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Original Research Article

Evaluation of Probabilistic Potential of Chloride-Induced Corrosion on Modification of Steel Bar in Reinforced Concrete Structures Exposed to Severe Media

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Abstract

The research evaluated the potential occurrence of corrosion in an induced media assessing the coating of reinforcing steel with Boswellia dalzielii (Burseraceae) exudates/resin gotten from the trunk of trees, the coating varies in thicknesses, embedded in concrete slabs, and exposed to the high severed coastal marine environment with acidic content. The maximum stability value calculated concrete resistivity from the controlled concrete sample was 63.55% compared to the corroded and coated values -44.28% and 84.61%, and the maximum controlled differential percentile was 2.8% compared to the corroded and 1.55% values and 5.53% coverage. The test results of controlled and coated samples with concrete resistance got a maximum average value of 14.38kΩcm and 16.28kΩcm with a value of $10 < \rho < 20$ (low) compared to a corrosion value of 8.85kΩcm with an indication of 5 < 10 (high) and the reference range of the relationship between concrete resistance and corrosion probability. The maximum obtained and corrosion potential values of the controlled and coated samples were -107.3mV and -121.5mV, indicating the relationship between corrosion potential and probability as $E\text{corr} > -200\text{mV}$ as the reference range. The results of this potential Ecorr result show that the value of controlled and resin-coated samples is low with a 90% probability that no corrosion of reinforcing steel is observed during the measurement (10% risk of corrosion, which averages 10% for samples without coating obtained maximum value - 341.7mV, the result lies in the correlation reference value between the corrosion potential value $-350\text{mV} \leq E\text{corr} \leq -200\text{mV}$ indicating a high range of values. The calculated maximum percentile ultimate tensile strength of controlled tensile strength is 2.06% compared to corrosion and coating values of 1.96% and 2.05%, and the possible differential values are 0.06% controlled, 0.01% corroded and 0.03 % coated. The calculated maximum percentile yield strength value of the controlled shear strength is 8.28% compared to the corroded and coated values of -7.61% and 8.28% and the controlled potential differential values are 0.05%, corrosion is 0.04% and 0.05% coated. The comparison results show that the low load carrying capacity is caused by the effect of corrosion attack on the exposed (corroded) elements, which damage reinforcing steel fibers, ribs and passive formations and surface modifications. The avearge values observed for the coated samples relate to the corrosion resistance potential to penetrate the reinforcing steel to form a protective membrane; This attribute indicates the effectiveness and effectiveness of the exudate/resin as an inhibitor against corrosive effects. exposed reinforced concrete structure on the edge of a strong sea area with high salinity. The maximum calculated percentile of corroded is 0.396% versus -1.17% and coated is 0.721%, the differential in the percentile of corrosion is 0.03% versus 0.003% coated. For comparison, the results of corroded samples showed reduction and reduction values compared to the diameter of the reinforcement before and after accelerated induction corrosion testing with a percentile decrease in value from 0.396% to -1.17% and an average value in the range of 11.93mm to 11.93mm. The differential in average and relative percentile between coated and corroded samples varied from 26.42% to -20.9%. The decrease in average and percentile values indicates that the corrosion effect has led to a reduction in diameter and cross-sectional area, fiber degradation, rib reduction and surface modification, while elements coated with exudates/resin confirm an increase in volume as thickness as there are shift differentials.

Keywords: Corrosion, Corrosion inhibitors, corrosion potential, concrete resistivity and Steel Reinforcemen.

1.0 INTRODUCTION

Corrosion may be the result of chloride contamination or carbonation of reinforced concrete structures, which can affect durability and life expectancy. Inorganic Resistors and Greener Approach Inhibitors are high and environmentally friendly, toxic, and generally, widely, inexpensive for future use. Based on these characteristics, there is a great demand for organic inhibitors due to their biodegradable properties. Environmental concerns are increasing worldwide and affecting the choice of corrosion inhibitors. The use of these natural products, such as compounds extracted from leaves or seeds as corrosion inhibitors, has been widely reported by many authors [1-15].

Charles *et al*., (2018) investigated the electrochemical process leading to electron transfer in the corrosion process of steel reinforcement in a harsh marine environment with high levels of chloride. Comparative results showed that corroded members increased in corrosion potential Ecorr, MV and decreased in concrete resistivity decreased. With respect to ultimate strength, nominal yield stress, weight loss, cross-sectional diameter reduction, corroded members decreased while coated members increased.

Investigated d the direct application of dacryodes edulis corrosion inhibitor resins to with varying thicknesses to 12mm diameter reinforcing steel, embedded in a concrete slab, with accelerated corrosion testing, half - cell measurement, concrete resistivity measurement. Comparatively results showed that corroded specimens increased corrosion potential rate and decreased in concrete resistivity with reduction in cross-sectional area of reinforcing steel [16].

Investigated the effects of chloride attack on reinforcing steel embedded in reinforced concrete structures constructed in marine environment. An experimental work simulated the acceleration process on the uncoated and coated reinforcement with acardium occidental l exudates/resin. Compared results showed that corroded has increased values of potential E_{corr}, mV, and decreased values of concrete resistivity [17].

Investigated the extent to which possible tests of half-cell corrosion estimation, concrete tensile test and tensile strength tests of control structures, molds and non-coated reinforcement with Moringa Oleifera lam resin paste on extracted trees. Compared results of non-coated and coated showed, corroded has increased of potential Ecorr, mV and decreased rates of concrete resistivity [18].

Assessed the use of environmentally inorganic exudates / resins extracted from the bark of Invincia gabonensis, layered to reinforce steel with different thicknesses, immersed in sodium chloride for corrosion tests in a 150 day fast process and compared the non-coated, coated and control samples. The aggregate results of the exudates / resin coated samples showed no indications of corrosion potential, and demonstrated that Invincia gabonensis exudates / resins were good corrosion inhibitors. Corroded samples exhibited cross-sectional area reduction with higher percentile reduction values as fiber loss negatively affects the mechanical properties of steel as a result of corrosion potential. The results of the weight loss of steel showed a high percentile of values against the control and coated models due to the effect of corrosion on the mechanical properties of steel [19].

Investigated the reinforcement corrosion rate of exudates/resins inhibited and non-inhibited reinforcing steel embedded in concrete slab structures submerged in a corrosive environment, and acceleration process using the Wenner four-probe measurement method. The estimated range of the samples indicates the significant corrosion probability (ρ <5, 5 <, <10, 10 <, <20, ρ> 20) for most, high, low to moderate and low, corrosion potential. The results showed high yields of the corrosive samples on the mechanical properties of the steel reinforcement and the coated samples. Steel weight loss results showed higher percentile values of non-coated samples against control and coating samples due to the effect of corrosion on the mechanical properties of steel [20].

Conducted tests of the half-cell potential, concrete resistivity, and reinforcing steel mechanical properties assessment test to examine the change in the surface state of the mechanical properties of the non-coated and exudates/resin coating samples, immersed in sodium chloride for 150 days in fast corrosive media in applied streams potential from -200 mV to 100mV of scan rate. Mechanical properties of corroded specimen percentile average value are 107.64% and percentile differential 7.64%, - 7.10% and -6.67% of control and coating specimens. The average mechanical properties of the corroded specimens were "steel weight loss" with a average value of 180.43% and percentile differentials of 80.43% to - 44.57% and -45.18% for control and coating samples. Cross-sectional reduction results showed higher percentile reduction values due to the effect of corrosion on the mechanical properties of steel [21].

Investigated the strengthening of steel reinforcement with the introduction of milicia excelsa exudates/resins to reduce surface changes and mechanical properties of reinforcing steel in concrete structures built in saltwater environments with corrosion acceleration process of 150 days and corrosion efficiency were determined. The corrosion properties of the spalling and fractures in the non-coated members showed that the overall experimental results were indicative of the low flexibility failure load. The effect of corrosion on the mechanical properties of reinforcing steel on corroded (controlled) members has not been observed [22].

Investigated the tendency of the passive loss of reinforcing steel with the use of natural inorganic exudates/resins paste of milicia excelsa with a coating thickness of 150μm, 300μm, and 450μm. The coated and uncoated members were embedded in the concrete slab and partially submerged in fast-flowing media with fast application currents of 1200mV to -200 mV, with a scan rate of 1mV for the non-coated and coated with a scan rate of half-particle corrosion potential, concrete resistivity, and tensile strength. The results of the non-coated sample cross-sectional area reduction result in higher corrosion values due to the effect of corrosion on the mechanical properties of reinforcing steel. Due to fiber / ribbed removal from the surface attack and the effect of corrosion on the mechanical properties of steel, the non-coated members showed higher percentile values against the control and coating samples. High-end yield and coating patterns of non-coated specimens with low load application to control lead to corrosion on the mechanical properties of steel reinforcement [23].

Evaluated the changes and mechanical properties of reinforcing steel coated with exudates /resins and of non-coated members, embedded in concrete members and exposed to corrosive media. The results showed a high yield of corrosion patterns in non-coating over coating samples due to the effect of corrosion on the mechanical properties of steel reinforcement. Due to the effect of corrosion on the mechanical properties of the steel, the weight loss results of the steel showed a high percentile of values against the control and coating models [24].

2.1 MATERIALS AND METHODS

2.1.1 Aggregates

Fine and coarse aggregates are purchased at landfills. Both meet the requirements of [25].

2.1.2 Cement

Limestone cement grade 42.5 was used for all concrete mixtures. The cement meets the requirements of [26].

2.1.3 Water

Water samples were taken from the Department of Civil Engrg. laboratory at Kenule Beeson Polytechnic, Bori, Rivers State. Water meets requirements [27].

2.1.4 Structural steel reinforcement

Reinforcement purchased directly from the market at Port Harcourt, Conformed to [28].

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

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

2.2 EXPERIMENTAL PROCEDURE

2.2.1 Experimental method

2.2.2 Prepare Samples for Reinforcement with Coated Exudate/Resin

This work evaluated the coating of reinforcing steel with Boswellia dalzielii (Burseraceae) exudate/resin, gotten from the trunk of trees, the coating varies in thicknesses, embedded in concrete slabs, and exposed to the high severed coastal marine environment with acidic content. The process of corrosion on reinforcing steel built within the coastal region takes years before manifestation. On the other hand, the artificially induced corrosion matures within a short time with the introduction of sodium chloride (NaCl) as an accelerator and a stimulant.

Of course, the manifestation of corrosion in reinforcement, metals, and related materials is a long-term process that takes many years. However, the artificial introduction of sodium chloride (NaCl) accelerates the rate of corrosion, and its manifestations occur in a short time.

The effect and devastating damage of corrosion rate measured by estimating the current density obtained or obtained from the polarization curve and the degree of quantification of the corrosion rate. The slabs for this research are achieved with concrete mixes were batched by material weight with the manual mixing method using a standard concrete ratio of 1.2.4, and a water-cement ratio of 0.65. Concrete standards are obtained by gradually adding cement, aggregates (fine and coarse), and water to achieve a consistent color. Concrete slabs of 100 mm × 500 mm × 500 mm (thickness, width, and length) cover of 10 mm are cast into a metal mold, compacted to air and void-free, and reinforced by 10 pieces of reinforcing steel with a diameter of 12 mm, at 100 mm c / c (top and bottom) are placed and de-molded after 72 hours, cured for 28 days at standard room temperature to harden. The hardened concrete slabs are wholly immersed in 5% sodium chloride (NaCl) solution to water and accelerated for a rapid corrosion process for 360 days with interval checks and routine tests of 90 days, 180 days, 270 days, and 360 days for record documentation of comparison.

2.3 Accelerated Corrosion Test

The corrosion process is a natural phenomenon that takes decades to actualized. This is a long-term process, but the fast induced and accelerated corrosion process using sodium chloride (NaCl) solution allows reinforcement embedded in concrete to undergo corrosion and can quicken the increase in corrosion that will occur over decades in a short time. To test the corrosion resistivity of concrete, experimental processes were developed that accelerate the corrosion process and maximize the corrosion resistivity of concrete. The accelerated corrosion test is an impress current technique, an effective technique for examining the corrosion process of steel in concrete and for assessing damage to the concrete cover protection to the steel bar. The laboratory acceleration process helps distinguish the role of individual factors that can influence chloride-induced corrosion. For the construction of structural elements and corrosion resistivity as well as for the selection of suitable materials and suitable protection systems, an accelerated corrosion test is carried out to obtain quantitative and qualitative information on corrosion.

2.4 Corrosion Current Measurement (Half-Cell Potential Measurement)

The classification of the severity of reinforcing steel corrosion is shown in Table 2.1. If the potential measurement results indicate a high probability of active corrosion, then the degree of corrosion can be assessed by measuring the resistivity of the concrete. However, care must be taken when using these data as it is assumed that the corrosion rate is constant over time. This has also been demonstrated through practical experience [Figg and Marsden [29], Gower and Millard [30]. Measurement of half potential is an indirect method of estimating the probability of corrosion. Recently, there has been much interest in developing tools for carrying out electrochemical measurements of disturbances on the steel itself to obtain a direct estimate of the corrosion rate (Stem and Geary [31]. Corrosion rate refers to electrochemical measurements, the first based on data.

Table 2.1: Dependence between potential and corrosion probability [32]

Potential E_{corr}	**Probability of Corrosion**
$E\text{corr} < -350\text{mV}$	Greater than 90% probability that reinforcing steel corrosion is occurring in that area at the time of measurement
$-350\text{mV} \leq Ec_{orr} \leq -200\text{mV}$	Corrosion activity of the reinforcing steel in that area is uncertain
$E_{corr} > -200\text{mV}$	90% probability that no reinforcing steel corrosion is occurring in that area at the time of measurement (10% risk of corrosion

2.5 Tests for Measuring the Resistivity of Concrete

Different measured values are measured at different points on the concrete surface. After the water has been applied to the slab surface, the resistivity of the concrete is measured daily at the reference point to determine its saturation state. This position was chosen on the side of the panel because special measurements of electrical resistivity can be made with water on top of the panel. A reading aid was recorded as the final resistivity measure in this study. The level of slab saturation is monitored by measuring the electrical resistivity of the concrete, which is directly related to the moisture content of the concrete. As soon as one plate reaches a saturated state, water can flow out while the other plate remains closed. The time limit is a major challenge for all experimental measurements because the saturation state of the concrete changes over time. This study used the Wenner method with four probes; For this purpose, the four probes touch the concrete of the reinforcing steel rail directly. From now on this measurement will be referred to as the "dry" measurement. Because each slab has a different water-cement ratio, the time required to saturate each slab not the same. Before water is applied to the slab, the electrical resistivity of the concrete is measured at certain points in the dry state. The electrical resistivity becomes constant as soon as the concrete reaches saturation.

Table 2.2: Dependence between concrete resistivity and corrosion probability [33]

Concrete resistivity ρ, kΩcm	**Probability of corrosion**
$\rho < 5$	Very high
$5 < \rho < 10$	High
$10 < \rho < 20$	Low to moderate
$\rho > 20$	Low

2.6 Tensile Strength of Reinforcement

To determine the yield strength and ultimate tensile strength peak point of the reinforcing steel bar, the concrete slabs reinforced with 10 numbers of 12mm diameter (top and bottom direction) of uncoated and coated reinforcing steel and tested under stress in an Instron Universal testing machine (UTM) to failure. A digitalized and computerized system records the results of yield strength, ultimate tensile strength, and strain ratio. To ensure stability, the remaining cut portions are used for other parameters examinations of rebar diameter before the test, rebar diameter - after corrosion, cross-sectional area reduction/increase, rebar weights- before the test; rebar weights- after corrosion, weight loss /gain of steel.

3.0 TEST RESULTS AND DISCUSSION

The results of the half-cell potential measurements in Table 1 are plotted against the Resistivity in Table 3 for ease of interpretation. 2. It is used as an indication of the probability of significant corrosion (ρ <5, 5 <ρ <10, 10 <ρ <20, ρ> 20) for very high, high, low to a moderate and low probability of corrosion. At another measurement point, the potential for correction was high (–350 mV ≤ $E\text{corr}$ ≤ –200 mV), indicating a corrosion probability of 10% or uncertain. The results of concrete resistivity measurements are shown in Table 2. It is proven that if the potential for corrosion is low (<-350 mV) within a certain range, there is a 95% chance of corrosion. Concrete resistivity is usually measured using the four-electrode method. Resistivity study data show whether certain states are conducive to lower ion movement, leading to greater and more corrosion.

Table 3.1: Potential Ecorr, after 28 days curing and 360days Accelerated Periods of Control Concrete slab Specimens

Sample Numbers	**BDS**	**BDS1**	**BDS2**	**BDS3**	**BDS4**	**BDS5**	**BDS6**	**BDS7**	**BDS8**	**BDS9**	**BDS10**	**BDS11**
	Time IntervaBD after 28 days curing											
Sampling and Durations	**Samples 1 (28 days)**			**Samples 2 (28 Days)**			**Samples 3 (28 Days)**			**Samples 4 (28 Days)**		
Potential Ecorr,mV	-112.6	-110.7	-106.5	-110.7	-107.8	-104.5	-112.9	-108.8	-104.1	-111.4	-110.4	-109.9
Concrete Resistivity ρ, kΩcm	14.25	14.25	14.24	14.23	14.23	14.39	14.39	14.38	14.37	14.37	14.31	14.23
Yield Strength, fy (MPa)	453.42	456.42	452.42	452.72	453.42	452.65	455.65	455.95	454.65	456.04	452.55	456.38
Ultimate Tensile Strength, fu (MPa)	628.90	626.85	628.53	624.31	627.84	628.26	628.06	628.86	627.46	629.01	628.51	628.37
Strain Ratio	1.39	1.37	1.39	1.38	1.38	1.39	1.38	1.38	1.38	1.38	1.39	1.38
Rebar Diameter Before Test (mm)	11.93	11.92	11.93	11.93	11.92	11.94	11.93	11.92	11.93	11.93	11.92	11.93
Rebar Diamete at 28 days(mm)	11.93	11.92	11.93	11.93	11.92	11.94	11.93	11.92	11.93	11.93	11.92	11.93
Cross-sectional Area Reduction/ Increase (Diameter, mm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rebar Weights- Before Test	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Rebar Weights- After at 28 days (Kg)	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Weight Loss /Gain of Steel (Kg) at 28 days	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.2: Potential Ecorr, after 28 days curing and 360days Accelerated Periods of Corroded Concrete slab Specimens

Sampling and Durations	**Samples 1 (90 days)**			**Samples 2 (180 Days)**			**Samples 3 (270 Days)**			**Samples 4 (360 Days)**		
Potential Ecorr,mV	-319.4	- 343.61	-340.5	-332.9	-342.7	-349.7	-383.6	-390.8	-394.9	-398.2	- 402.22	-400.4
Concrete Resistivity ρ, kΩcm	8.47	8.65	9.48	8.48	9.26	8.82	8.44	8.99	9.03	8.63	8.80	8.81
Yield Strength, fy (MPa)	418.78	421.78	417.78	418.08	418.78	418.01	421.01	421.31	420.01	421.40	417.90	421.74
Ultimate Tensile Strength, fu (MPa)	616.59	614.54	616.22	612.00	615.53	615.95	615.75	616.55	615.15	616.70	616.20	616.06
Strain Ratio	1.47	1.46	1.47	1.46	1.47	1.47	1.46	1.46	1.46	1.46	1.47	1.46
Rebar Diameter Before Test (mm)	11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.93
Rebar Diameter- After Corrosion(mm)	11.88	11.88	11.88	11.88	11.88	11.88	11.88	11.88	11.88	11.88	11.88	11.88
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Rebar Weights- Before Test(Kg)	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.87	0.88	0.88
Rebar Weights- After Corrosion(Kg)	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
Weight Loss /Gain of Steel (Kg)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table 3.3: Potential Ecorr, after 28 days curing and 360days Accelerated Periods of Boswellia dalzielii Exudate / Resin Coated Specimens

Sampling and Durations	**Samples 1 (90 days)**			**Samples 2 (180 Days)**			**Samples 3 (270 Days)**			**Samples 4 (360 Days)**		
	150µm (Exudate/Resin) coated			300µm (Exudate/Resin) coated			450µm (Exudate/Resin) coated			600µm (Exudate/Resin) coated		
Potential Ecorr, mV	-122.9	-126.6	-122.3	-120.9	-123.5	-120.3	-128.7	-124.4	-120.0	-122.3	-126.3	-117.8
Concrete Resistivity ρ, kΩcm	15.68	15.83	16.11	16.24	15.93	16.22	16.17	16.32	16.35	15.82	15.71	15.56
Yield Strength, fy (MPa)	453.41	456.41	452.41	452.71	453.41	452.64	455.64	455.94	454.64	456.03	452.54	456.37
Ultimate Tensile Strength, fu (MPa)	628.91	626.86	628.54	624.32	627.85	628.27	628.07	628.87	627.47	629.02	628.52	628.38
Strain Ratio	1.39	1.37	1.39	1.38	1.38	1.39	1.38	1.38	1.38	1.38	1.39	1.38
Rebar Diameter Before Test (mm)	11.95	11.94	11.95	11.95	11.94	11.96	11.95	11.94	11.95	11.95	11.94	11.95
Rebar Diameter- After Corrosion(mm)	12.02	12.01	12.02	12.02	12.01	12.03	12.02	12.01	12.02	12.02	12.01	12.02
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Rebar Weights- Before Test (Kg)	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.87	0.88	0.88
Rebar Weights- After Corrosion (Kg)	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Weight Loss /Gain of Steel (Kg)	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

Table 3.4: Average Potential Ecorr, after 28 days curing and 360days Accelerated Periods (Control, Corroded and Exudate/Resin Coated (specimens)

Sampling and Durations	**Control Concrete slab Specimens**				**Corroded Concrete slab Specimens**				**Boswellia dalzielii Exudate / Resin Coated Specimens**			
	Average Potential Ecorr, Values of Control Concrete slab Specimens				Average Potential Ecorr, Values of Corroded Concrete slab Specimens				Average Potential Ecorr, Values of Boswellia dalzielii Exudate / Resin Coated Specimens			
Potential Ecorr,mV	-109.7	-107.3	-108.5	-110.4	-334.5	-341.7	-389.7	-400.3	-123.9	-121.5	-124.4	-122.6
Concrete Resistivity ρ, kΩcm	14.25	14.29	14.38	14.30	8.86	8.85	8.82	8.75	15.87	16.13	16.28	15.69
Yield Strength, fy (MPa)	454.08	452.93	455.41	454.99	419.44	418.29	420.77	420.35	454.08	452.92	455.41	454.98
Ultimate Tensile Strength, fu (MPa)	628.09	626.80	628.12	628.63	615.78	614.49	615.82	616.32	628.10	626.81	628.13	628.64
Strain Ratio	1.38	1.38	1.38	1.38	1.47	1.47	1.46	1.47	1.38	1.38	1.38	1.38
Rebar Diameter Before Test (mm)	11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.95	11.95	11.95	11.95
Rebar Diameter- After Corrosion(mm)	11.93	11.93	11.93	11.93	11.88	11.88	11.88	11.88	12.02	12.02	12.02	12.02
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.07	0.07	0.07	0.07
Rebar Weights- Before Test(Kg)	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Rebar Weights- After Corrosion(Kg)	0.88	0.88	0.88	0.88	0.82	0.82	0.82	0.82	0.94	0.94	0.94	0.94
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.07	0.07	0.07	0.07

Table 3.5: Average Percentile Potential Ecorr, after 28 days curing and 360days Accelerated Periods (Control, Corroded and Exudate/Resin Coated (specimens)

	Control Concrete slab Specimens				**Corroded Concrete slab Specimens**				**Boswellia dalzielii Exudate / Resin Coated Specimens**			
	Percentile Average Potential Ecorr, Values of Control Concrete slab Specimens				Percentile Average Potential Ecorr, Values of Corroded Concrete slab Specimens				Percentile Average Potential Ecorr, Values of Boswellia dalzielii Exudate / Resin Coated Specimens			
Potential Ecorr,mV	-67.19	-68.60	-72.15	-72.40	169.87	181.21	213.30	227.89	-62.95	-64.44	-68.08	-69.50
Concrete Resistivity ρ, kΩcm	60.75	61.34	63.09	63.55	-44.16	-45.10	-45.83	-44.28	79.08	82.14	84.61	79.45
Yield Strength, fy (MPa)	8.26	8.28	8.23	8.24	-7.63	-7.65	-7.61	-7.61	8.26	8.28	8.23	8.24
Ultimate strength (N/mm2)	2.00	2.01	2.06	2.05	-1.96	-1.97	-1.96	-1.96	2.02	2.05	2.05	2.03
Strain Ratio	-5.79	-5.79	-5.81	-5.73	6.15	6.14	6.16	6.08	-5.79	-5.79	-5.81	-5.73
Rebar Diameter Before Test (mm)	0.383	0.384	0.396	0.389	0.380	0.391	0.380	0.385	0.387	0.397	0.393	0.401
Rebar Diameter-After Corrosion(mm)	0.386	0.454	0.396	0.389	-1.17	-1.20	-1.17	-1.17	0.719	0.721	0.719	0.718
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-20.90	-20.90	-20.90	-20.90	26.42	26.42	26.42	26.42
Rebar Weights-Before Test(Kg)	0.344	0.347	0.34	0.323	0.324	0.335	0.324	0.329	0.331	0.341	0.337	0.345
Rebar Weights-After Corrosion(Kg)	13.81	13.93	13.93	13.81	-12.55	-12.55	-12.63	-12.55	14.36	14.36	14.46	14.36
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	-16.92	-16.92	-16.92	-16.92	20.37	20.37	20.37	20.37

3.1 Results of Concrete Resistivity ρ, kΩcm and Potential Ecorr, mV, on Concrete Slab Members

Reinforcement corrosion is still one of the most common and important causes of degradation of reinforced concrete structures built within the costal marine environmental with unique severity. Chloride ion and carbon dioxide attack structures causing chemical changes in the concrete solution through the pores they creating decay of a thin protective layer, called the passivation layer, which forms on the surface of steel under alkaline conditions.

The results of corrosion potential $E_{corr,}$ mV and concrete resistivity kΩcm are obtained from Tables 3.1 - 3.3 and summarized into average and percentile values in Tables 3.4 and 3.5, plotted graphically in Figures 3.1-3.8b, are the result of uncoated and coated samples for 36 concrete slabs, divided into 3 sets of 12 controlled samples which are the determinant reference range, 12 uncoated samples (corroded) and 12 exudate/resin coated samples.

The average and minimum and maximum percentiles of concrete resistivity with a controlled sample potential differential were 14.25kΩcm and 14.38kΩcm (60.75% and 63.55%) and the differential values were 0.13kΩcm and 2.8%, respectively. The corrosion samples were 8.75kΩcm and 8.85kΩcm (-45.83% and -44.28%), the different values were 0.1kΩcm and 1.55% and the coated samples were 15.69kΩcm and 16.28kΩcm (79 0.08% and 84.61%) and the different values are 0.59 mV and 5.53%, respectively. The maximum stability value calculated concrete resistivity from the controlled concrete sample was 63.55% compared to the corroded and coated values -44.28% and 84.61%, and the maximum controlled differential percentile was 2.8% compared to the corroded and 1.55% values and 5.53% coverage. The test results of controlled and coated samples with concrete resistance got a maximum average value of 14.38kΩcm and 16.28kΩcm with a value of 10 <ρ <20 (low) compared to a corrosion value of 8.85kΩcm with an indication of 5 < 10 (high) and the reference range of the relationship between concrete resistance and corrosion probability with significant corrosion probability (ρ < 5, 5 < < 10, 10 < < 20, > 20) for very high, high, low to moderate and low, for probabilistic corrosion From the result of comparison of coated and corrosion samples, the maximum values obtained for both samples clearly indicate the value of coated samples in the range of 10 < 20 , which classifies the range from low to moderate, with information such as significant corrosion probability. The maximum value of the corroded sample is in the range of 10 < < 20, which indicates high signs that the sample is present, indicating the possibility of corrosion, which was confirmed in the work [16, 19, 17, 22, 20, 21]. From the results obtained it can be compared that the effect of corrosion attack was observed in the uncoated samples, while the samples with exudates/resin coating had corrosion protection properties with highly resistant and water-resistant membranes that prevented corrosion of reinforcing steel structures. From the results obtained, it can be compared that the effect of corrosion attack was observed in uncoated samples, while samples with exudates/resin coating had anti-corrosion properties with highly resistant and water-resistant membranes that prevented corrosion of concrete. The reinforcing steel plate is embedded and exposed to the induced accelerated corrosion medium.

The average and percentile of the minimum, maximum, and corrosion potential differential measurements calculated from the semi-cellular measurements were the controlled values of 110.4 mV and -107.3 mV (-72.4% and -67.19%) with a potential differential of 3.1 mV and 5.21%), the corroded samples were -400.3 mV and -341.7 mV (169.87% and 227.89%), the different values were 58.6 mV and 58.02% and the sample coated are -124.4 mV and -121.5 mV (-69.5% and -62.95% and the potential differential is 2.9 mV and 6.55% respectively from the maximum control value calculated from the percentile is 67 ,19% compared to the corroded and coated values of 227.89% and -62.95% and the differential in values controlled for corrosion potential is 5.21%, corroded 58.02% and coating 6.55%.

The maximum obtained and corrosion potential values of the controlled and coated samples were -107.3 mV and -121.5 mV, indicating the relationship between corrosion potential and probability as $Ecorr > -200\text{mV}$ as the reference range. The results of this potential Ecorr result show that the value of controlled and resin-coated samples is low with a 90% probability that no corrosion of reinforcing steel is observed during the measurement (10% risk of corrosion, which averages 10% for samples without coating obtained maximum value - 341.7mV, the result lies in the correlation reference value between the corrosion potential value -$-350\text{mV} \leq Ecorr \leq -200\text{mV}$ indicating a high range of values, 10% or indicating corrosion uncertainty The sample shows corrosion due to accelerated induced corrosion compared to the coated sample which does not show corrosive attack on the reinforced reinforcement embedded in concrete exposed to a corrosive environment by forming a stable layer.

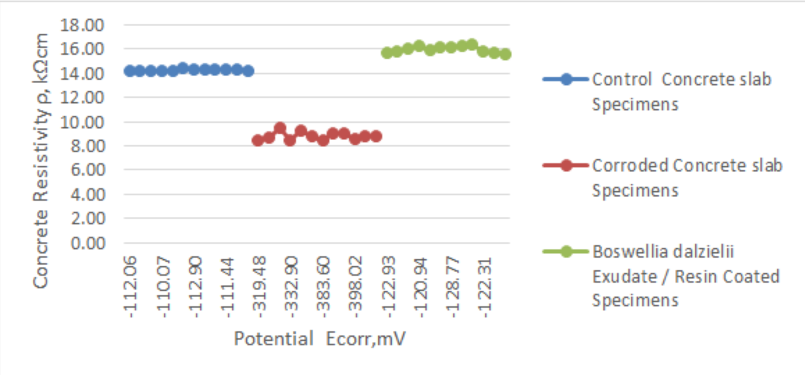

Figure 3.1: Concrete Resistivity ρ, kΩcm versus Potential Ecorr,mV Relationship

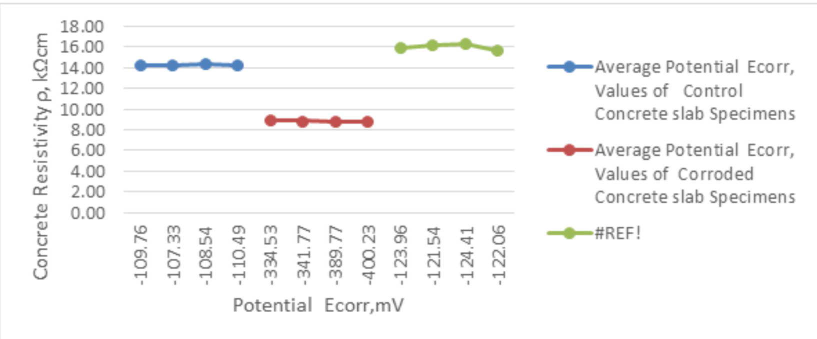

Figure 3.1A: Average Concrete Resistivity versus Potential Relationship

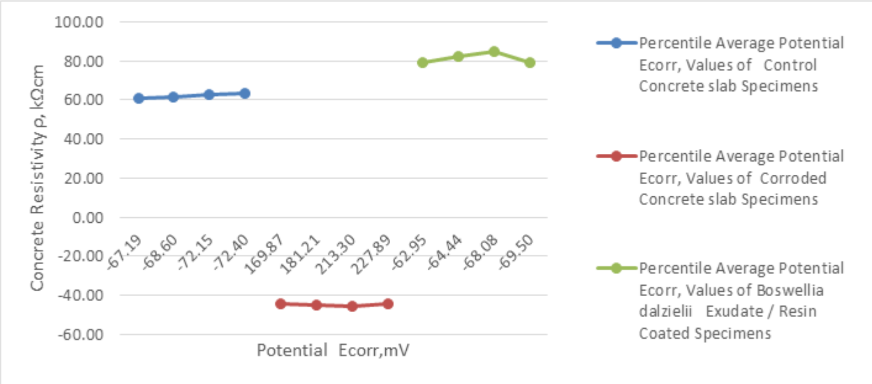

Figure 3.1B: Average Percentile Concrete Resistivity versus Potential Relationship

3.2 Results of Mechanical Properties of Yield Strength, Ultimate Strength and Strain Ratio of Embedded Reinforcing Steel in Concrete Slab

Deterioration of the structural strength of corroded reinforced concrete is very common, especially inmarine construction prone to corrosion, in road and bridge construction and construction in saline areas, corrosion of steel [34]. The damage to life and property caused by the corrosion of steel should not be neglected. Steel corrosion has a very bad impact in design features: effective cross-sectional area, nominal yield strength, breaking strength, and elongation rate are reduced by corrosion products; With the corrosion growth rate of steel and the influence of environmental factors, the quality of the corroded intermediate joint deteriorates. The average values, percentiles and differentials between the minimum and maximum values of ultimate tensile strength, fu (MPa) of the controlled samples were 626.8MPa and 628.63MPa (2.0% and 2.06%) and the different values were 1.83MPa and 0.06%. They corroded 614.49MPa and 616.32MPa (-1.97MPa and -1.96%) and a differential of 1.83MPa and 0.01%, coated of 626.81MPa and 628.64MPa (2.02 % and 2.05% and various values 1.83MPa) and 0.03%. The calculated maximum percentile ultimate tensile strength of controlled tensile strength is 2.06% compared to corrosion and coating values of 1.96% and 2.05%, and the possible differential values are 0.06% controlled, 0.01% corroded and 0.03 % coated.

The strain ratio of the average minimum and maximum deformation, percentile and various controlled sample values were 1.38 and 1.38 (-5.81% and -5.73%) with different values of 0.00 and 0.08%, the sample values being Corrosion values were 1.46 and 1.47 (6.08% and 6.16%) and the differential values were 0.01 and 0.08%, coated samples were 1.38 and 1.38, -5, 81% and - 5.73%) and the differential value of 0.00 and 0.08%. The maximum percentile calculated for comparison controlled -5.73% versus corroded 6.16% and closed -5.73%, and various peaks controlled up to 0.08% corroded 0.08% and covered 0.08%, as in confirmedwork [16, 19, 17, 22, 20, 21].

The yield strength fy (MPa) average, percentile and the differential results of the minimum and maximum obtained values of the controlled sample were 452.93MPa and 455.41MPa (8.23% and 8.28%) and the differential value was 2.48MPa or 0.05%. The corroded samples were 418.29MPa and 420.77MPa (-7.65% and -7.61%) and the differential values were 2.48MPa and 0.04%, the coated sample values were 452.92MPa and 455.41MPa (8.23% and 8.28%) and the differential between 2.49MPa and 0.05%. The calculated maximum percentile yield strength value of the controlled shear strength is 8.28% compared to the corrosion and coating values, or -7.61% and 8.28% and the controlled potential differential values are 0.05%, corrosion is 0.04% and 0.05% coated.

The results of the calculations, which are summarized in Tables 3.4 and 3.5 and shown graphically in Figures 3.1 - 3.8, were used to determine the yield strength, tensile strength and deformation ratio of the avearge, percentile and controlled values of the differential potential concrete slab samples, uncoated (corroded) and coated, the coated sample has a higher failure load compared to the corroded sample with reduced failure force and low load bearing capacity and with the avearge and percentile values compared to the reference area, while the uncoated (corroded) sample has a bearing capacity low load and lower value compared to the reference area. The comparison results show that the low load carrying capacity is caused by the effect of corrosion attack on the exposed (corroded) elements, which damage reinforcing steel fibers, ribs and passive formations and surface modifications. The avearge values observed for the coated samples relate to the corrosion resistance potential to penetrate the reinforcing steel to form a protective membrane; This attribute indicates the effectiveness and effectiveness of the exudate/resin as an inhibitor against corrosive effects. exposed reinforced concrete structure on the edge of a strong sea area with high salinity.

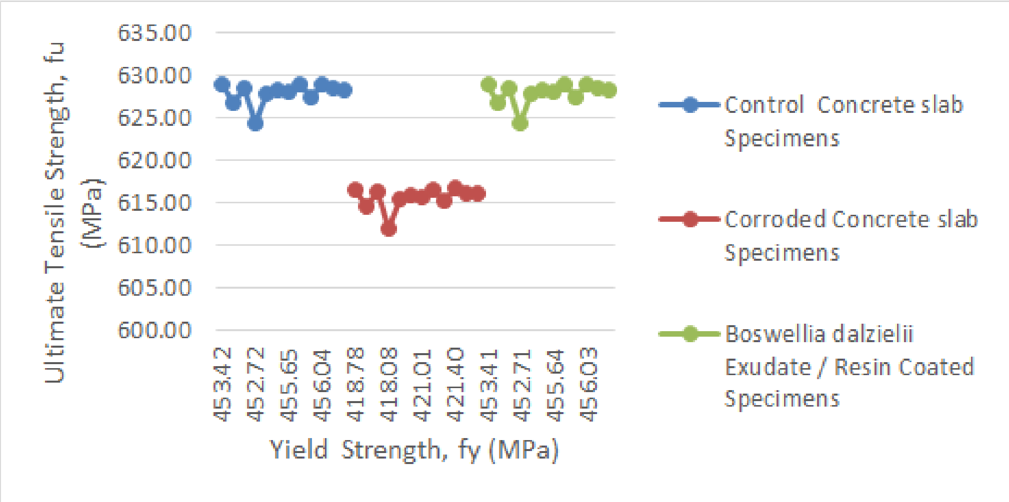

Figure 3.2: Yield Strength versus Ultimate strength

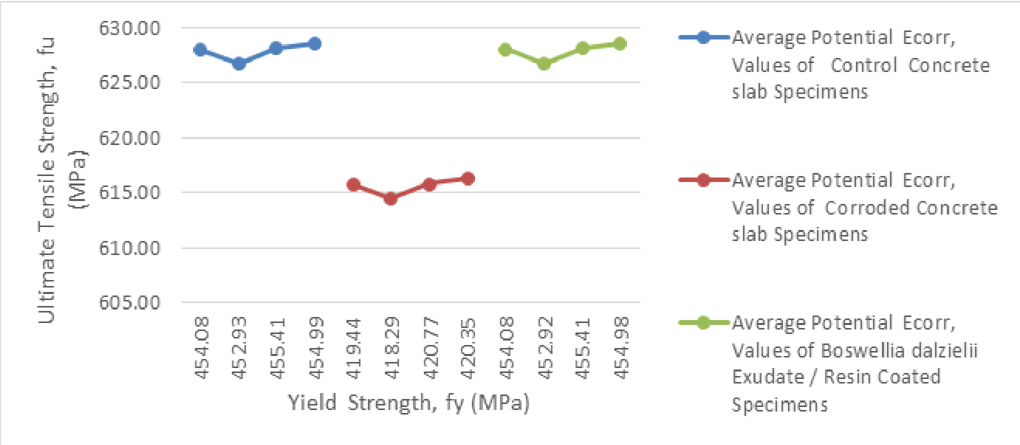

Figure 3.2A: Average Yield Strength versus Ultimate Tensile Strength

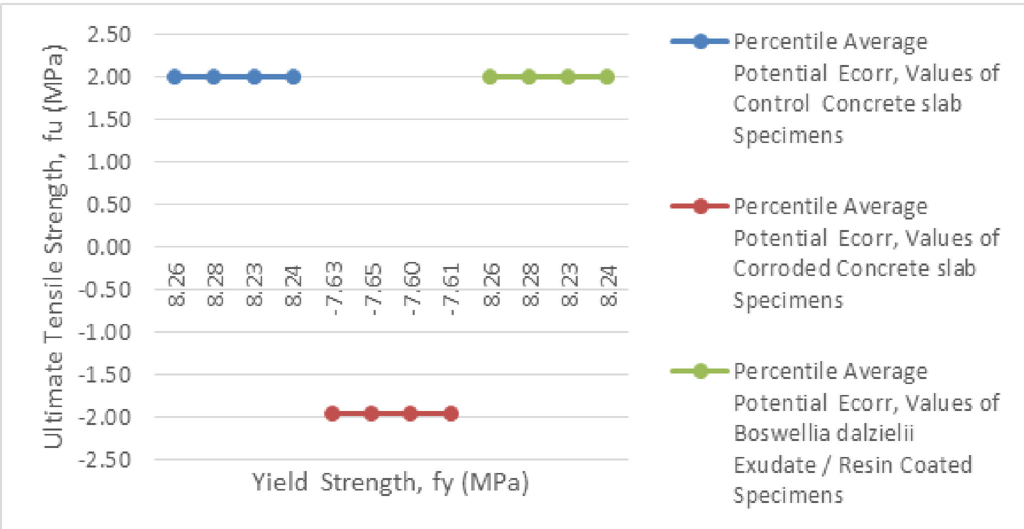

Figure 3.2B: Average Percentile Yield Strength versus Ultimate Tensile Strength

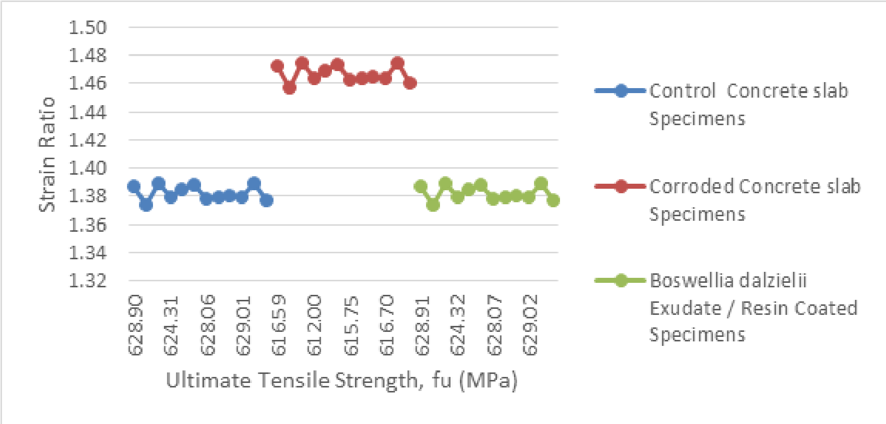

Figure 3.3: Ultimate Tensile Strength versus Strain Ratio

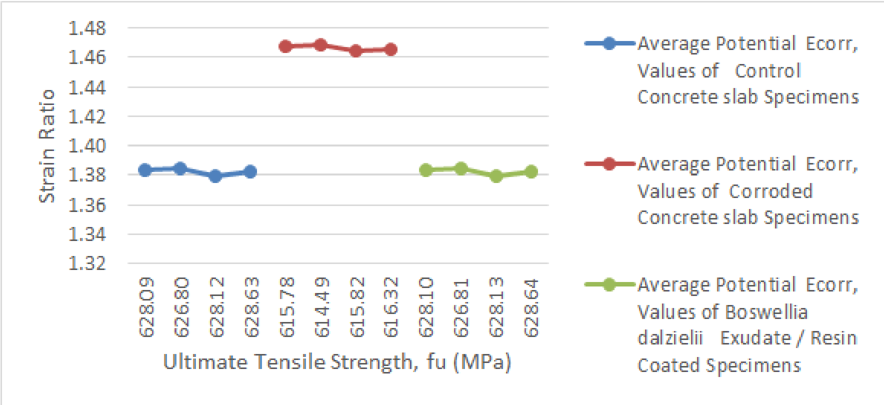

Figure 3.3A: Average Ultimate Tensile Strength versus Strain Ratio

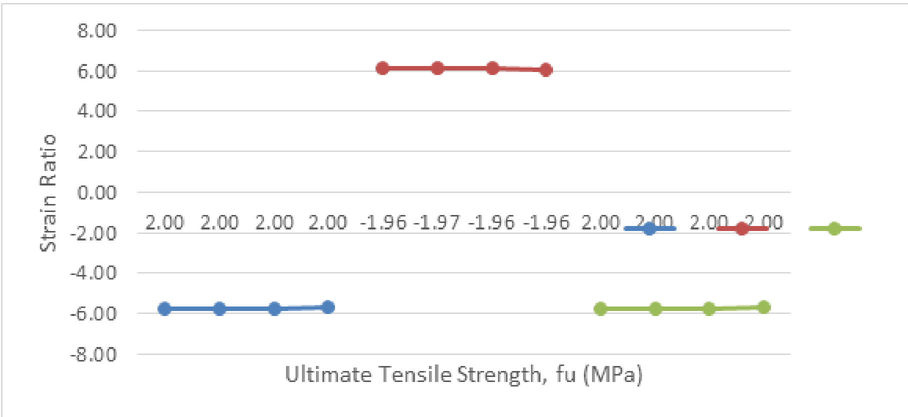

Figure 3.3B: Average percentile Ultimate Tensile Strength versus Strain Ratio

3.3 Results of Mechanical Properties of Rebar Diameter, Cross-Sectional Area of Embedded Reinforcing Steel Concrete Slab

Active corrosion of reinforcement is thermodynamically favorable, which leads to the occurrence of two main damage mechanisms, namely a reduction in the cross-sectional area of steel bars and an expansion in the volume of the corrosion product produced. The effects of steel corrosion are observed at many levels: at the structural level, such as a reduction in the ultimate load-bearing capacity of the structure and the ability to redistribute loads due to changes in failure modes; at a global level, such as reduction of bending and critical capacity; and at the local or material level, such as reduced bond between steel and concrete due to cracks in joints and changes in the material properties of steel reinforcement.

The results of rebar diameter before testing (mm), the minimum and maximum average and percentile values were controlled from 11.93 mm and 11.93 mm (0.383% and 0.396%) with a differential of

0.00 mm and 0.013%, respectively. the corrosion values of the samples were 11.93 mm and 11.93 mm (0.38% and 0.391%) and the different values were 0.00 mm and 0.011%, and the values for the coated samples were 11.95 mm and 11.95 mm%) and 0.401 mm and different calculated values of 0.00 mm and 0.014%).

The unit weight of reinforcement before the corrosion test showed smaller differentials based on the shape of the product and the company and by-products used in obtaining the minimum and maximum values obtained for the average, percentile and differential in diameter of reinforcement after corrosion (mm) for a controlled sample of 11.93 mm. and 11.93 mm (0.383% and 0.396%) with a differential of 0.00 mm and 0.013%, because the reference value was maintained at 100%, the corroded sample values were 11.88 mm and 11.88 mm (-1.2% and -1.17%) and the differential between n is 0.00 mm and 0.03%, the values of coated samples are 12.02 mm and 12.02 mm (0.718 .) % and 0.721%) and the differential is 0.00 mm and 0.003%. The maximum calculated percentile of corroded is 0.396% versus -1.17% and coated is 0.721%, the differential in the percentile of corrosion is 0.03% versus 0.003% coated. The results obtained in Tables 3.4 and 3.5, which are summarized in Tables 3.1, 3.2 and 3.3 and shown graphically in Figures 3.3-3.6b, show the effect of corrosion attack on reinforcing steel embedded in the concrete slab, the acceleration of the induction of corrosion activity. For comparison, the results of corroded samples showed reduction and reduction values compared to the diameter of the reinforcement before and after accelerated induction corrosion testing with a percentile decrease in value from 0.396% to -1.17% and an average value in the range of 11.93mm to 11.93mm.

The decrease / increase (diameter) of the average value and the minimum and maximum percentile of the cross-sectional area were checked to 100%, without decreasing or increasing after 360 days of immersion in fresh water. Corroded sample values were 0.05 mm and 0.05 mm (-20.9% and -20.9%) and the differential in % of the corroded, closed sample values were 0.07 mm and 0.07 mm (26, 42% and 26.42%) and the differential between 0.00 mm and 3.29%. The differential in average and relative percentile between coated and corroded samples varied from 26.42% to -20.9%. The decrease in average and percentile values indicates that the corrosion effect has led to a reduction in diameter and cross-sectional area, fiber degradation, rib reduction and surface modification, while elements coated with exudates/resin confirm an increase in volume as thickness as there are shift differentials [16, 19, 17, 22, 20, 21].

In summary, the exudates/resin has the property of inhibiting the corrosive effect of the reinforcing steel embedded in the concrete slab sample, induced in a high salinity environment.

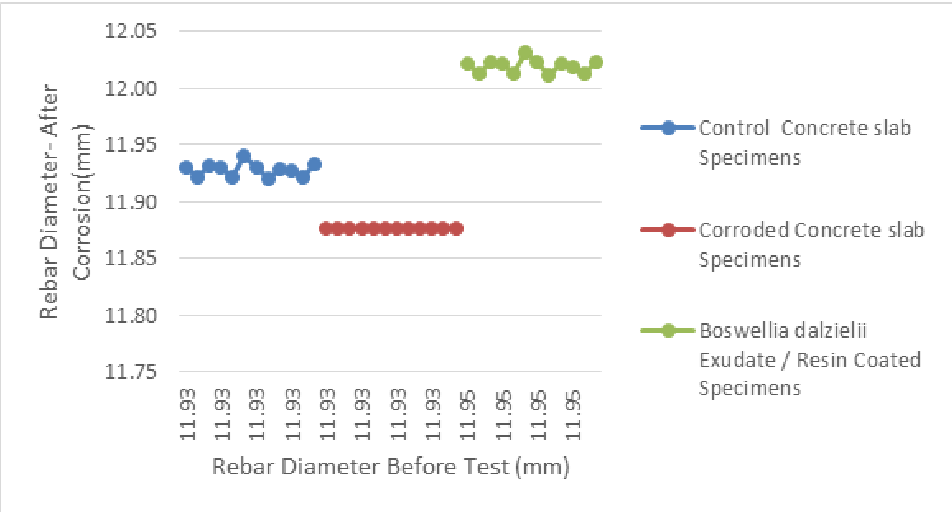

Figure 3.4: Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

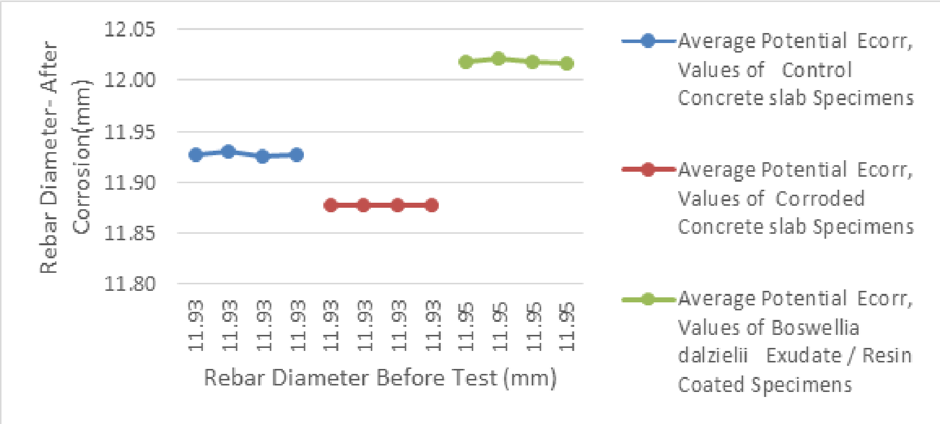

Figure 3.4A: Average Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

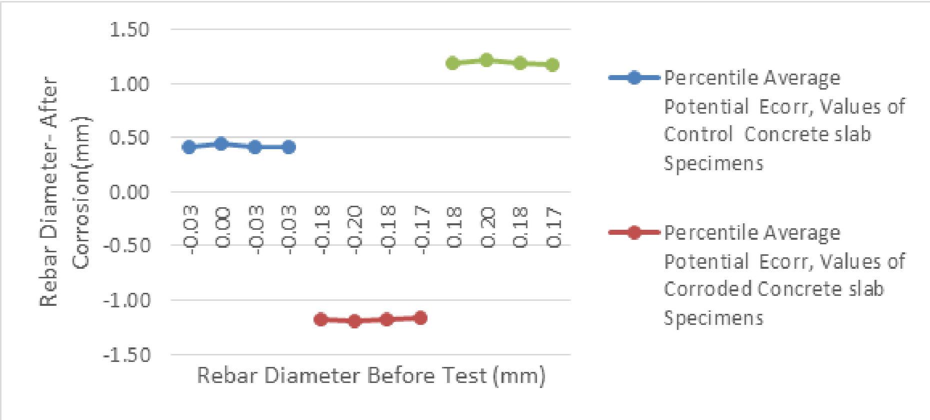

Figure 3.4B: Average Percentile Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

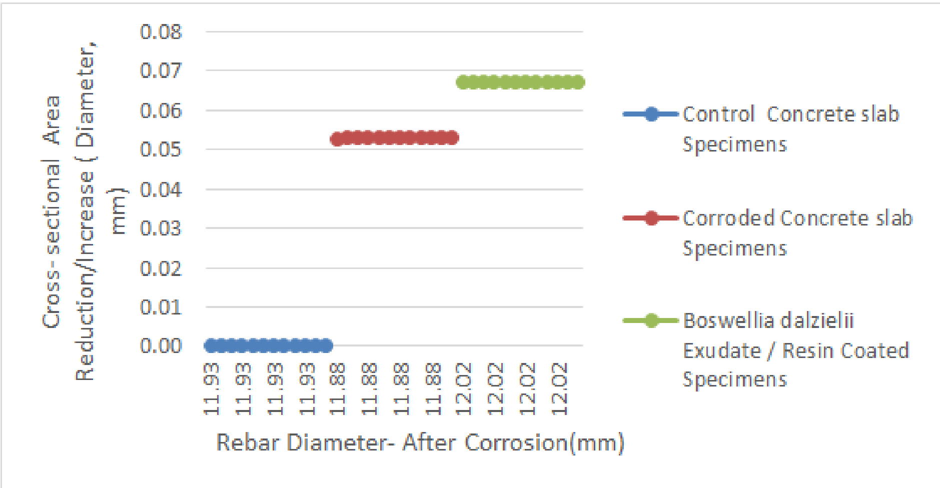

Figure 3.5: Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

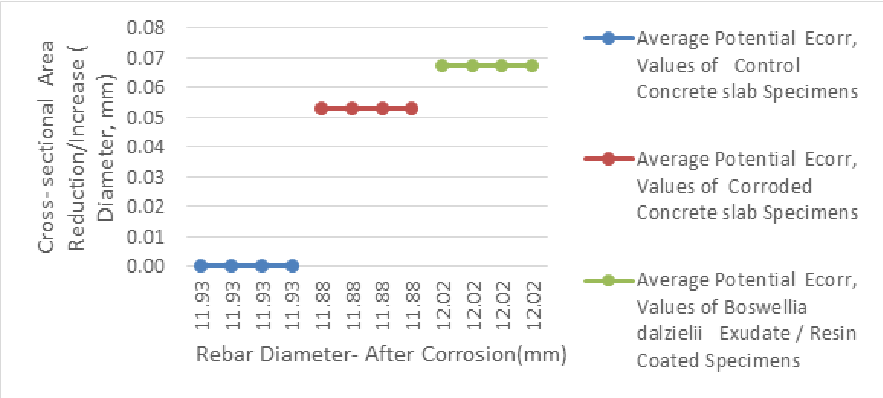

Figure 3.5A: Average Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

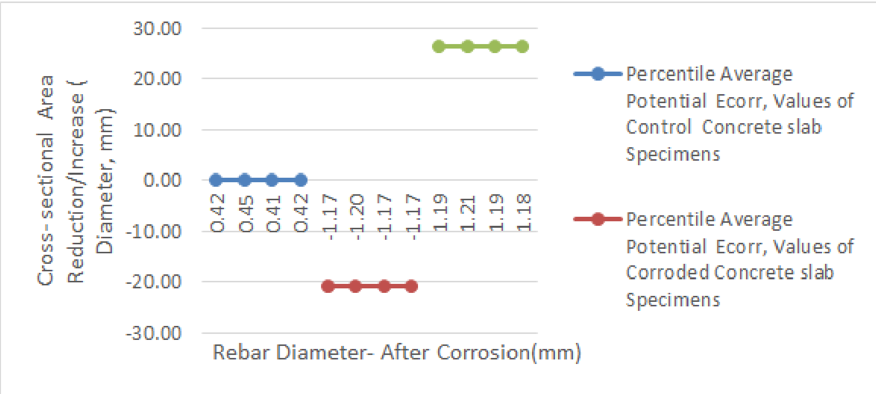

Figure 3.5B: Average Percentile Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

3.4 Results of Mechanical Properties of Rebar Unit Weight Loss / Increase of Embedded Reinforcing Steel in Concrete Slab

The value of rebar unit Weight - Before Test (kg), the minimum, maximum and differential average and percentile of controlled samples were 0.88kg and 0.88kg (0.323% and 0.347%) and the differential was 0% and 0.024%, corroded samples were 0.88 kg and 0.88kg (0.324% and 0.335%) and the differential was 0.00% and 0.01%, coated samples were 0.88kg and 0.88kg (0.331% and 0.345%) with a differential of 0.00% and 0.014%. The results of the average value and percentile of reinforcement weight after corrosion (Kg) and the total differential between the minimum and maximum values of the controlled samples were 0.88kg and 0.88kg (13.81% and 13.93%), and the differential value is 0.0% and 0.12%, the samples corroded 0.82kg and 0.82kg (-12.63% and -12.55%), and the differential is 0.00% and 0.08%, the values of the coated samples were 0.94kg and 0.94kg (14.36% and 14.46%) and the differential was between 0.00% and 0.1%. The average and minimum and maximum unit loss/gain in percent steel (Kg) and percent differential are values maintained at 100% as a result of aggregation in freshwater reservoirs with no trace of corrosion potential compared to sample corrosion values of 0.05 kg and 0.05 kg (-16.92% and -16.92%) and with layers 0.07kg and 0.07kg (20.37% and 20.37%). The calculation results in Tables 3.1-3.3 and 3.4 - 3.5 are summarized and plotted in Figure 3.7-3.8B, listing the effects of corrosion on uncoated (corroded) and coated reinforcing steel and the unit weight of the reinforcement before and before corrosion. For comparison, the results obtained unit weight loss/gain showed a reduction/reduction and reduction of the average and percentile values for the coating from 0.07 kg to 0.05 kg and corroded 20.37% to -16.92%, as confirmed in the work [16, 19, 17, 22, 20, 21]. The combined results show that the corrosive effect on the corroded samples causes a decrease/decrease in weight compared to coatings with percentile load and an increase in the average value, causing a slight increase in volume with coating thickness. This study demonstrates the efficacy and effectiveness of exudate/resin as an inhibitor against the effects of corrosion on reinforcement embedded in a sample of concrete slab exposed to induced corrosion.

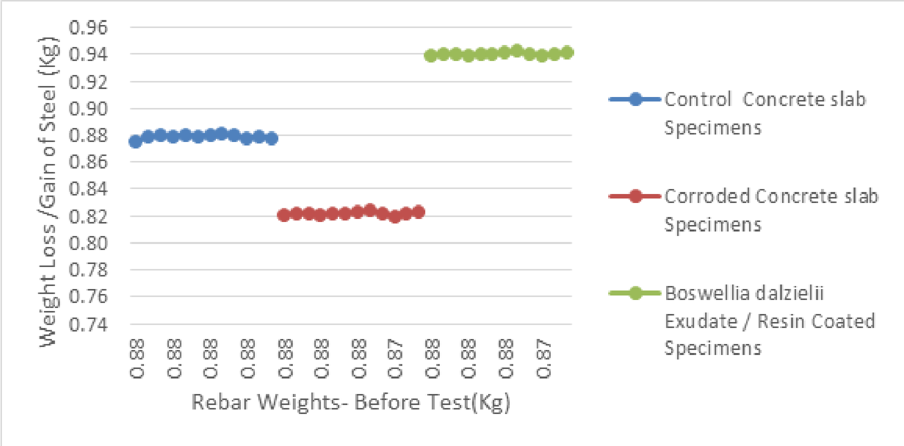

Figure 3.6: Rebar Diameter - After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

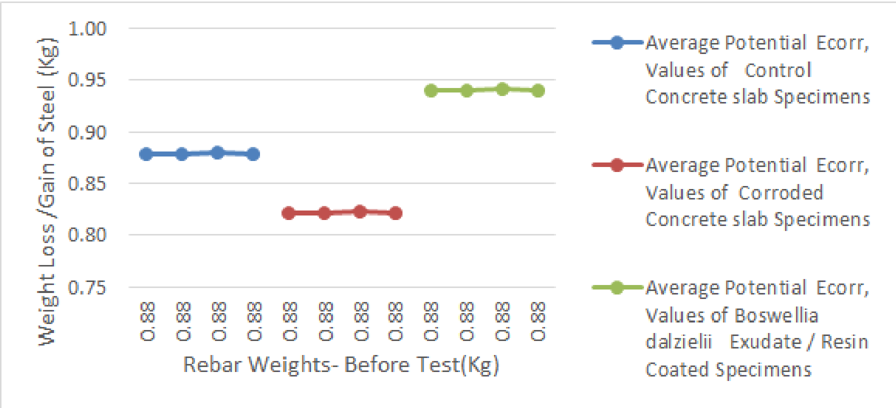

Figure 3.6A: Average Rebar Diameter - After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm

Figure 3.6B: Average Percentile Rebar Diameter - After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

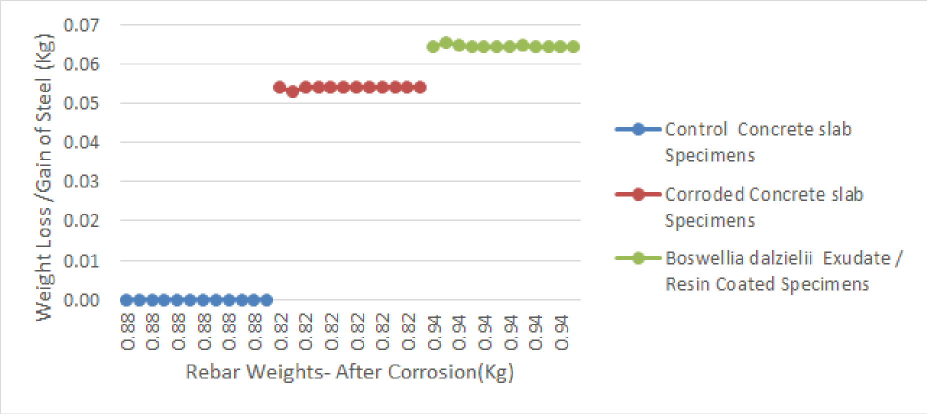

Figure 3.7: Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

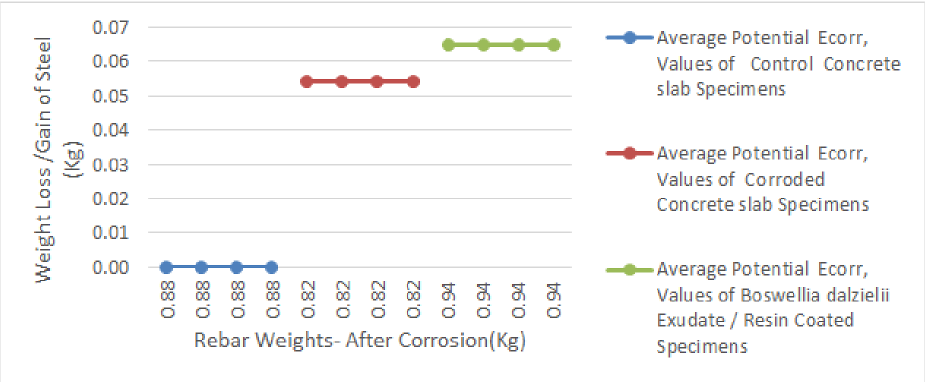

Figure 3.7A: Average Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

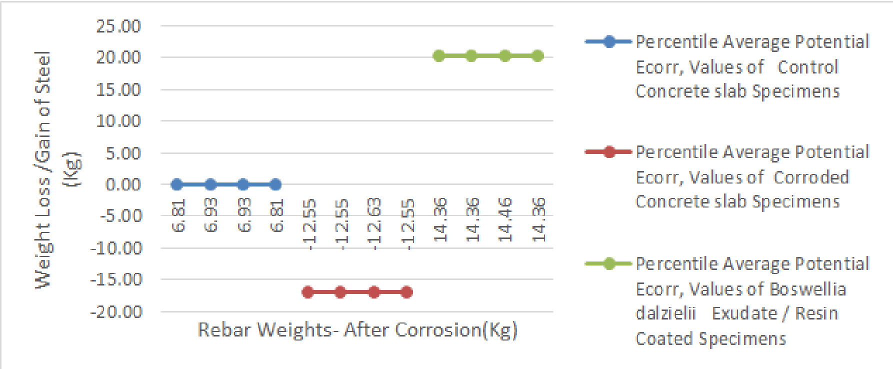

Figure 3.7B: Average Percentile Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

4.0 CONCLUSION

Experimental results showed the following conclusions:

i. Coated reinforcing steel showed no indications of corrosion presence.
ii. Boswellia dalzielii exudates / resins showed an inhibitory properties against corrosion attacks.
iii. Reduction in diameter and cross-sectional areas were noticed in corroded samples.
iv. Weight loss was witnessed in corroded samples while inhibited samples exhibited minute volumetric increase.
v. Yield strength and ultimate tensile strength reduction was noticed in corroded samples resulting from corrosion effect.
vi. The corroded sample maximum value is within the range of $5 < \rho < 10$ indicating high, the signs showed the presence of corrosion probability.

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