resistance of reinforced concrete cubes. The obtained results revealed that the failure bond load, bond strength, and the maximum slip of the coated resin cubes were high. Similar results were obtained with higher resin-coated and non-corroded steel reinforcement.

[10] investigated the effects of deformed and coated reinforcement on the stress generated from the bond separation of non-corrode, corroded, and resins/exudates paste coated members. The results showed that the corrosion rates increased compared with the coated models, which resulted in adhesion conditions from the resins/exudates to strengthen the reinforcement and also served as a protective coat against corrosion.

[11] Examined the bond strength of non-corroded, corroded, and exudates/resin coated samples of reinforced concrete structures of 150 mm x 150 mm x150 mm standard cubes, immersed in a corrosive medium for 150 days, with non-coated corroded and coated. Collective results demonstrated that corroded specimens with weak maximum slip during split separation testing and high failure load and lower bond strength. Non-corroded and exudates/resin-coated models have high bond strength and low failure load. Exudate/resin designs show high protective properties against corrosion effects, thereby acting as inhibitors. Exudates/resins coated specimens exhibit high-performance resistance properties for bond strength, and maximum slip with minimal failure compared to corroded specimens.

[12] Examined the effect of corrosion 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 exudates coated samples control samples increased. The overall results showed higher values of pull-out bond strength in the control and exudates/resin coated members as against corroded samples.

[13] Studied the application of environmentally-friendly corrosion inhibitors of exudates/resins from a natural source to reinforcing steel bars of 150µm, 300µm, and 450µm thickness are coated and embedded in concrete cubes, cured in fast corrosive media, and investigated pull-out bond strength parameters against non-coated ones. Relatively, the results of the corroded specimens' decreased while controlled, and cola accuminata exudates/ resins increased in steel bar coated samples. Overall results show that natural exudates/resins be explored as inhibitors for corrosion effects in steel reinforcement in concrete construction in areas where chloride is expected.

[14]) 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/resin extract of artocarpus altilis was used to enhance reinforcing steel coating with 150µm, 300 µm, 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.

[15] Explored the impact of olibanum exudates/resins in reinforcing steel corrosion in coastal zones under the influence of saltwater on concrete structures. The non-coated and exudates / resin-coated steel were embedded in concrete cubes and pooled in a corrosive medium to evaluate the effects of corrosion. Tests have shown that the values of non-coated samples have deteriorated due to the reduced corrosion attack. The average percentage bond strength load is 33.13% and the coating members are 45.66% and 71.84% compared to the control differential. The mean maximum slip values were 0.083 mm and average 33.87% and 75.30%, respectively, compared to control and finish -25.30%. Experimental results show that reduced samples have lower bond strength and higher failure bond load and lower maximum slip, while exudates/resins coated samples have lower test samples and higher percentage values compared to corrosive samples.

[16] Examined the effect of corrosion attack on Acacia Senegal exudates/resin paste coated non-coated reinforcing steel and submerged in an aggressive medium for 178 days. The obtained results showed that non-coated members failed in bond loading value against controlled and exudates/resins coated members. In comparison, the values of the corroded specimens are reduced but controlled and the exudates/resins coated members are increased, indicating the potential of acacia Senegalese.

[17]Examined the characteristics of bond strength between steel and reinforced concrete structures using corroded and khaya senegalensis inhibited reinforcing steel members, embedded in concrete members, and exposed to corrosive media. The results of the failure bond loads showed a difference of -43.62% and 77.37% and 79.67% for corrosive and coated exudates/resin members, respectively. The reduced average percentage bond strength load ranges from 57.06% to 36.33% and 106.57% in stained and coated samples. The obtained results clearly show that corrosive bond loads are higher for the corroded than for the exudates / adhesive coating members of the corrosion sample. The cohesive strength of corroded and coated specimens showed a greater affinity for coated compared to corroded specimens.

MATERIALS AND METHODS FOR EXPERINMENT

This research involves the direct application of exudates/resins tapped from plants known as inhibitors, which are coated in steel reinforcement and laboratory tested experimentally. The test specimen reflects severe acid conditions that represented sea salt concentration conditions in reinforced concrete, cubes with embedded reinforcing steel were wholly submerged and specimens maintained in pooling tank for corrosion accelerated process. Samples were designed with 36 numbers of reinforced concrete cubes of 150 mm × 150 mm × 150 mm, with a single strip of 12 mm diameter embedded centrally for pullout bond testing for controlled, non-coated, and coated samples and all immersed in sodium chloride (NaCl) for 360 days after initial 28 days curing process. Samples of acidic media were monthly renewed and samples monitored for effective performance.

Aggregates

Excellent wholesale and coarse aggregate purchased. Both met the requirements of [18]

Cement

Portland lime cement grade 42.5 is the most common type of cement in the Nigerian market. It was used for all concrete mixtures in this trial. Meets the requirements of Cement [19]

Water

The water samples were clean and free from contaminants. Freshwater was obtained from the tap at the Department of Civil Engineering Laboratory, Kenule Beason Polytechnic, Bori, Rivers State. Water [20] met the requirements

Structural steel reinforcement

Reinforcements are obtained directly from the market at Port Harcourt, [21]

Corrosion Inhibitors (Resins / Exudates) Raphia hookeri

The gum exudates/resins were obtained from the cut sections of the raffia palm tree stem inflorescent part from Ubeta forest in Ahoada – West Local Government Area of Rivers State.

Experimental procedures

Corrosion acceleration test was performed on high yielding steel (reinforcement) with a diameter of 12 mm and a length of 650 mm, the sample surface was treated with a wire brush and the samples were thoroughly cleaned with water, washed with acetone, and then coated raphia hookeri exudates/resins) pastes with varying thicknesses of 150µm, 300µm, 450µm, and 600µm coatings before testing. The test cubes were cast with a 150 mm x 150 mm x 150 mm metal mold and de-molded after 72 hours. Samples were treated at room temperature in tanks for an initial curing period of 28 days, followed by a rapid acceleration corrosion test and a trial procedure that allowed 360 days of regular monthly monitoring. For corrosion-accelerated specimens the cubes were taken approximately every 3 months at 90 days, 180 days, 270 days, and 360 days, and the gain of failure bond loads, binding strength, maximum slip, re-cross-sectional area reduction/increase, and weight loss/steel reinforcement.

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 and less time to unravel by the introduction of accelerated media representing the saltwater of the sea area. The samples were immersed in a 5% NaCl solution for 360 days to test the surface and mechanical properties of the transitions and effects and to test both the unbound and the exudate/resin coated samples.

Pull-out Bond Strength Test

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

Tensile Strength of Reinforcing Bars

Yield strength and Ultimate tensile strengths of 12 mm diameter, non-coated and coated reinforcing concrete cube members subjected to the universal testing machine for maximum failure to direct tension.

EXPERIMENTAL RESULTS AND DISCUSSION

The interaction between concrete and reinforcing steel is expected to be cordially perfect to enable the exhibition of maximum bonding in the surroundings concrete structures. The increase in deformed (rib) reinforcing bars and slip bonds mainly depends on the bearings or mechanical interlocks between the concrete around the ribs on the surface of the bar. The damaging effect from the attack by corrosion has rendered many structures unserviceable and designed life span shortened.

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

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

Sample Numbers	RHC	RHC1	RHC2	RHC3	RHC4	RHC5	RHC6	RHC7	RHC8	RHC9	RHC10	RHC11
	Time Interval after 28 days curing											
Sampling g and Durations	Samples 1 (28 days)			Samples 2 (28 Days)			Samples 3 (28 Days)			Samples 4 (28 Days)		
Failure Bond Loads (kN)	28.382	27.904	27.927	29.007	27.732	28.740	28.437	27.554	28.756	27.871	28.915	28.375
Bond strength (MPa)	8.544	8.777	8.077	7.863	8.577	8.894	9.232	9.608	8.784	8.804	9.724	9.875
Max. slip (mm)	0.102	0.107	0.102	0.102	0.117	1.000	0.104	0.105	0.109	0.117	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)	11.998	11.989	11.999	11.998	11.990	12.008	11.995	11.984	11.996	11.997	11.986	11.996
Rebar Diameter- at 28 Days Nominal(mm)	11.998	11.989	11.999	11.998	11.990	12.008	11.995	11.984	11.996	11.997	11.986	11.996
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)	0.586	0.583	0.588	0.582	0.585	0.585	0.584	0.591	0.582	0.583	0.588	0.584
Rebar Weights- at 28 Days Nominal (Kg)	0.586	0.583	0.588	0.582	0.585	0.585	0.584	0.591	0.582	0.583	0.588	0.584
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)	15.922	15.235	15.525	14.967	14.215	15.083	14.662	14.970	14.668	15.903	14.782	15.516
Bond strength (MPa)	7.187	7.197	6.961	7.184	6.950	6.923	6.721	7.410	6.385	6.873	6.721	7.033
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)	11.933	11.924	11.934	11.933	11.924	11.943	11.934	11.923	11.933	11.930	11.924	11.934
Rebar Diameter- After Corrosion(mm)	11.884	11.875	11.885	11.884	11.875	11.894	11.885	11.874	11.884	11.881	11.875	11.885
Cross- section 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)	0.559	0.560	0.560	0.558	0.561	0.561	0.561	0.561	0.560	0.562	0.559	0.559
Rebar Weights- After Corrosion (Kg)	0.507	0.513	0.507	0.509	0.509	0.508	0.516	0.506	0.507	0.513	0.508	0.510
Weight Loss /Gain of Steel (Kg)	0.052	0.047	0.053	0.049	0.052	0.052	0.045	0.055	0.053	0.050	0.051	0.049

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Table 3.3: Results of Pull-out Bond Strength Test (τu) (MPa) of Raphia hookeri Exudate / Resin (Steel Bar Coated Specimen)

Sampling and Durations	Samples 1 (90 days)			Samples 2 (180 Days)			Samples 3 (270 Days)			Samples 4 (360 Days)		
Sample	**150µm (Exudate/Resin) coated**			**300µm (Exudate/Resin) coated**			**450µm (Exudate/Resin) coated**			**600µm (Exudate/Resin) coated**		
Failure Bond Loads (kN)	27.438	25.349	25.913	26.509	27.324	27.025	27.549	27.366	27.431	29.242	28.366	28.568
Bond strength (MPa)	9.484	10.376	8.874	9.804	10.177	11.100	11.194	10.524	10.558	11.264	10.575	11.122
Max. slip (mm)	0.102	0.104	0.104	0.107	0.098	0.117	0.100	0.104	0.112	0.110	0.114	0.112
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)	11.961	11.953	11.962	11.962	11.952	11.972	11.962	11.951	11.962	11.959	11.952	11.963
Rebar Diameter - After Corrosion(mm)	12.009	12.001	12.010	12.010	12.000	12.020	12.010	11.999	12.010	12.007	12.000	12.011
Cross- section Area Reduction/Increase (Diameter, mm)	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
Rebar Weights- Before Test (Kg)	0.592	0.593	0.593	0.591	0.593	0.593	0.594	0.594	0.593	0.595	0.592	0.592
Rebar Weights- After Corrosion (Kg)	0.663	0.664	0.664	0.662	0.665	0.665	0.665	0.665	0.664	0.666	0.663	0.663
Weight Loss /Gain of Steel (Kg)	0.072	0.073	0.072	0.070	0.073	0.072	0.067	0.067	0.066	0.067	0.066	0.066

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)	28.071	28.279	28.222	28.493	15.561	15.242	14.902	14.755	26.233	25.924	26.582	26.953
Bond strength (MPa)	8.466	8.239	8.172	8.445	7.115	7.114	7.032	7.019	9.578	9.685	9.618	10.361
Max. slip (mm)	0.104	0.104	0.107	0.406	0.084	0.088	0.089	0.090	0.103	0.105	0.103	0.107
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)	11.996	11.996	11.996	11.999	11.930	11.930	11.930	11.933	11.959	11.959	11.959	11.962
Rebar Diameter- After Corrosion(mm)	11.996	11.996	11.996	11.999	11.881	11.881	11.881	11.884	12.011	12.011	12.011	12.014
Cross- section Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.049	0.043	0.049	0.049	0.052	0.052	0.052	0.052
Rebar Weights- Before Test (Kg)	0.586	0.584	0.585	0.584	0.560	0.559	0.560	0.560	0.592	0.592	0.592	0.592
Rebar Weights- After Corrosion (Kg)	0.586	0.584	0.585	0.584	0.509	0.510	0.508	0.509	0.664	0.664	0.664	0.669
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.051	0.050	0.051	0.056	0.072	0.075	0.072	0.075

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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)	80.397	85.532	89.378	93.106	-40.683	-41.203	-43.938	-45.256	68.587	70.077	78.374	82.670
Bond strength (MPa)	18.986	15.812	16.219	20.311	-25.714	-26.545	-26.893	-32.254	34.615	36.137	36.786	47.609
Max. slip (mm)	23.315	17.306	20.744	33.995	-18.662	-15.879	-14.201	-16.678	22.944	18.876	16.551	20.016
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)	0.249	0.241	0.250	0.247	0.248	0.242	0.240	0.240	0.240	0.242	0.240	0.241
Rebar Diameter-After Corrosion(mm)	0.964	0.965	0.965	0.964	-1.079	-1.081	-1.079	-1.079	1.091	1.093	1.091	1.091
Cross- section Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	-5.318	-5.318	-5.320	-5.318	5.617	5.617	5.622	5.617
Rebar Weights-Before Test (Kg)	4.599	4.477	4.561	4.303	4.479	5.482	5.480	5.479	5.797	5.800	5.798	5.797
Rebar Weights-After Corrosion (Kg)	15.014	14.666	15.091	14.754	-23.313	-23.177	-23.395	-23.357	30.400	30.169	30.539	30.474
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	-29.688	-30.608	-28.534	-28.974	42.223	44.108	39.927	40.794

Failure load, Bond Strength, and Maximum slip

Bar cladding also reduces the relative area of the ribs and reduces the transmission of forces from the concrete to the reinforcement strip due to reduced mechanical interactions. The reinforcement layer is a weak layer between the reinforcement and the surrounding concrete. The shear deformation of the layer increases the slip between the concrete and the reinforcement. Therefore, the epoxy reinforcing layer affects the bond strength and thus the usability of the reinforced concrete structure.

The detrimental effects of this coating can be minimized by (1) providing a longer joint length; (2) large reinforcement covers, and (3) side closures over the joint area as reported by the [22]. Increasing the reinforcement cover can be effective before the concrete cracks. Data presented of failure bond load, bond strength and maximum slip of shown in tables 3.1, 3.2 and 3.3 and collapsed into 3.4 and 3.5 are data obtained from experimental tested conducted on 36 averagely and randomly selected samples of concrete cube of controlled, uncoated (corroded) and coated. The pullout bond test was used to examined the performances of these samples in highly and severe harsh environment for 360 days and on documentative and test intervals of 3 months and ascertained the morphological surface changes at 90 days, 180 days, 270 days and 360 days, also studied the effects of coating thicknesses of the studied exudates / resin. The samples were pressure tested to failure in Instron Universal Testing Machine of 50kN and results digitally and systematically recorded.

The obtained computed data are summarized from tables 3.1-3.3 into 3.4 -3.5 for failure bond load with the average and percentile minimum and maximum values for evaluations are controlled 28.071kN to 28.493kN (80.397% to 93.106%), uncoated (corroded) are 14.755kN and 15.561kN (-45.256% and -40.683%) and coated are 26.233kN and 26.953kN (68.587% and 82.67%.

Bond strength results for controlled are 8.172MPa and 8.466MPa (18.986% and 20.311%) corroded are 7.032MPa and 7.115MPa (-32.254% and -25.714%) and coated are 9.578MPa and 10.361MPa (34.615% and 47.609%), results of maximum slip are controlled are 0.104mm and 0.107mm (20.744% and 33.995%), uncoated corroded are 0.084mm and 0.090mm (-18.662% and -14.201%) and coated 0.103mm 0.107mm (16.551% and 22.944%). From the result presented in tables 3.4 of average values derived from tables 3.1, 3.2 and 3.3 and summarized into 3.5 from 3.4 to percentile values difference, the failure bond load are corroded -40.683% against 82.67% and 82.67% coated and controlled respectively, this results showed an indications of low failure loads recorded in corroded, decreased values resulted from the attacks from corrosion that has affected the mechanical properties of reinforcing steel. Similarly, the bond strength maximum corroded values are corroded and maximum slip of corroded samples are -25.714%) against 20.311% and 47.609% controlled and coated. This result showed decreased and low bond strength as compared to both controlled and coated samples, attributing highest strength in coated due to the sticky and gummy characteristics exhibited exudates/resin. The maximum slip values for corroded are -14.201, coated 33.995% and controlled 22.944%. and with the indications that the higher percentile values in controlled and coated resulted to no loss of mechanical properties of reinforcing steel as against corroded with now ribs due to corrosion attack.

The result showed indications of the effect of corrosion on the failure bond load, bond strength and maximum slip as stated in the studies of ([9], [13],[18], [15]). Corrosion presence reduced the performance of corroded materials there by reducing mechanical characteristics of surface modification which affects bonding and the interaction between concrete and reinforcing steel.

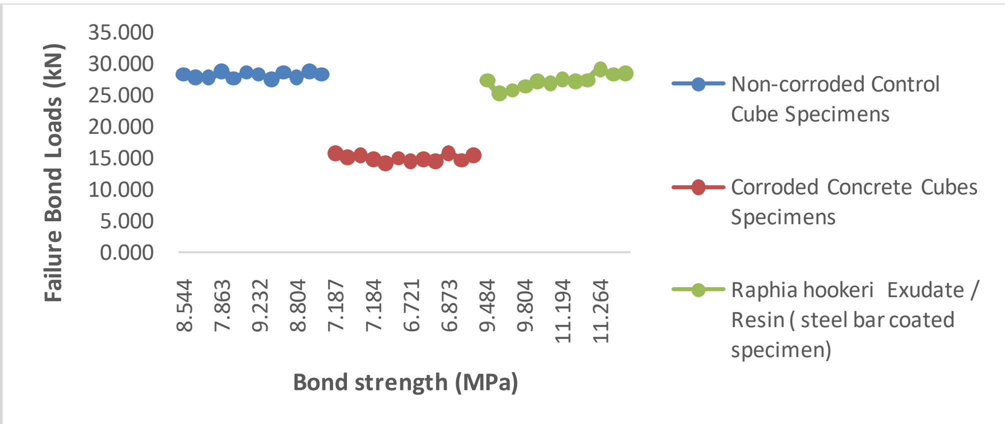

Figure 1: Failure Bond loads versus Bond Strengths

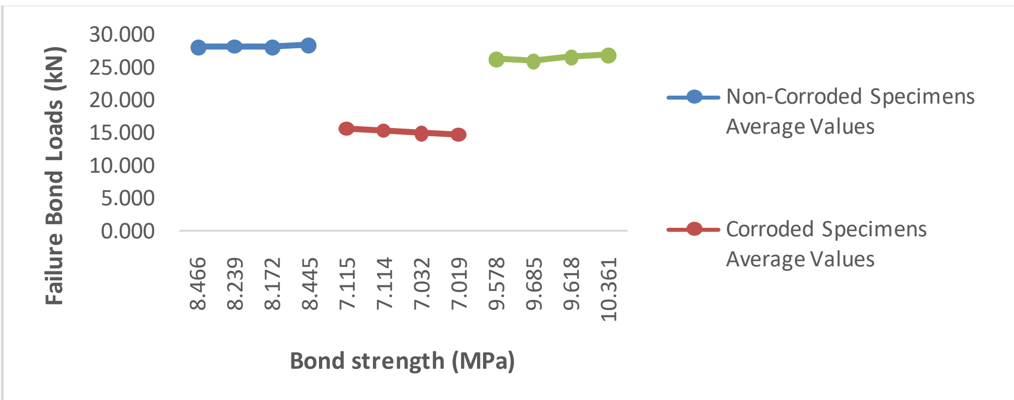

Figure 1a: Average Failure Bond loads versus Bond Strengths

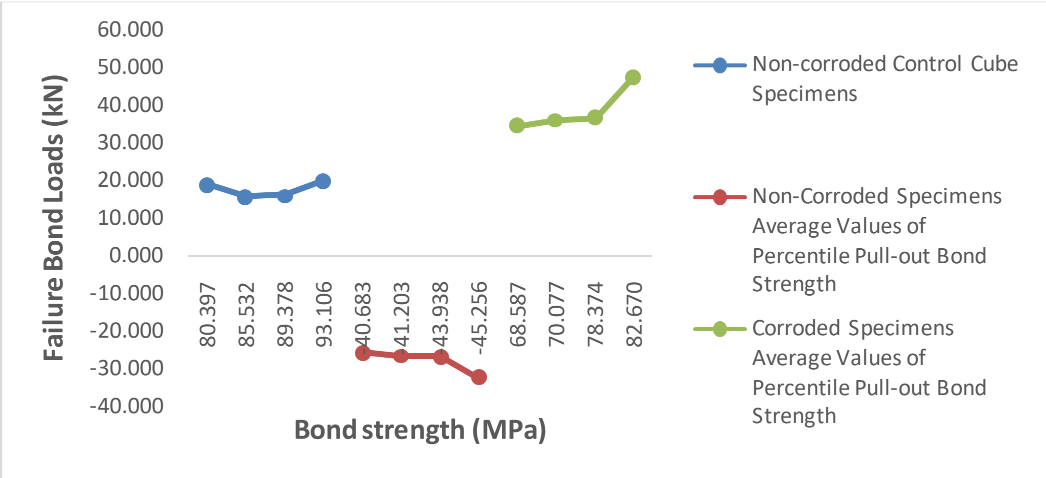

Figure 1b: Average Percentile Failure Bond loads versus Bond Strengths

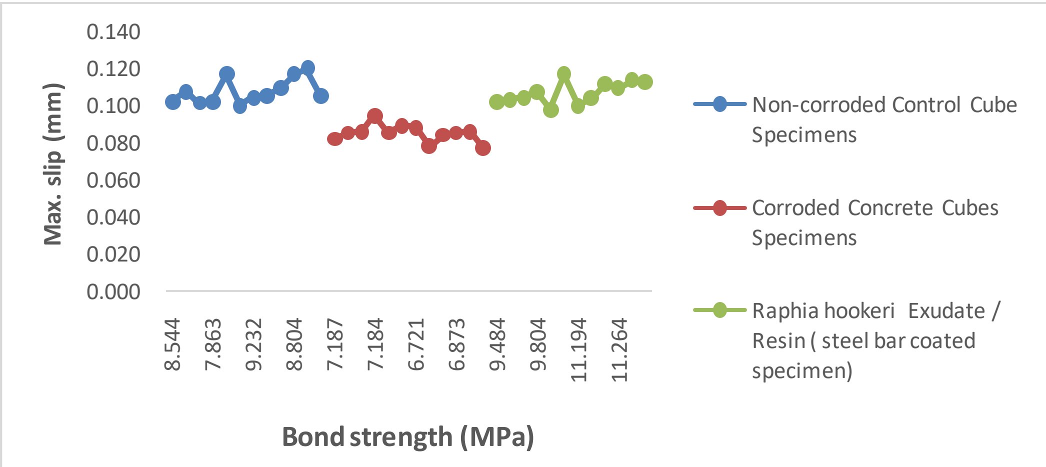

Figure 2: Bond Strengths versus Maximum Slip

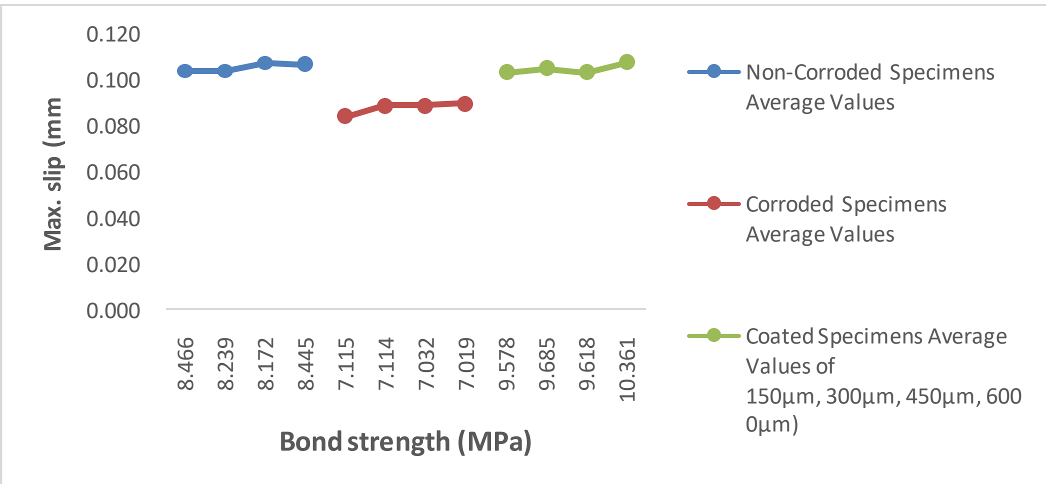

Figure 2a: Average Bond Strengths versus Maximum Slip

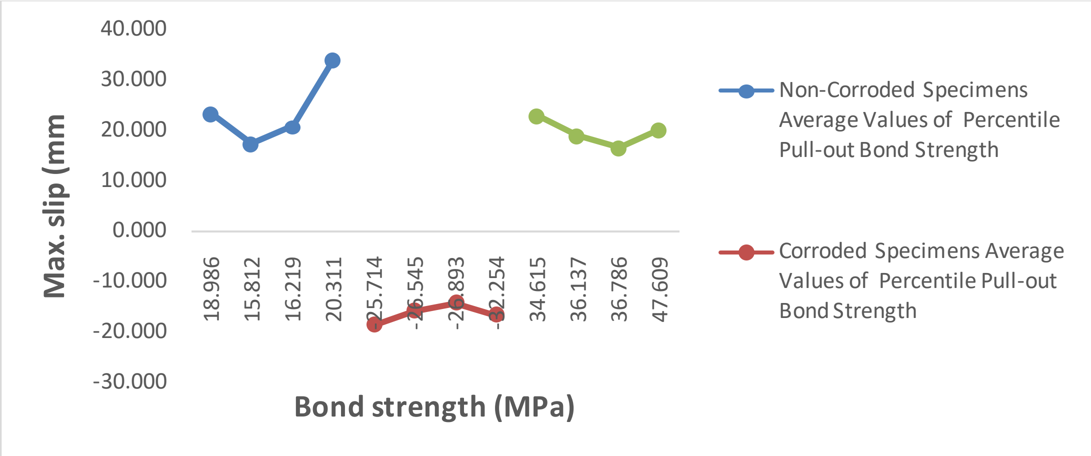

Figure 2b: Average Percentile Bond Strengths versus Maximum Slip

3.3 Mechanical Properties of Reinforcing Bars

The bond strength is mainly derived from the weak chemical bond between steel and hardened cement, but this strength is destroyed under small pressure. Once slippage occurs, friction will help bond. In smooth steel bars, friction is an important part of strength. Reinforcing steel bars with ribs under increased sliding connections mainly depend on the bearing or mechanical interlocking between the ribs and the surrounding concrete on the surface. This research introduced the application of exudates/resin to increase the slippage problem encountered by smooth reinforcing steel.

Data presented in table 3.1, 3.2 and 3.3 and collapsed into table 3.4 and further (finally) summarized into 3.5 accounted for the behavioral characteristics of the mechanical characteristics of controlled, uncoated (corroded) and coated concrete cube members subjected to failure state in Instron Universal Testing machine after corrosion accelerated induced process for 360 days and ascertained the periodic performances of the samples on an interval of 3 months respectively as stated in the tables and plotted in figures 1 – 6b. The controlled samples result are 100% values because they are pooled in tank of freshwater of compliance to (BS 3148) requirements.

The results are summarized into minimum and maximum values obtained from tables 3. 4 and 3.5.

Nominal diameter steel bars of all samples are 100%, and the minimum and maximum diameters of the steel bars measured before the test are within the range of 11.930 mm and 11.999mm (0.240% and 0.250%). The diameter of the rebar uncoated samples (corroded) after corrosion are 11.881 mm and 11.881mm (-1.081% and -1.079%), after coated are 12.011mm and 12.014mm (1.091% and 1.098 %), the uncoated coating (corrosion) is 0.049 mm and 0.047 mm (-14.634% and -14.306%) , the coating is 0.057 mm (16.951% and 17.143%) .

The results of cross - sectional area for uncoated (corroded) are 0.049mm and 0.043mm (-5.318% and -5.320%), for coated are 0.052mm and 0.058mm (5.617% and 5.622%). The result for rebar weight before test for all samples are 0.560Kg and 0.592Kg (4.303% and 5.797%), weight after corrosion test for corroded are for 0.508Kg and 0.510Kg (-23.395% and 23.313%), coated are 0.664Kg and 0.669Kg (30.169% and 30.539%) and weight loss /gain of steel are corroded 0.051Kg and 0.056Kg (-28.534% and -30.608%) and coated values are 0.072Kg and 0.075Kg (39.927% and 44.108%).

From the results obtained and presented in the figures, the effect of corrosion on uncoated and coated reinforcing steel are enumerated, in figures 3 and 6b on diameter of rebar, it can be seen that the diameter of uncoated decreased by maximum value of -1.079% and coated increased by 1.098 %, for the cross - sectional area, corroded has maximum reduction value of -5.320% and coated increased by 5.622%, weight loss and gain are corroded -28.534% decreased (loss) and coated 44.108% increase (gain). Indication as analyzed from the experimental work showed that the effect of corrosion on uncoated concrete cubes caused diameter and cross – sectional area reduction and weight decrease while coated concrete cubes have diameter and cross – sectional area increases and weight gain resulting from the varying thickness coated to reinforcing steel as stated in the studies of ([10][111][113],[115],[14]).

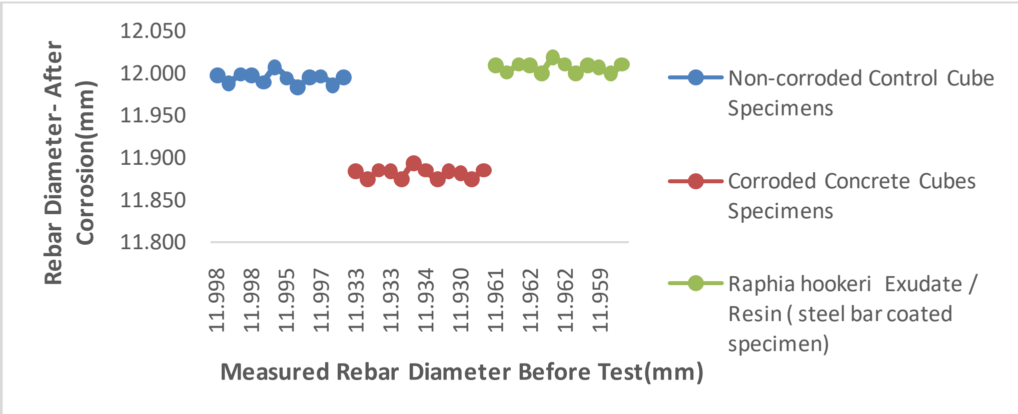

Figure 3: Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

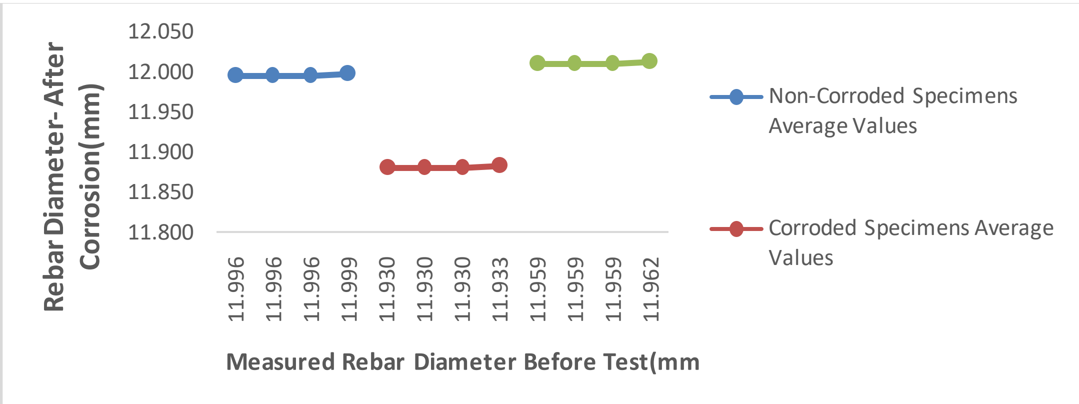

Figure 3a: Average Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

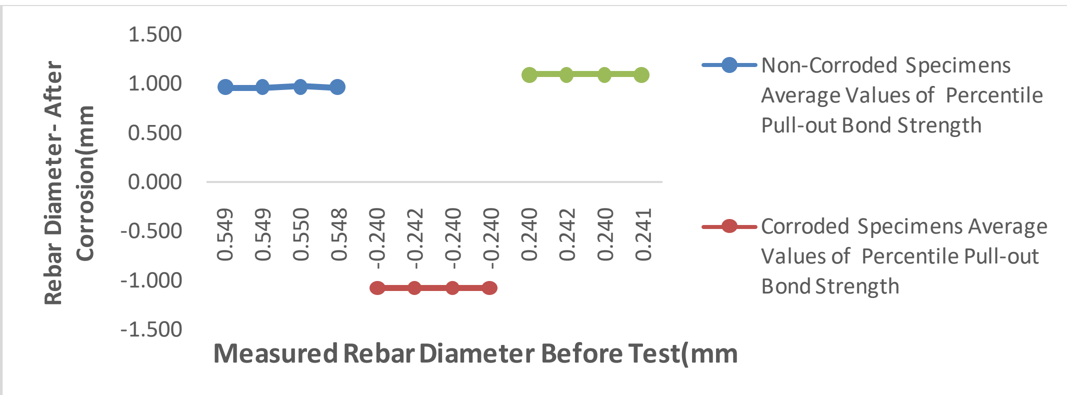

Figure 3b: Average Percentile Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

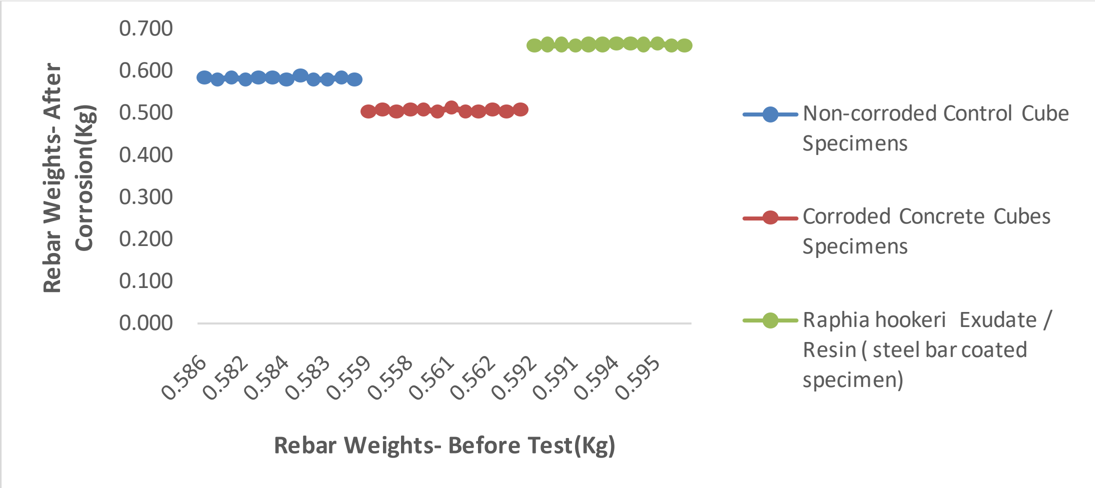

Figure 4: Rebar Diameter- after Corrosion versus Cross - Sectional Area Reduction/Increase

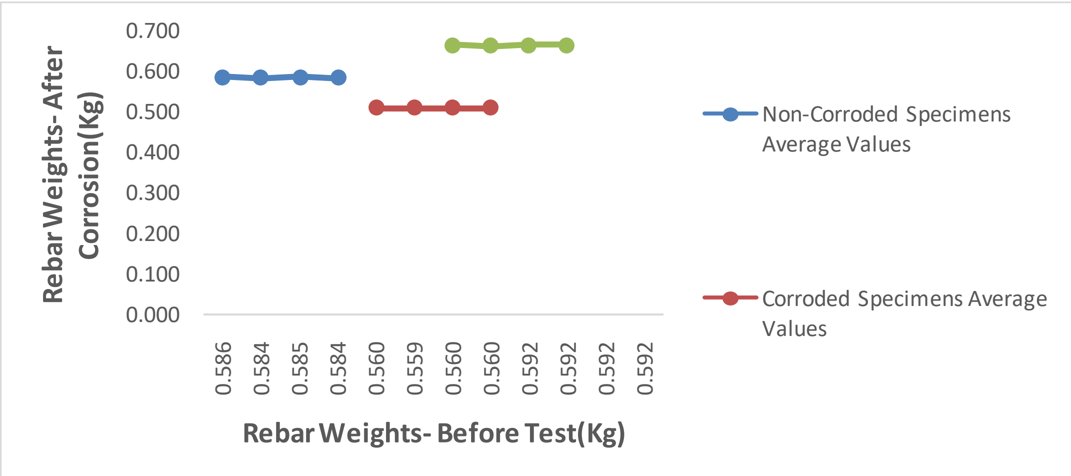

Figure 4a: Average Rebar Diameter- after Corrosion versus Cross – Sectional Area Reduction/Increase

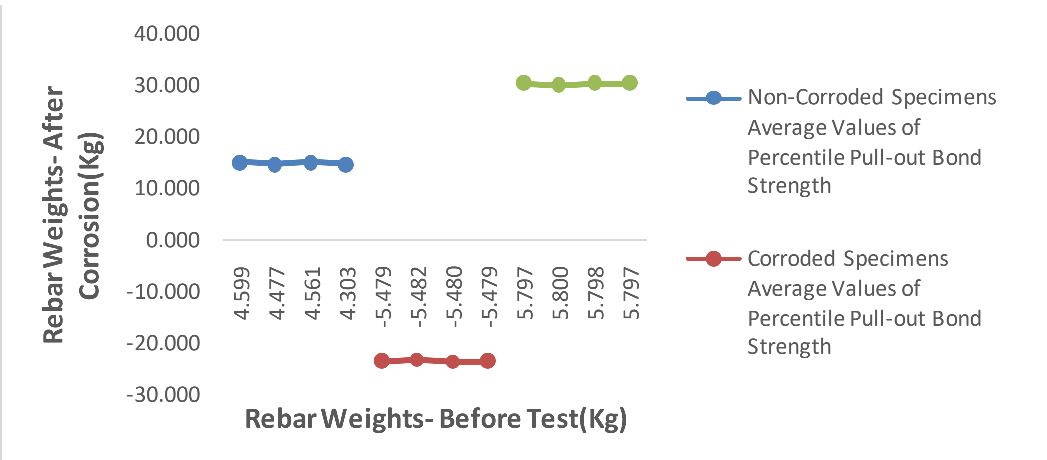

Figure 4b: Average percentile Rebar Diameter- after Corrosion versus Cross - sectional Area Reduction/Increase

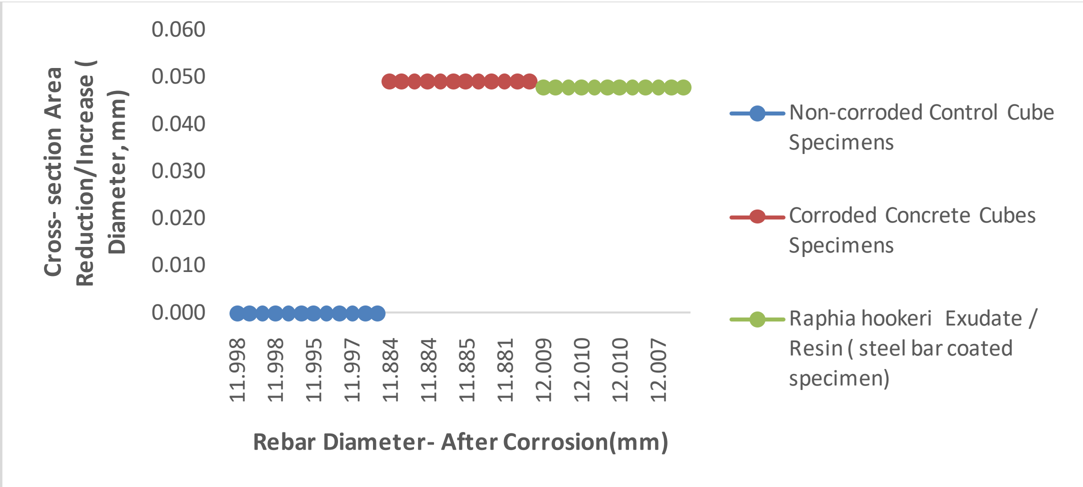

Figure 5: Rebar Weights- before Test versus Rebar Weights- after Corrosion

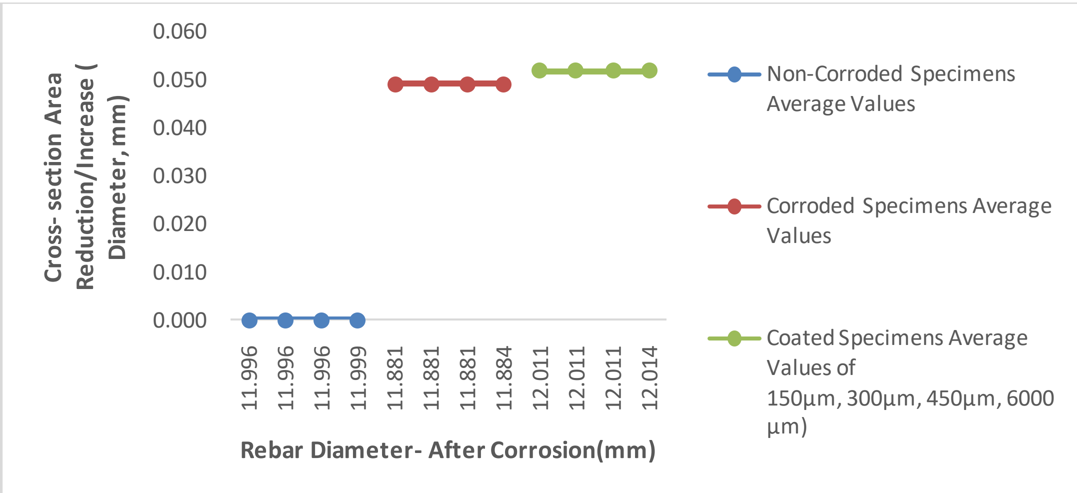

Figure 5a: Average Rebar Weights- before Test versus Rebar Weights- after Corrosion

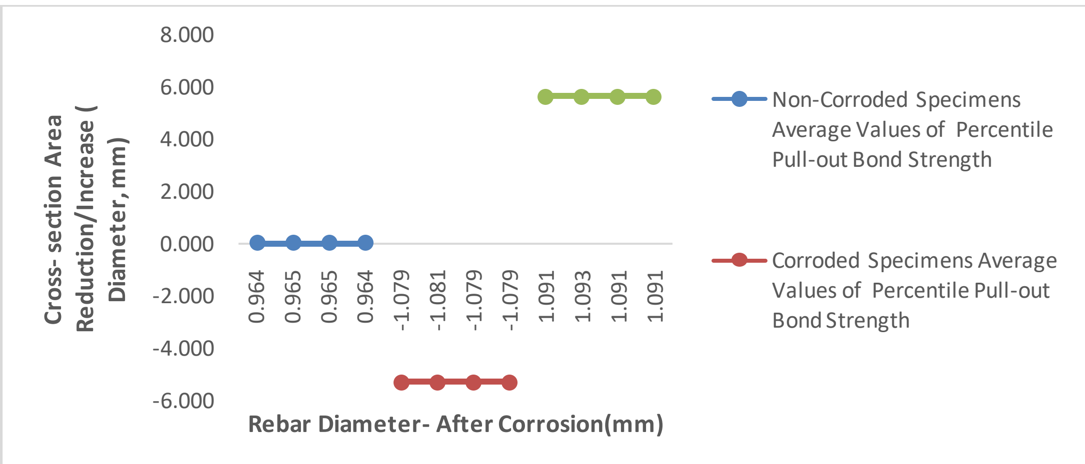

Figure 5b: Average Percentile Rebar Weights- before Test versus Rebar Weights- after Corrosion

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

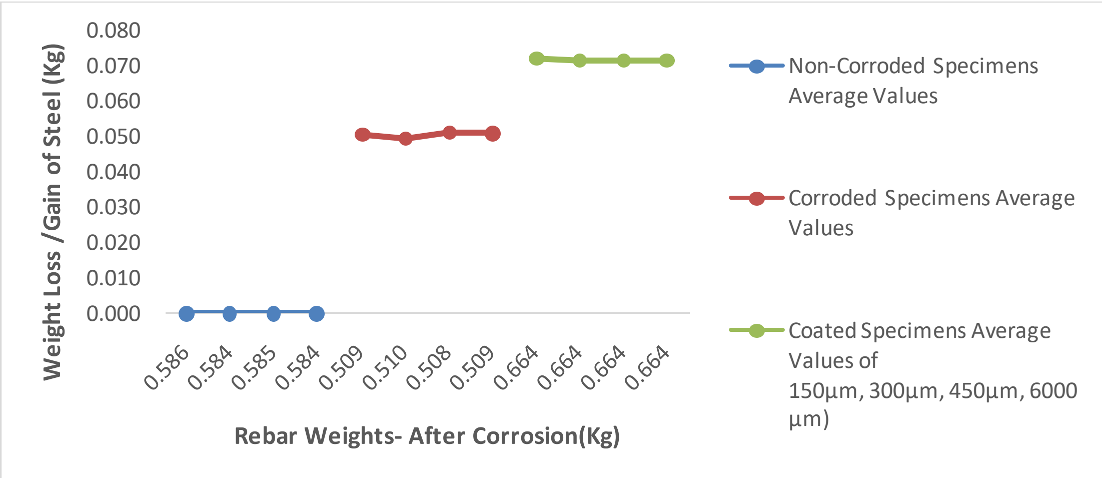

Figure 6a: Average Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

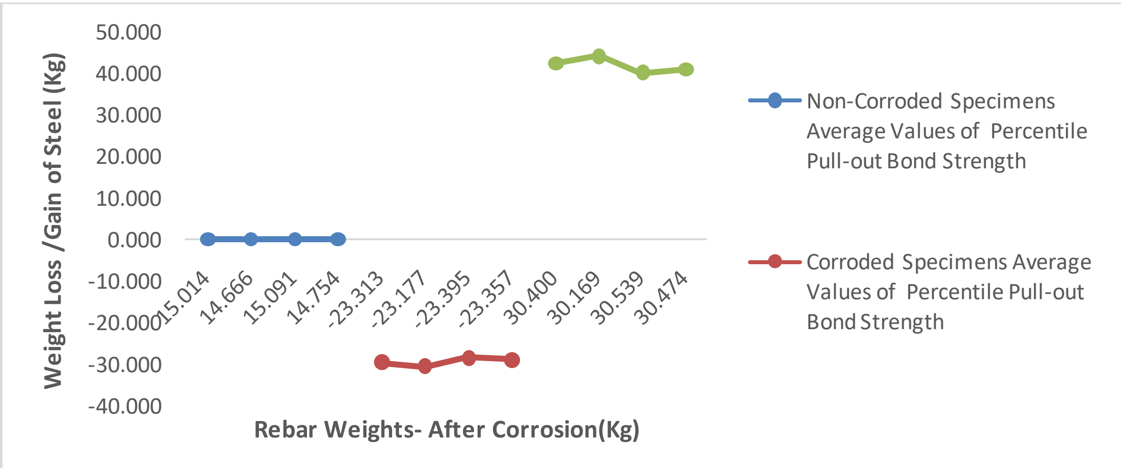

Figure 6b: Average percentile Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

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

Comparatively, from the data in tables 3.1, 3.2 and 3.3 and in figures 3, 4,5 and 6 for 12 controlled samples pooled in a freshwater tank for 360 days, 12 uncoated and 12 coated pooled in 5% sodium chloride (NaCl) aqueous solutions for 360 days ad described in 3.1 – 3.3 and summarized into tables 3.4 – 3.5 and figures 3a,3b,4a,4b,5a,5b, 6a and 6b for average and percentile values for failure bond loads, bond strength and maximum slip, cross – sectional reduction / increase, diameter of rebar before /after corrosion, weight loss/gain. The results obtained in comparison showed that the failure bond load for controlled and coated maintained close range of values while corroded members yielded on lower load application, similar factors are on bond strength and maximum slip. On the mechanical properties of the reinforcing steel, the effect of corrosion on the reinforcing steel exhibited cross – section reduction on the diameter of the bar as compared to nominal diameter before test, weight loss also notice while and coated members posses cross -sectional area increased, diameter increase and weight increase as compared to nominal rebar, these increased resulted from the coating materials varying thicknesses. It can be concluded that the studied exudate/resin showed potency of inhibitory characteristics against corrosion attack and can be used as an inhibitor to corrosion.

CONCLUSION

In the experiment, the results obtained are drawn as:

i. The exudate/resin has an inhibitory effect on corrosion as its waterproofing resisted to corrosion penetration and attacks.
ii. The interaction between concrete and steel in the coated component is greater than that in the corroded samples
iii. The properties of the bonds in the coated and controlled components are greater than those in the corroded
iv. The lowest failure bond load, bond strength, and maximum slip were recorded in corroded member
v. The coating and control sample registered higher values of bond load and bond strength.
vi. Weight loss and reduction in cross section are mainly recorded in corroded coatings and controlled samples

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