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Original Research Article

Evaluation of Pullout Bond Effects of Inhibitive and Non-Inhibitive Reinforcing Steel

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Abstract

The study examined the usefulness of exudates/resin extrudes from tree trunk as inhibitive material against corrosion attacks to reinforcing steel embedded in concrete structures and exposed to high levels of salt in coastal marine areas. The maximum recorded average and percentile values are controlled 45.546% against corroded and coated values of 36.881% and 78.747% and with differentially potential values of the bond strength controlled 1.409MPa and 19.437% against corroded values of 0.276MPa and 7.174% and coated values 1.409MPa and 20.317%. The lower load failure characteristic has been attributed to the effect of corrosion attack resulting in rib-less (smooth) and surface modification, the effect of corrosion resulted to the swollen surface with peeled off fibre while coated samples exhibited highly resistive characteristics to corrosion attacks showing the effectiveness of exudates/resin as an anti-corrosive material in curbing the scourge and menace faced by reinforced concrete structures built in the coastal the marine region with unique and severe characteristics of high salinity. Comparatively, obtained results showed decreased slippage failure load exhibition by the corroded samples over the controlled and coated samples with a highly lower value range to the reference with coated samples exhibiting higher slippage failure load with increased values over-controlled. From the result of average values and percentile values difference, the failure bond load, bond strength, and maximum slip all failed at low load applications with decreased percentile values compared to controlled and coated concrete cube samples. This reduction in rebar diameter and the cross-sectional area has resulted in higher failure bond loads, lower bond strengths, and lower slippages, and these characteristics revealed the effects of corrosion on the reinforcing steel that resulted from surface modification, reduction of rebar fibre, and high yield to load applications. 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 the diameter of rebar, it can be seen that the diameter of uncoated decreased by the maximum value of -0.841% and coated increased by 0.922%, for the cross-sectional area, corroded has maximum reduction value -20.649% and coated increased by and 26.022%, weight loss, and gain are corroded -19.905% decreased (loss) and coated 36.334% increase (gain).

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

1.0 INTRODUCTION

The major cause of the deterioration of concrete structures in today's world is the effects of corrosion. Two major causes of corrosion of concrete reinforcement are carbon dioxide and chlorine. Both of these elements cause deterioration in the reinforcing steel layer, allowing active corrosion to continue. When the corrosion of iron begins, there are many negative consequences. Corrosion products take up more space than real metal atoms. As these corrosion products increases, the area around the reinforcing steel expands. Due to the limited strength of the hardened concrete, this expansion causes cracks to grow in the concrete. Eventually, this split can extend over, allowing a clear path from the outer surface to the top of the line layer. The strength of the bonds is important for the reinforced concrete to act as a composite material. The bond between the reinforcing steel and the concrete is known to be the bond stress, as the transfer of stress load across the interface between the concrete and the reinforcing bars. It represents the interaction between steel reinforcement and the surrounding concrete [1]. In general, increasing the relative rib area of a steel bar increases bond strength

[2-4]. Deterioration of concrete by cracking can eventually lead to the concrete falling to the structure. This broader form of cracking is known as spalling. Splitting and cracking are signs of deterioration that can be seen with the naked eye. These warning signs, however, are advanced stages of rust damage. As soon as concrete begins to spread on the building, the integrity of the concrete member structure is already undermined.

Investigated the effect of different classes of deformed bar types with different rib patterns and relative rib area on bond strength [5]. It has been observed that models with steel rods having a higher rib area and exhibit higher bond stress. Steel bar size is one of the important factors influencing the bond stress between steel reinforcement and surrounding concrete. Ribbed bar affects bond strength, whereas large bar diameters develop lower bond strength compared to smaller bar diameters. This effect was identified in ACI 408 (2003) by indicating the steel bar size factor in its development length formula. Also, several researchers have investigated the effect of strengthening bar diameter on bond strength.

Attempts to draw a 175 mm × 175 mm × 350 mm concrete prism with 19 mm diameter reinforcement built into the central concrete sample [7]. The average compressive strength of concrete is 28 MPa. To speed up the corrosion process with 3% chloride by weight of cement, which is added to the concrete mix? Before the accelerated corrosion process, the concrete samples were immersed in a sodium chloride solution of up to 3% for three days. Corrosion rates ranged from 0% for control samples to 5.91% for other samples, bond strength and standard bond strength were reported as a function of percent mass loss.

Provided experimental evidence that the effect of bar size on bond strength depends on the level of constraint [8]. In their tests, it was found that the bond strength decreases with increasing bar size for models with lower constraint and separation failures, but this effect is much smaller as explained by [9, 10] reported that the diameter of the steel bar had a significant effect on bond strength.

Other factors affect the bond strength between the reinforcing bar and the concrete, including environmental impacts such as steel bar rusting. The corrosion effect of steel reinforcement on structural behavior is considered a major problem today, as evidenced by numerous experimental studies [11-15]. Also, [16, 17] reported that high/low temperatures affect bond strength.

Tensile tests were carried out on specimens of 150 mm concrete cubes. Reinforcement bars in three different sizes are planted in the center of the concrete sample [18]. The installation length of 40 mm was chosen to ensure that the cracks of the concrete sample were made from a concrete mix with a w/c ratio of 0.55 with an average compressive strength of 28 days 30MPa. The corrosion rate varied from 0% for control samples to 7.8% for other samples. The best bond strength is given for pre-cracking, cracking and cracking according to the degree of corrosion and as a function of the corrosion rate.

Reported that the residual bond strength increased when the temperature was between 50˚C and 150˚C due to an increase in the residual compressive strength. After that, the residual bond strength decreases as the temperature reaches 150˚C [19].

A tensile test was carried out on a concrete sample measuring 140 mm × 140 mm × 180 mm. Reinforcement with a diameter of 20 mm is placed in the middle of the concrete sample [20]. The average compressive strength of concrete for 28 days is 52.1MPa. The corrosion rate varied between 0% for control samples and 9% for other samples. The bonding force is given as a function of the corrosion rate for smooth and corrugated rods with and without stirrups.

Studied the use of environmentally friendly exudates/resin corrosion inhibitors from natural sources, coated with reinforcing steel with a thickness of 150μm, 300μm and 450μm and embedded in a reinforced concrete cube, hardened and accelerated on a fast corrosive medium by pulling the bonds, checking the strength parameters against non-cover [21]. In comparison, the yield of the corroded model decreased while the control and exudates/cola aluminum resin in the coated samples increased.

The effect of corrosive attack on acacia resin exudates and coated resin and uncoated reinforcing steel, embedded in a concrete cube and immersed in an aggressive environment for 178 days, was investigated [22]. The results obtained showed that the uncoated elements corroded and failed at the bond percentages of 56.61% and 59.15% compared to the controlled elements and the exudates/resin elements. The bond strength for bonding showed 83.04%, 94.92% and -45.36%, and the percentage value decreased compared to corroded and coated with exudates/resin. In comparison, the corroded sample values were reduced but coated and the exudates/resin coated elements increased, indicating the potential of Acacia Senegal as an inhibitor.

The overall results show that the exudates/natural resins have a corrosion-inhibiting effect on steel reinforcement in concrete structures in areas where chloride is expected [23]. Stated that bond strength between the concrete and the reinforcement was investigated, which led to a decrease in diameter due to the decreasing effect of the reinforcing steel from the near shore saltwater area? Application of artocarpus altilis resin extract on reinforcing steel with a layer thickness of 150µm, 300µm and 450µm and uncoated reinforcing steel immersed in a concrete cube dipped in sodium chloride and subjected to an accelerated corrosion process for 150 days. The comparison results show that the value of the corroded sample decreases and the sample coated with exudates/resin increases. Overall results showed higher tensile strength values under control and exudates/resin coated compared to corroded samples.

Investigated the effect of olibanum resin /exudates in limiting the corrosion tendency of reinforcing steel in coastal areas by the action of saltwater on concrete structures [24]. Tests show that the uncoated samples are corroded and show damaged characteristics. The average attachment strength percentile load was 331.34% compared to control difference and closed elements of 45.66% and 71.84%, respectively. The average maximum slip value is 0.083567 mm and represents 33.87% and 75.30% respectively compared to the control and coated -25.30%. The test results show that the corroded model has low bond strength and failure load. This has a high maximum slip and has a low maximum slip, while the model with exudate/resin with a lower experimental model shows that the exudate/resin has a higher percentage than the corroded sample.

The bond strength of reinforcing steel in self-compacting concrete was investigated [25]. They concluded that self-compacting concrete samples had a higher bond with reinforcement than normal concrete samples and that the relationship between bond strength and compressive strength of normal weight concrete was more consistent.

2.1 Test Program

The study examined the usefulness of exudates/adhesive/resin extrudes from tree trunk as inhibitive material against corrosion attacks to reinforcing steel embedded in concrete structures and to expose high levels of salt in coastal marine areas. Tapped exudate/resin paste was coated to reinforcing steel of different thicknesses, embedded in concrete cubes, and simulated in corrosion acceleration process of sodium chloride (NaCl) to determine the eco-friendly use of commonly available materials as to control the effects of changes commonly encountered on concrete structures at marine regions. The test sample refers to the level of hard acid, which indicates the level of sea salt concentration in the marine atmosphere 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 made of 36 reinforced concrete cubes, and the standard method of concrete mix ratio was adopted, manual batching by weight of the material. Concrete mixing ratio 1: 2: 4, water-cement ratio 0.65 by weight of concrete. Manual mixing was used on a clean concrete banker, and the mixing was inspected and water was added gradually to obtain a complete mixing design concrete. The standard uniform color and consistency were obtained by the addition of cement, water, and aggregates, concrete cubes of dimensions of 150 mm x 150 mm x 150 mm, with 12 mm diameter reinforcement embedded at the center for pullout bond test, with 360 days for immersion in sodium chloride after 28 days after initial cube treatment. Acid corrosive media solutions were modified monthly and solid samples were reviewed to explore higher efficiencies and changes.

2.1 Materials and methods for testing

2.1.1 Aggregate

Aggregates (fine and rough) were purchased. Both meet the requirements of [26]

2.1.2 Cement

Portland lime cement grade 42.5 is the most common type of cement in the Nigerian market. It was used for all concrete mixes in this test. It meets the requirements of cement [27].

2.1.3 Water

The water samples were clean and free of contaminants. Freshwater was gotten from Civil Engineering Laboratory, Kenule Beeson Saro-Wiwa Polytechnic. Water conforms to [28] requirements.

2.1.4 Structural Steel Reinforcement

Reinforcements are obtained directly from the market at Port Harcourt [29],

2.1.5 Corrosion Inhibitors (Resins / Exudates) Persea americana mill

The gum exudates were extracted from the tree bark by tapping. The tree is abundantly planted in Nigeria. Exudates was gotten from Oyigba Village in Ahoada –West Local Government Area of Rivers 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 and a coating thickness of 150µm, 300µm, 450µm, and 600µm before the corrosion test. The test cubes were placed on 150 mm x 150 mm x 150 mm metal molds and removed after 72 hours. Samples were treated at room temperature in the tank 28 days prior to the initial treatment period, followed by rapid accelerated corrosion testing and monthly routine monitoring for 360 days. Cubes for corrosion-acceleration samples were taken at approximately 3 days 90 days, 180 days, 270 days, and 360 days, and failed bond loads, binding strength, maximum slip, cross-section reduction/increase area, and weight loss/steel reinforcement.

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 in 5% NaCl solution for 360 days to test the reinforcing surface and mechanical properties of the steel and its effects on both non-coating and exudates/adhesive coated specimens.

2.4 Pull-out Bond Strength Test

The Pullout-bond strength of the concrete cube is embedded in the center of a 12 mm diameter steel-concrete cube measuring 150 mm × 150 mm × 150 mm with a total of 36 cubes were subjected to Universal Testing Machine (UTM) of 50kN pressure load.

2.5 Tensile strength of reinforcement bars

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

3.1 EXPERIMENTAL DISCUSSION

It is expected that the interaction between the concrete and reinforcing steel is perfect to allow maximum adhesion of the composite to the surrounding concrete structure. The increase in deformation (rib) of reinforcement and joint joints mainly depends on the bearing or mechanical barrier between the concrete around the ribs on the surface of the beam. The harmful effects of corrosive attacks render many structures unusable and are designed to last a lifetime.

The experimental data presented in Tables 3.2.3.2 and 3.3, summarized in Tables 3.4 and 3.5, were examined on 36 concrete cube samples of 12 placed in freshwater for 360 days, 12 uncoated and 12 with exudate/resin-coated samples, all embedded performed with reinforcing steel added and immersed in 5% sodium chloride (NaCl) solution for 360 days and its performance through inspection, monitoring, verification and testing at intervals of 3 months to 90 days, 180 days, 270 days and 360 days assessing. The manifestation of corrosion is a long-term process that takes decades to fully function, but the artificial introduction of sodium chloride causes the manifestation and occurrence of corrosion in a shorter time. Experimental work describes an ideal high salinity coastal marine area and the possible use of Persea Americana exudate extract/resin as an inhibitor to limit the bullish and risk of corrosive effects on heavy and rough reinforced concrete structures.

Table-3.1: Results of Pull-out Bond Strength Test (τu) (MPa)

	Non-corroded Control Cube Specimens											
Sample Numbers	PAMC	PAMC1	PAMC2	PAMC3	PAMC4	PAMC5	PAMC6	PAMC7	PAMC8	PAMC9	PAMC10	PAMC11
	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)	28.642	26.553	27.117	27.713	28.529	28.229	28.753	28.570	28.635	30.446	29.570	29.772
Bond strength (MPa)	11.309	12.201	10.699	11.629	12.002	12.925	13.019	12.349	12.383	13.089	12.400	12.947
Max. slip (mm)	0.130	0.132	0.122	0.127	0.126	0.125	0.138	0.142	0.150	0.148	0.152	0.150
Nominal Rebar Diameter	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
Measured Rebar Diameter Before Test(mm)	11.984	11.994	11.984	11.984	11.984	11.994	11.983	11.995	11.994	11.995	11.993	11.985
Rebar Diameter- at 28 Days Nominal(mm)	11.984	11.994	11.984	11.984	11.984	11.994	11.983	11.995	11.994	11.995	11.993	11.985
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)	0.566	0.568	0.566	0.566	0.566	0.573	0.568	0.566	0.565	0.565	0.568	0.573
Rebar Weights- at 28 Days Nominal (Kg)	0.566	0.568	0.566	0.566	0.566	0.573	0.568	0.566	0.565	0.565	0.568	0.573
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

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

Sampling g and Durations	Samples 1 (90 days)			Samples 2 (180 Days)			Samples 3 (270 Days)			Samples 4 (360 Days)		
Failure Bond Loads (kN)	19.952	19.264	19.554	18.997	18.245	19.112	18.691	19.000	18.697	19.932	18.812	19.545
Bond strength (MPa)	9.114	9.124	8.888	9.111	8.877	8.850	8.648	9.337	8.312	8.800	8.648	8.960
Max. slip (mm)	0.078	0.082	0.083	0.091	0.082	0.086	0.085	0.075	0.081	0.082	0.083	0.074
Nominal Rebar Diameter	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
Measured Rebar Diameter Before Test(mm)	11.995	11.991	11.984	11.984	11.994	11.985	11.984	11.991	11.983	11.994	11.984	11.985
Rebar Diameter-After Corrosion(mm)	11.948	11.944	11.938	11.937	11.948	11.938	11.938	11.944	11.937	11.948	11.938	11.938
Cross- section Area Reduction/Increase (Diameter, mm)	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047
Rebar Weights-Before Test (Kg)	0.565	0.566	0.573	0.566	0.566	0.567	0.564	0.566	0.566	0.565	0.565	0.567
Rebar Weights-After Corrosion (Kg)	0.527	0.528	0.535	0.528	0.528	0.529	0.526	0.528	0.528	0.527	0.527	0.529
Weight Loss /Gain of Steel (Kg)	0.038	0.037	0.038	0.038	0.038	0.035	0.040	0.038	0.039	0.039	0.038	0.038

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

Sampling g and Durations	Samples 1 (90 days)			Samples 2 (180 Days)			Samples 3 (270 Days)			Samples 4 (360 Days)		
Sample	**150µm coated**	**(Exudate/Resin)**		**300µm coated**	**(Exudate/Resin)**		**450µm coated**	**(Exudate/Resin)**		**600µm coated**	**(Exudate/Resin)**	
Failure Bond Loads (kN)	30.988	28.898	29.462	30.059	30.874	30.575	31.098	30.916	30.980	32.791	31.916	32.117
Bond strength (MPa)	14.231	15.124	13.621	14.552	14.925	15.848	15.941	15.271	15.306	16.011	15.323	15.869
Max. slip (mm)	0.149	0.150	0.141	0.146	0.145	0.144	0.157	0.161	0.169	0.166	0.171	0.169
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)	11.984	11.994	11.994	11.984	11.984	11.984	11.994	11.993	11.983	11.994	11.993	11.991
Rebar Diameter-After Corrosion(mm)	12.042	12.053	12.053	12.042	12.042	12.042	12.053	12.052	12.042	12.053	12.052	12.049
Cross- section Area Reduction/Increase (Diameter, mm)	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
Rebar Weights-Before Test (Kg)	0.566	0.567	0.564	0.566	0.566	0.567	0.567	0.566	0.564	0.567	0.566	0.565
Rebar Weights-After Corrosion (Kg)	0.615	0.616	0.613	0.616	0.616	0.616	0.616	0.615	0.613	0.616	0.616	0.614
Weight Loss /Gain of Steel (Kg)	0.049	0.050	0.050	0.050	0.049	0.053	0.050	0.049	0.047	0.616	0.050	0.050

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

Sample	Control, Corroded and Resin Steel bar Coated											
	Non-Corroded Specimens Average Values				Corroded Specimens Average Values				Coated Specimens Average Values of 150μm, 300μm, 450μm, 6000μm)			
Failure load (KN)	27.437	28.157	28.653	29.929	19.590	18.784	18.796	19.430	29.783	30.502	30.998	32.275
Bond strength (MPa)	11.403	12.186	12.583	12.812	9.042	8.946	8.766	8.803	14.325	15.108	15.506	15.734
Max. slip (mm)	0.128	0.126	0.133	0.130	0.081	0.086	0.080	0.079	0.147	0.145	0.142	0.149
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)	11.987	11.987	11.991	11.991	11.990	11.987	11.986	11.988	11.991	11.984	11.990	11.993
Rebar Diameter- After Corrosion(mm)	11.987	11.987	11.991	11.991	11.943	11.941	11.940	11.941	12.049	12.042	12.049	12.051
Cross- section Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.047	0.047	0.047	0.047	0.059	0.059	0.059	0.059
Rebar Weights- Before Test (Kg)	0.566	0.568	0.566	0.568	0.568	0.566	0.565	0.565	0.565	0.566	0.565	0.566
Rebar Weights- After Corrosion (Kg)	0.566	0.568	0.566	0.568	0.530	0.528	0.527	0.527	0.615	0.616	0.615	0.615
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.038	0.037	0.039	0.038	0.049	0.051	0.048	0.050

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)	40.058	49.896	52.440	54.039	-34.223	-38.417	-39.364	-39.799	52.030	62.382	64.919	66.110
Bond strength (MPa)	26.109	36.212	43.556	45.546	-36.881	-40.787	-43.470	-44.055	58.430	68.881	76.897	78.747
Max. slip (mm)	58.249	45.858	79.080	89.255	-44.735	-40.163	-50.503	-52.924	80.945	67.120	102.031	112.423
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)	0.220	0.227	0.228	0.229	0.227	0.232	0.235	0.242	0.247	0.232	0.235	0.222
Rebar Diameter- After Corrosion(mm)	0.370	0.388	0.429	0.417	-0.879	-0.841	-0.907	-0.914	0.887	0.848	0.915	0.922
Cross- section Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	-20.649	-20.649	-20.649	-20.649	26.022	26.022	26.022	26.022
Rebar Weights- Before Test (Kg)	0.324	0.357	0.364	0.352	0.348	0.324	0.331	0.328	0.336	0.324	0.331	0.338
Rebar Weights- After Corrosion (Kg)	6.934	7.572	7.385	7.794	-13.875	-14.249	-14.277	-14.315	16.111	16.616	16.655	16.707
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	-23.913	-26.651	-19.905	-23.077	31.429	36.334	24.851	30.001

3.2 Failure load, Bond Strength, and Maximum slip

The bond between the steel reinforcement and the concrete is essential to ensure the composite interaction of the two materials. At very low stress, the bonding force is mainly due to the chemical bond between the concrete and the steel reinforcement but depends on the mechanical interlocking between many factors that influence the bond between concrete and reinforcing steel, such as concrete strength, concrete composition, and environments. Corrosion-resistant steel reinforcement in concrete is governed by the availability of oxygen, moisture, and carbonation (CO2). The mechanisms of chemical adhesion and friction are most important in the case of smooth reinforcing steel. For deformed reinforcing steel, mechanical inhibition of reinforcing steel ribs in concrete is the main mechanism that determines the behavior of adhesion and sliding strength [30-32]. The results of failure bond load, bond strength and maximum slip conducted on 36 concrete cubes as presented in tables 3.1. 3.2 and 3.3 and concise into 3.4-2.5 and graphically plotted in figures 1 – 6b. The obtained results are for 12 samples of controlled, 12 corroded and 12 coated tested to failure using Instron Universal Testing Machines with 50kN as described in the test procedure.

The minimum and maximum computed average and percentile derived results of failure bond load are controlled 27.437kN and 29.929kN (40.058% and 54.039%), corroded 18.784kN and 19.59kN (-39.799% and -34.223%), coated 29.783kN and 32.275kN (52.03% and 66.11%).

The differential maximum values computed of the average and percentile ranges of failure bond load are controlled (2.492kN and 13.981%) against corroded samples values are (0.806kN and 5.576%), coated are (2.492kN and 14.08%). From the obtained results, the maximum values of controlled, corroded and coated samples for comparison are 54.039%), -34.223% and 66.11%. The comparative results showed higher percentile failure bond load in controlled and coated samples over corroded sample with lower percentile failure bond loads. The lower failure loads revealed effect of corrosion on the reinforcing steel that resulted surface modification, reduction fibre and high passivity and spalling. The difference in percentile values recorded showed high reductive and decreased value in corroded sample as compared to the reference range (controlled), with an increased value in coated with closed values to the reference range. The computed data showed the effective and efficiency of exudates/resin as an inhibitory substance in curbing the effect of corrosion on reinforcing steel embedded in concrete beams, exposed to corrosive media as results validated by works of [19, 20, 22, 25].

Bond strength values for controlled are 11.403MPa and 12.812MPa (26.109% and 45.546%), corroded 8.766MPa and 9.042MPa (-44.055% and -36.881%), Coated are 14.325MPa and 15.734MPa (58.43% and 78.747%). The maximum recorded average and percentile values are controlled 45.546% against corroded and coated values of 36.881% and 78.747% and with differentially potential values of the bond strength controlled 1.409MPa and 19.437% against corroded values of 0.276MPa and 7.174% and coated values 1.409MPa and 20.317%. The results showed indications of lower bonding exhibition by the corroded samples and higher failure on pullout bond as compared to the reference range values from the controlled samples. Coated samples exhibited higher bonding on pullout with lower failure loads showing closed values range with the reference (controlled) samples. The lower load failure characteristic has been attributed to the effect of corrosion attack resulting to rib-less (smooth) and surface modification, the effect of corrosion resulted to swollen surface with peeled off fibre while coated samples exhibited highly resistive characteristics to corrosion attacks showing the effectiveness of exudates/resin as an anti-corrosive materials in curbing the scourge and menace faced by reinforced concrete structures built in the coastal marine region with unique and severe characteristics of high salinity [19, 20, 22, 25].

Results of maximum slip are controlled are mm and 0.126mm and 0.133mm (45.858% and 89.255%), corroded 0.079mm and 0.086mm (-52.924 % and -40.163%), coated 0.142mm and 0.149mm (67.12% and 112.423%). The maximum recorded average and percentile values of controlled 89.255% against corroded and coated samples of 40.163% and 112.423% and with differential recorded values of the controlled 0.0070mm and 43.397% against corroded values of 0.0069 mm and 12.761% and coated values 0.0070mm and 45.303%. Comparatively, obtained results showed decreased slippage failure load exhibition by the corroded samples over the controlled and coated samples with highly lower value range to the reference with coated samples exhibiting higher slippage failure load with increased values over controlled. These attributes demonstrated the potential and efficiency of the exudates/resin as corrosion inhibitive materials. The lower average and percentile values obtained from the non-coated (corroded) samples are been attributed to the effect of corrosion on the reinforced concrete structures fully submerged in corrosive media.

From the result presented in tables 3.4 of average values derived from tables 3.1, 3.2 and 3.3 and collapsed into 3.5 from 3.4 to percentile values difference, the failure bond load, bond strength and maximum slip all failed at low load applications with decreased percentile values compared to controlled and coated concrete cube samples. The result showed indications of the effect of corrosion on the failure bond load, bond strength and maximum slip [19, 20, 22, 25].

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.

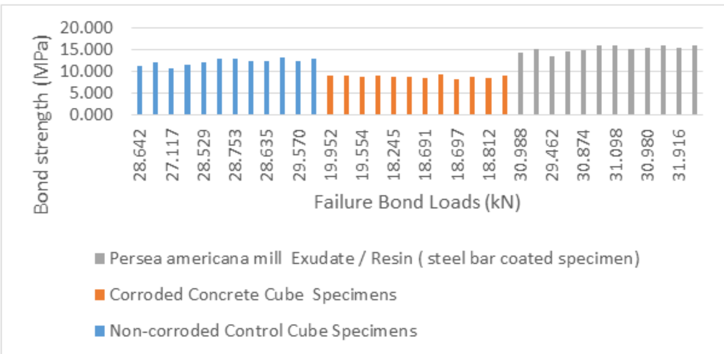

Fig-1: Failure Bond loads versus Bond Strengths

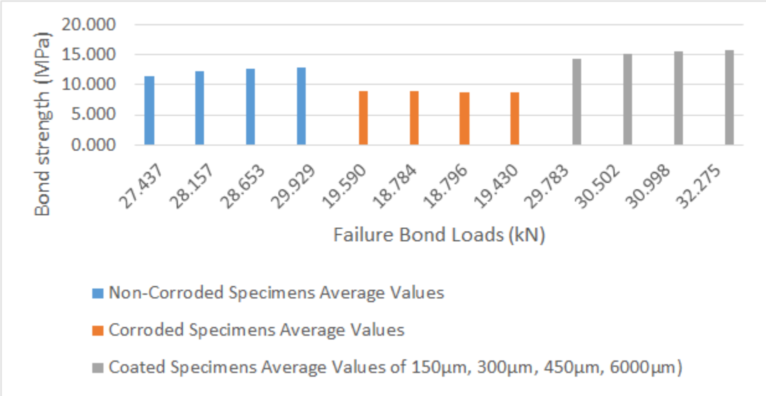

Fig-1a: Average Failure Bond loads versus Bond Strengths

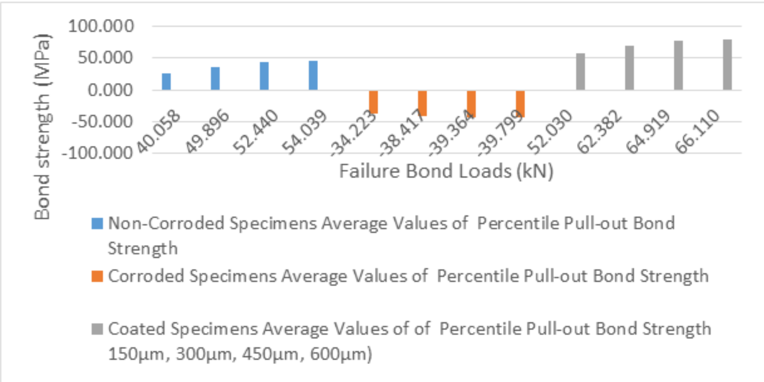

Fig-1b: Average Percentile Failure Bond loads versus Bond Strengths

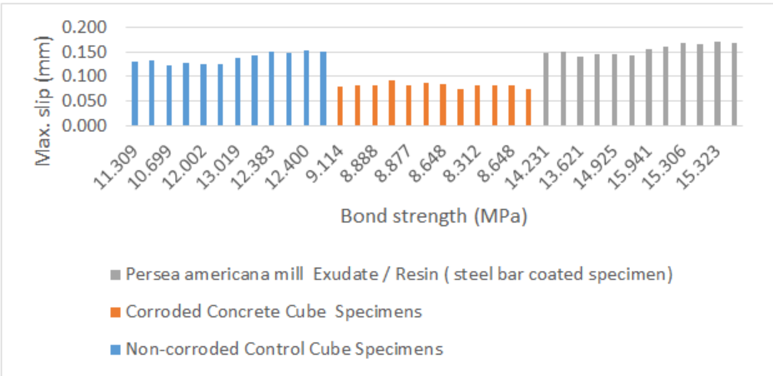

Fig-2: Bond Strengths versus Maximum Slip

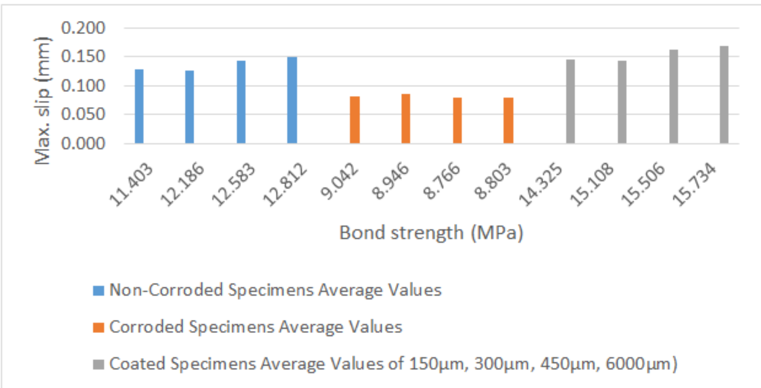

Fig-2a: Average Bond Strengths versus Maximum Slip

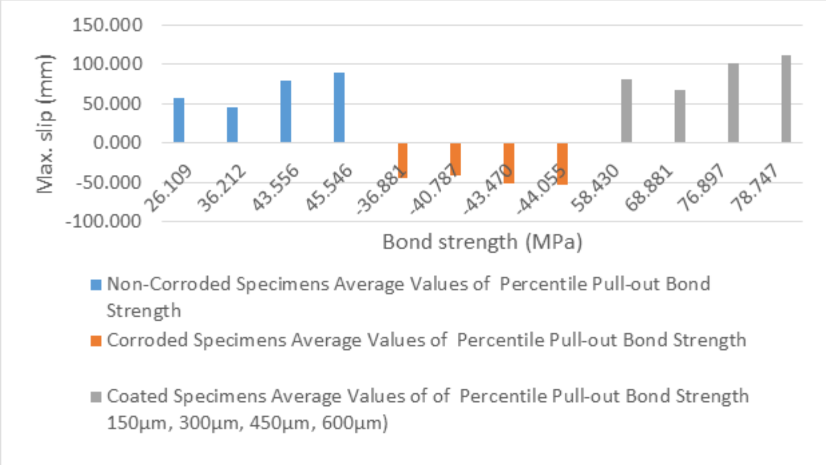

Fig-2b: Average Percentile Bond Strengths versus Maximum Slip

3.3 Mechanical Properties of Reinforcing Bars

The corrosion effect causes cracks in the concrete, reduces the effective cross-sectional area of steel reinforcement, and weakens the connection between steel and concrete. This has a significant impact on the viability and lifespan of the reinforced concrete structure and therefore basic facilities such as bridge decks are a major concern for many transport companies. Damage to the reinforced steel reduces the cross-sectional area of the steel bar and increases the growth of corrosion products, which reduces the ductility and strength of the steel. The fracture product is 2 to 6 times greater than the original reinforced steel (Liu, Weirs, 1998). Initial corrosion products on the surface of the steel belt can cause longitudinal cracking, cracking, and deformation of the concrete shell. The loss of the concrete cover creates adhesion between the steel rails and the concrete by reducing bond strength in the intermediate zone. The adhesive strength is mainly due to the weak chemical bond between the steel and the hardened cement, but this strength disintegrates at low pressure. As soon as slippage occurs, friction will help bond. With fine steel bars, friction is an important part of strength. Reinforced steel bars with ribs with elevated shear joints are primarily dependent on mechanical supports or connections between the reinforcement and the surrounding concrete at the surface. This study introduces the use of exudates/resin to improve the slippage problem of fine reinforcing bars.

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 a 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 tests are within the range of 11.987mm and 11.991mm (0.37% and 0.429%). The diameter of the rebar uncoated samples (corroded) after corrosion test are 11.940mm and11.943mm (-0.914% and -0.841%), after coated are 12.042mm and 12.051mm (0.848% and 0.922%). From the obtained results, the maximum values of the controlled, corroded, and coated samples for comparison are 0.429%, -0.841%, and 0.922%. The maximum recorded average and percentile differential values of the rebar diameter after corrosion tests are controlled 0.0070mm and 43.397% against corroded values of 0.0069 mm and 12.761% and coated values 0.0070mm and 45.303%. The results of cross-sectional area for uncoated (corroded) are 0.047mm and 0.047mm (-20.649% and -20.649%), for coated are 0.059mm and 0.059mm (26.022% and 26.022%). Comparative results computed of maximum percentile values are corroded -20.649% against coated 26.022%. The maximum recorded average and percentile differential values of the cross-sectional area are controlled 0.004mm and 0.059% against corroded values of 0.003mm and 0.073 % and coated values 0.009mm and 0.074%. The comparative results showed lower percentile values in corroded samples against controlled and coated samples with reduced /decreased rebar diameter resulting in cross-sectional area reduction. This reduction in rebar diameter and the cross-sectional area has resulted in higher failure bond loads, lower bond strengths, and lower slippages, and these characteristics revealed the effects of corrosion on the reinforcing steel that resulted from surface modification, reduction of rebar fibre, and high yield to load applications [19, 20, 22, 25].

The result for rebar weight before test for all samples are 0.566Kg and 0.568 Kg (6.934% and 7.794%), weight after corrosion test for corroded are for 0.527Kg and 0.53Kg (-14.315% and -13.875%), coated are 0.615Kg and 0.616Kg (16.111% and 16.707%), with maximum percentile values of 7.794% controlled, -13.875% corroded and 16.707% and weight loss /gain of steel are corroded 0.037Kg and 0.039Kg (-26.651% and -19.905%) and coated values are 0.048Kg and 0.051Kg (24.851% and 36.334%). 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 the diameter of rebar, it can be seen that the diameter of uncoated decreased by the maximum value of -0.841% and coated increased by 0.922%, for the cross-sectional area, corroded has maximum reduction value -20.649% and coated increased by and 26.022%, weight loss, and gain are corroded -19.905% decreased (loss) and coated 36.334% 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 a diameter and cross-sectional area increases and weight gain resulting from the varying thickness coated to reinforcing steel [19, 20, 22, 25].

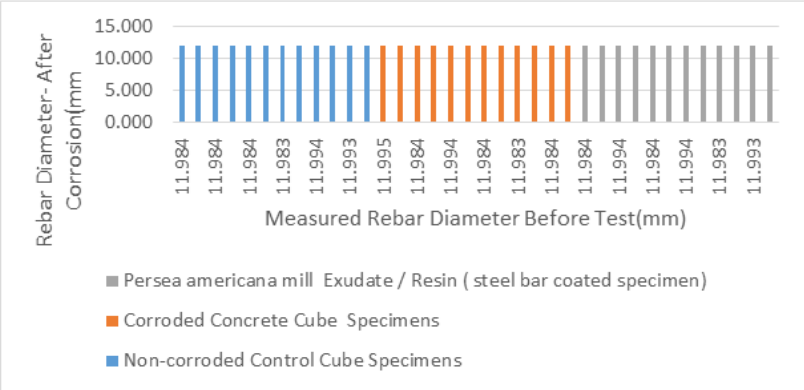

Fig-3: Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

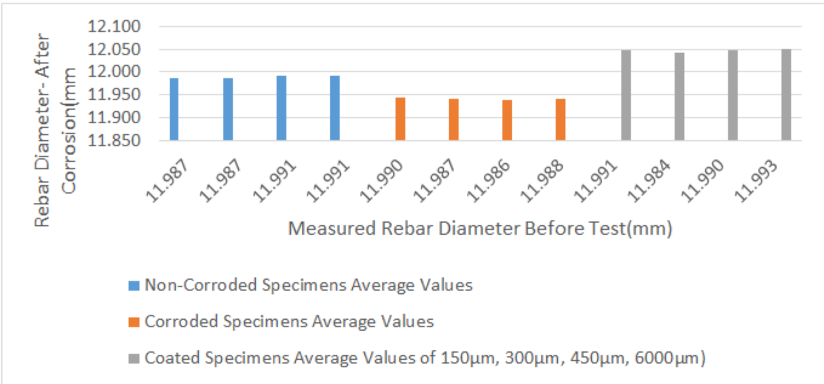

Fig-3a: Average Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

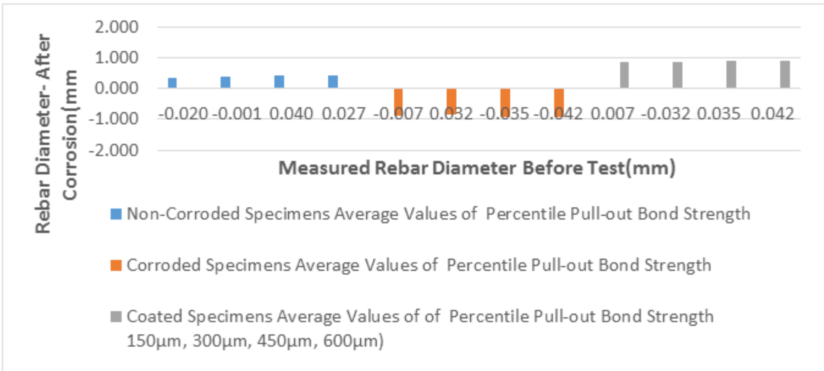

Fig-3b: Average Percentile Measured (Rebar Diameter before Test vs rebar Diameter- After Corrosion

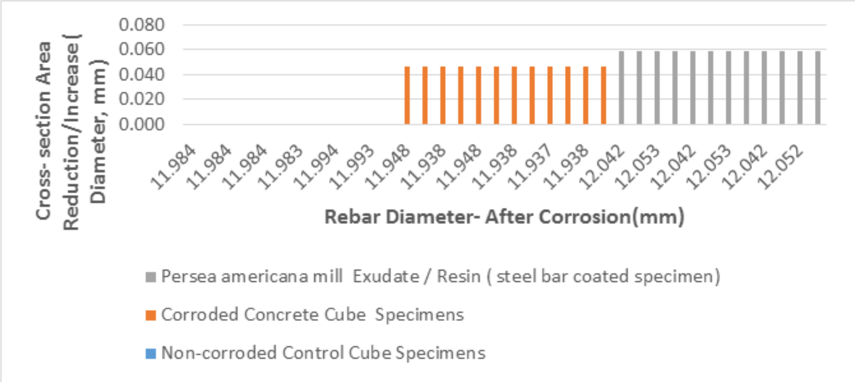

Fig-4: Rebar Diameter- After Corrosion versus Cross – Sectional Area Reduction/Increase

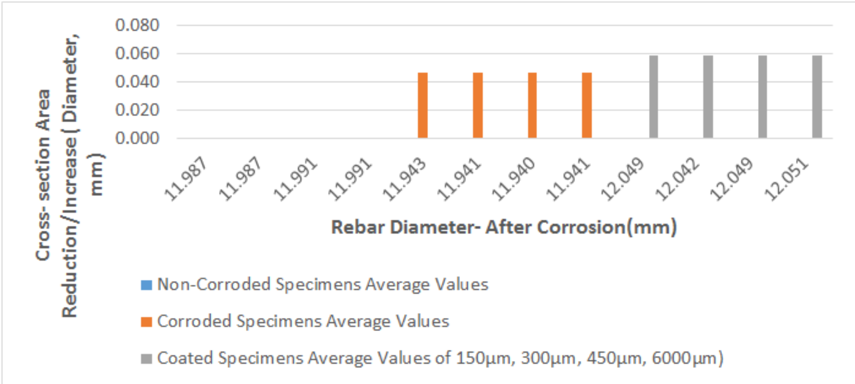

Fig-4a: Average Rebar Diameter- After Corrosion versus Cross – Sectional Area Reduction/Increase

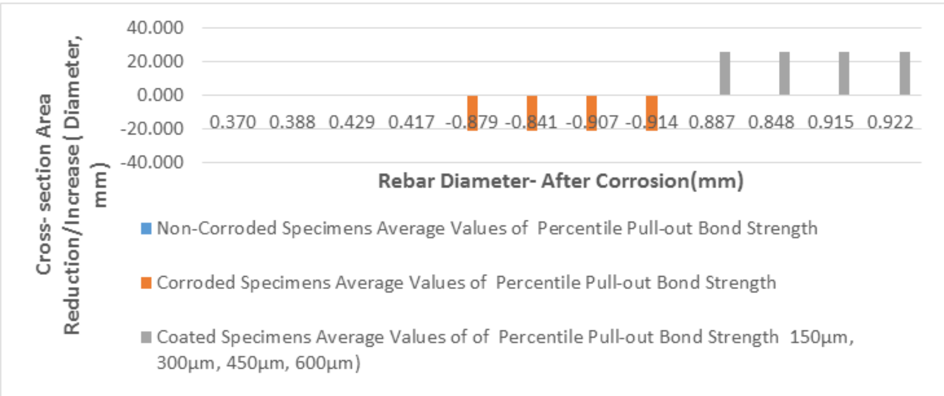

Fig-4b: Average percentile Rebar Diameter- after Corrosion versus Cross - sectional Area Reduction/Increase

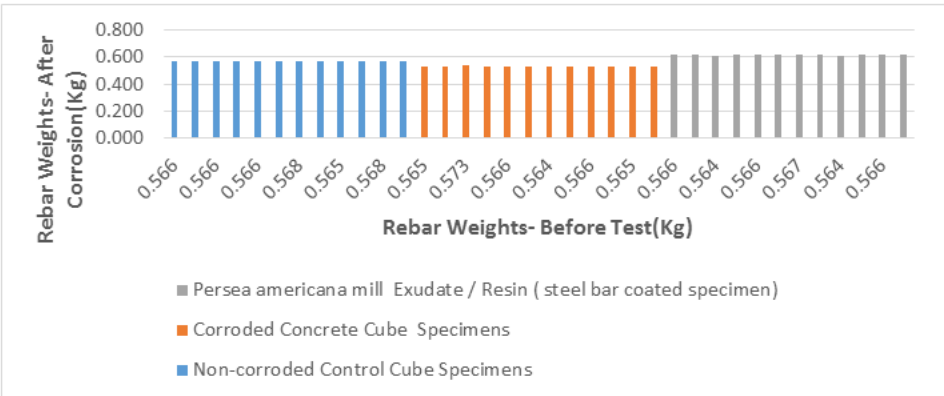

Fig-5: Rebar Weights- Before Test versus Rebar Weights- After Corrosion

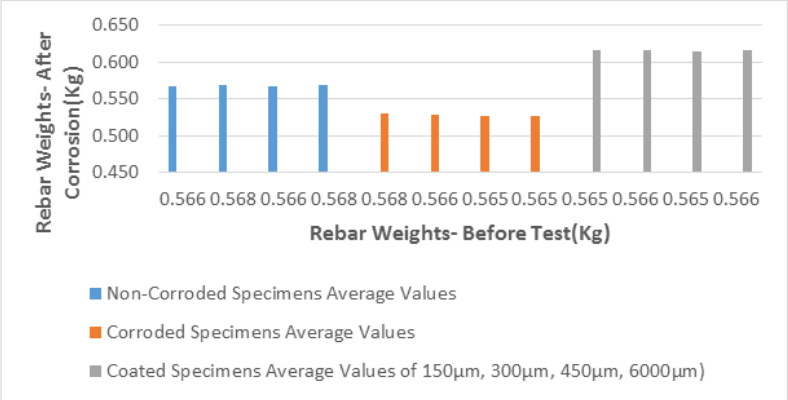

Fig-5a: Average Rebar Weights- Before Test versus Rebar Weights- After Corrosion

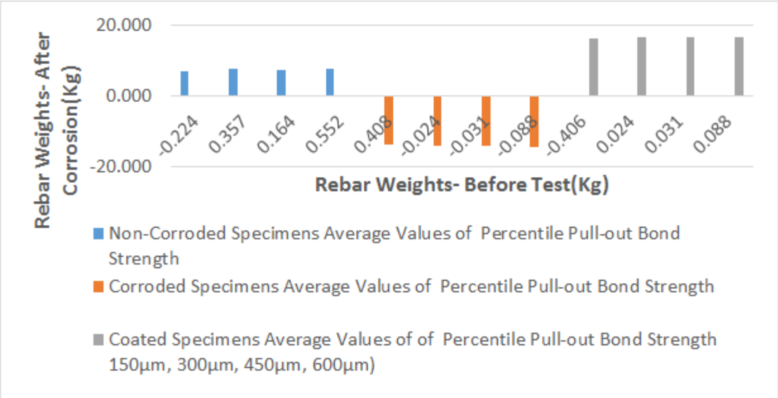

Fig-5b: Average Percentile Rebar Weights- Before Test versus Rebar Weights- After Corrosion

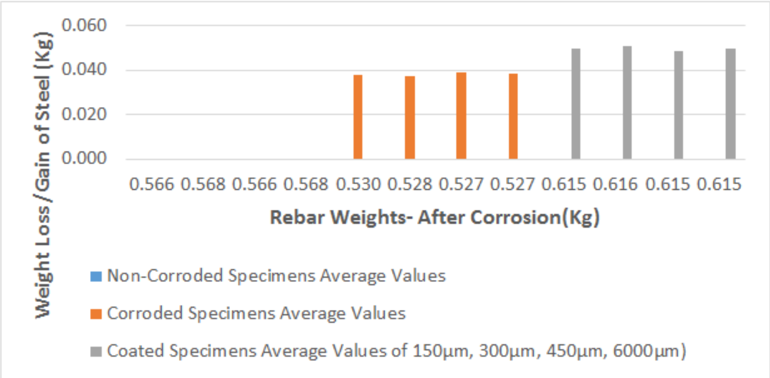

Fig-6: Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

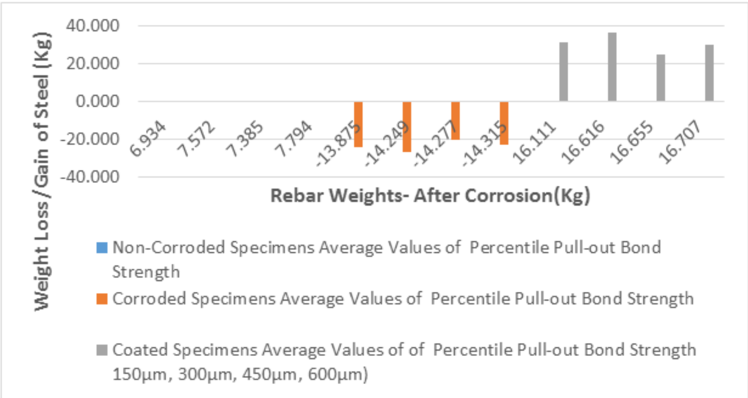

Fig-6a: Average Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

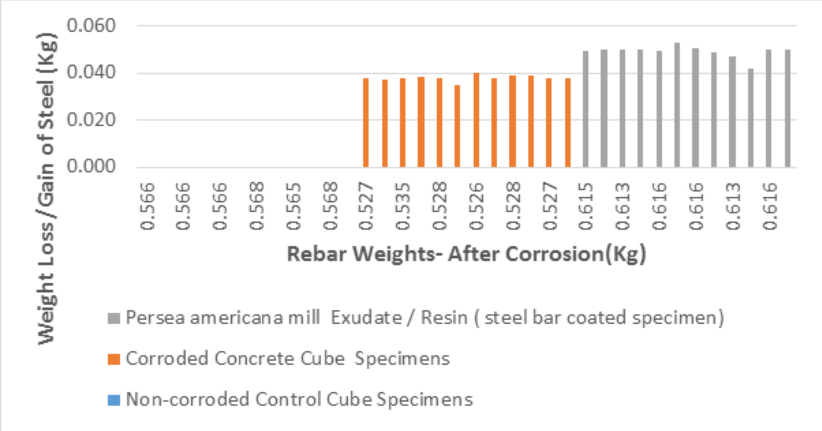

Fig-6b: Average percentile Rebar Weights- after Corrosion versus Weight Loss /Gain of Steel

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

From the obtained results of failure bond load, the maximum values of controlled, corroded, and coated samples for comparison are 54.039%), -34.223%, and 66.11%. The comparative results showed a higher percentile failure bond load of controlled and coated samples over the corroded sample with lower percentile failure bond loads. The lower failure loads revealed the effect of corrosion on the reinforcing steel that resulted in surface modification, reduction fibre, and high passivity and spalling. The difference in percentile values recorded showed high reductive and decreased value in the corroded sample as compared to the reference range (controlled), with an increased value in coated with closed values to the reference range. The computed data showed the effectiveness and efficiency of exudates/resin as an inhibitory substance in curbing the effect of corrosion on reinforcing steel embedded in concrete beams, exposed to corrosive media.

The maximum recorded average and percentile values are controlled 45.546% against corroded and coated values of 36.881% and 78.747% and with differentially potential values of the bond strength controlled 1.409MPa and 19.437% against corroded values of 0.276MPa and 7.174% and coated values 1.409MPa and 20.317%. The results showed indications of lower bonding exhibition by the corroded samples and higher failure on pullout bond as compared to the reference range values from the controlled samples [19, 20, 22, 25].

Coated samples exhibited higher bonding on pullout with lower failure loads showing closed values range with the reference (controlled) samples. The lower load failure characteristic has been attributed to the effect of corrosion attack resulting in rib-less (smooth) and surface modification, the effect of corrosion resulted to the swollen surface with peeled off fibre while coated samples exhibited highly resistive characteristics to corrosion attacks showing the effectiveness of exudates/resin as an anti-corrosive material in curbing the scourge and menace faced by reinforced concrete structures built in the coastal the marine region with unique and severe characteristics of high salinity.

Comparatively, obtained results showed decreased slippage failure load exhibition by the corroded samples over the controlled and coated samples with a highly lower value range to the reference with coated samples exhibiting higher slippage failure load with increased values over-controlled. These attributes demonstrated the potential and efficiency of the exudates/resin as corrosion inhibitive materials. The lower average and percentile values obtained from the non-coated (corroded) samples are been attributed to the effect of corrosion on the reinforced concrete structures fully submerged in corrosive media.

From the result presented in tables 3.4 of average values derived from tables 3.1, 3.2, and 3.3 and collapsed into 3.5 from 3.4 to percentile values difference, the failure bond load, bond strength, and maximum slip all failed at low load applications with decreased percentile values compared to controlled and coated concrete cube samples. The result showed indications of the effect of corrosion on the failure bond load, bond strength, and maximum slip.

Comparative results computed of maximum percentile values are corroded -20.649% against coated 26.022%. The maximum recorded average and percentile differential values of the cross-sectional area are controlled 0.004mm and 0.059% against corroded values of 0.003mm and 0.073 % and coated values 0.009mm and 0.074%. The comparative results showed lower percentile values in corroded samples against controlled and coated samples with reduced /decreased rebar diameter resulting in cross-sectional area reduction. This reduction in rebar diameter and the cross-sectional area has resulted in higher failure bond loads, lower bond strengths, and lower slippages, and these characteristics revealed the effects of corrosion on the reinforcing steel that resulted from surface modification, reduction of rebar fibre, and high yield to load applications.

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 the diameter of rebar, it can be seen that the diameter of uncoated decreased by the maximum value of -0.841% and coated increased by 0.922%, for the cross-sectional area, corroded has maximum reduction value -20.649% and coated increased by and 26.022%, weight loss, and gain are corroded -19.905% decreased (loss) and coated 36.334% 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 a diameter and cross-sectional area increases and weight gain resulting from the varying thickness coated to reinforcing steel.

4.0 CONCLUSION

In the experiment, the results obtained are drawn as:

i. The exudates/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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