Electrochemical Evaluation of Corrosion Potential and Electrical Resistivity of Rebar in Chloride Induced Media

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ABSTRACT

The Investigative work examined the use of treculia africana exudate/resin, tapped from tree trunks with potentiality of environmentally stable properties of non-hazardous. The resulting exudate/resin is coated directly with reinforcing steel of different thicknesses, embedded in concrete slabs, and exposed to sodium chloride (NaCl) for corrosion acceleration process and examined varying surface modification for 360days. The results of corrosion potential of maximum calculated percentile control value is -67.19% compared to the corroded and coated values of 227.89% and -62.95% and the controlled potential difference value is 5.21%, corroded 58.02%, and coated 6.55%. The results of controlled and coated samples with concrete resistance at the maximum average value are 14.38 kΩcm and 16.28kΩcm with a description of the value 10 <ρ <20 (low) compared to the corrosion value of 8.86kΩcm with specifications 5 <ρ < 10 (high) and with a reference range of dependence between concrete resistance and corrosion probability at significant corrosion probability (ρ < 5, 5 < ρ < 10, 10 < ρ < 20, ρ > 20) for very high, high, low to moderate and low, for corrosion probability. The calculated maximum percentage value of the controlled yield strength was 8.28% compared to the corroded and coated values -7.61% and 8.28% and the possible difference values were 0.049% controlled, 0.04% corroded, and 0.049% coated. The maximum calculated percentage of the maximum controlled tensile strength is 2.00% relative to the corrosion and coating values -1.97% and 2.00% and the potential difference value is 0.03% checked, 0.01% is corroded and 0.01% coated -5.73%, and differential peak controlled 0.079%, corroded 0.08% and coated 0.07%. For comparison, the results of the corroded samples showed reduction in values compared to the diameter of the reinforcement before and after the induction accelerated corrosion test with a percentage reduction in value from 0.344% to -1.17% and an average value in the range from 11.99 mm to 11.88mm. For comparison, the results obtained showed a reduction and reduction in the mean and percentile values for coatings from 0.07kg to 0.50kg and corrosion 20.37% to -16.92%.The aggregate results show that the corrosion effect causes a reduction in weight/reduction of the corroded sample compared to the percentile layer and an increase in mean, resulting in a slight increase in volume around the layer thickness..

Key Words: *Corrosion, Corrosion inhibitors, corrosion potential, concrete resistivity and Steel*

Reinforcement

1.0 Introduction

The reduction of the effects of corrosion that occur when steel reinforcement is embedded into reinforced concrete structures such as protective coverings, cathodic protection, and corrosion protection have been researched and investigated by many. Corrosion produces partial pressures on the steel reinforced concrete thus leading to initial deviations and negatively to the service life of the structures. Chlorides are known to be imported into concrete by several sources (Morris et al. [1], Ann and Song, [2]), stated that concrete containing chloride ions from seawater and aggregates can be used as a speeding agent.

Global environmental problems are on the rise and are likely to influence future selection of corrosion inhibitors. Inhibitors and Greener pathway inhibitors are highly effective and natural, free of toxicity, usually, cheap and cheap for future use, depending on these properties, there is a great need for green inhibitors for biomaterials because of their innate properties.

The use of corrosion inhibitors is probably the most attractive from an economical point of view and with ease of use; inhibitors are widely used to delay the emergence of corrosion.

Novokshcheov [4] studied and showed that calcium nitrite does not in any way damage the concrete structures as seen in the case of sodium or potassium-based inhibitors.

Skotinck [5] and Slater [6] showed that considering the longer-term trial, calcium nitrite was better in terms of strength.

Charles et al. [7] investigated the electrochemical processes that led to electron transfer during the corrosion process of steel reinforcement in a harsh marine environment with a high chloride content. Corrosion tests were carried out on 12 mm high strength reinforcing steel bars, the rough surfaces of the samples were treated with Symphonia globulifera resin extract with different layer thicknesses, polished and embedded in concrete slabs. Control samples, non-inhibited samples, and resin-inhibited samples were cured for the first 28 days and the corrosion acceleration process with sodium chloride lasted 119 days with a verified reading interval of 14 days. Compared to the corroded sample, the corroded sample showed a 70.1% increase in the potential value of Ecorr, mV and a 38.8% decrease in the value of the concrete strength, the tensile stress relative to the maximum force compared to corrosion, due to the 100% nominal extension of the strength of 103 0.06% to 96.12% reduction and a 67.5% weight reduction compared to 48.5% and a 47.80% reduction to 94.82% of the cross-sectional diameter, both of which had reduced corrosion values compared to the exhibit cover sample.

Charles et al. [8] investigated the strength of corrosion, concrete formulation and rigorous testing of the non-corroded, corroded and coated reinforced concrete cast member. Direct application of the corrosion inhibitor of dacryode edulis resins in size 150μm, 250μm and 350μm was integrated into a 12mm thickness, placed in a concrete slab and exposed to a corrosive environment for 119 days for accelerated corrosion test, half-cell potential measurements, concrete resistivity measurement and tensile tests. Compared with the corroded samples, the corroded has 70.1% increased values and 38.8% reduced concrete resistivity, producing greater compressive strength.

Charles et al. [9] investigated the effects of chloride attack on reinforcing steel embedded in reinforced concrete layers built into the marine environment. Experimental work has measured the rapid process with the acceleration process of the non-coated and inhibited acardium occidentale l.

of coating thicknesses of 150µm, 250µm and 350µm, fixed to a concrete slab and placed in sodium chloride and accelerated for 119 days using the Wenner method, by placing the four connected surfaces concrete directly above the reinforcing steel line and assess the viability of the cell component, the concrete size and the tensile strength of the corrosion rigidity. Compared to corrosive samples, the corroded has 75.4% increased values of Ecorr, mV and 33.54% reduction in concrete resistivity.

Charles et al. [10] investigated the potential for estimating possible corrosion rates by measuring half-cell potential tests, concrete resistance tests and tensile tests, mechanical properties of reinforcement that were not corroded, corroded and retarded with Moringa Oleifera laminated resin paste made from wood extract. The sample was immersed in concrete and accelerated in a corrosive environment for 119 days. The average percentage of Ecorr potential, mV and concrete resistance are 29.9% and 68.74%, respectively. Compared to the corroded sample, the corroded sample showed a 70.1% increase in the potential value of Ecorr, mV and a 35.5% decrease in the resistance value of concrete. The results of the calculation of the average percentage of stress at the melting point compared to corrosion because 100% nominal melting point decreased from 105.75% to 96.12% and weight loss was 67.5% compared to 48.5% and 48.34% to 94.82%, area reduction, both of which showed lower corrosion values compared to the coated samples.

Charles et al. [11] investigated the use of inorganic inhibitors and greener method inhibitors to evaluate potentiality of corrosion studies using mangifera indica resins paste residues deposited to stabilize the reinforcing steel. The average results for the corrosion potential Ecorr, mV, and concrete resistivity are 26.57% and 61.25%, respectively. Compared to corrosive samples, it produced higher values of 70.1% of Ecorr mV strength, and 38.8% of concrete decrease, subtracted total compression pressures and average sulfur content generated by 100% higher values and reduced to maximum strength 105.36% to 96.12%, the decrease in weight compared with the cross-sectional reduction decreased due to the decrease from sodium chloride from attacks.

Charles et al. [13] evaluated the efficacy of natural herbicide inorganic inhibitors exudates / resins extracts of Symphonia globulifera linn, Ficus glumosa and Acardium occidentale. The Uninhibited and inhibited reinforcement with exudates / resins of 150µm, 250µm and 350µm thicknesses was added to a concrete slab with exposed surfaces, sodium chloride solution and accelerated frequency and calculated repetition rates for the average yield stress compared to the average strength as the 100% yield strength decreased with total strength from 103.06% to 96.12%, 112.48% to 89.25%, and 108.38% to 90.25% of symphonia globulifera linn, Ficus glumosa and acardium occidentale l respectively, the weight reduction found in symphonia globulifera linn specimens are 67.5% versus 48.5%.

Daso et al. [14]) Evaluated the use of original inorganic eco-friendly exudates / resin extract from cola acuminate, as a preventive measure for the corrosive action of salt water attack on embedded reinforcing steel in seawater concrete structures using an experimental application of half-cell potential Ecorr,mV The probability of immersion and applied currents for 150 days in a fast corrosive medium embedded in a concrete slab of uncoated and exudates / resin coating samples to observe the change in the surface condition is in the range of 200 mV to 1200mV, with a scan rate of 1mV / s. The results showed a high ultimate yield of the corroded specimens to control and coating specimens due to the effect of corrosion on the mechanical properties of steel reinforcement. The results of the weight loss of steel showed a high percentage of values against the control and coating models due to the effect of corrosion on the mechanical properties of the steel.

Letam et al [15] reported on concrete slab structures embedded with exudates/resins coated and non-coated reinforcing steel immersed in corrosion media using Wenner accelerated four-inspection methods. The results showed a higher yield of corrosion samples in non-coated over coated samples due to corrosion impact on the mechanical properties of steel reinforcement. Steel weight loss results showed higher percentage values of non-coated against the control and coating models due to the impact of corrosion on the mechanical properties of the steel.

Nelson et al. [16] investigated the application of environmentally friendly inorganic exudates/resins extracted from the bark of Invincia gabonensis, coated to reinforce steel with different thicknesses and non-coated members, and immersed in sodium chloride for corrosion testing in a 150-day rapid process with a flow rate of 200 mV by 1200mV with a scan rate of 1mV / s. The overall results of the exudates/resin coating samples showed no indications of corrosion potential, results showed that Invincia gabonensis exudates/resins were good corrosion inhibitors. Cross-sectional area reduction results showed higher percentage reduction values as fiber loss was negative on the mechanical properties of steel as a result of corrosion potential. The results of the weight loss of steel showed a high percentage of values against the control and coating models due to the effect of corrosion on the mechanical properties of the steel.

[Kanee et al. [17] investigated the strength of steel reinforcement with the introduction of milicia excelsa exudates/resins to minimize surface modifications and mechanical properties of reinforcing steel in concrete structures by corrosion accelerated process of 150 days. Overall the experimental results showed that the corrosion properties of spills and cracks in the coating members indicate a low flexibility failure load. The effect of corrosion on the mechanical properties of reinforcing steel on depleted (controlled) members has not been observed.

Gregory et al. [18] evaluated steel reinforcement modifications and mechanical properties of exudates /resins coated and non-coated reinforcing steel embedded in concrete members and exposed to corrosive media. The results showed a higher yield of corrosion values in non-coated specimens over coated specimens due to the impact of corrosion on the mechanical properties of steel reinforcement. Steel weight loss results showed higher percentage values against control and coated specimens due to the impact of corrosion on the mechanical properties of steel.

Philip et al [19] examined the use of acacia senegal exudates/resins tree extract as corrosion inhibitors. Reinforcing steel of non-coated and exudates/resins paste coated with varying thickness were embedded in concrete and immersed in corrosive media for 150 days in an accelerated process. The results of percentile average potential Ecorr corroded values are -230.4854% versus -69.7415% and -67.3178% for control and coating samples. The potential Ecorr results ($-350\text{mV} \leq E\text{corr} \leq -200\text{mV}$) showed that the values of the corroded specimens with the range are high, indicating an uncertain probability of 10% or corrosion. Concrete resistivity ρ, the mean value of kΩcm percentage -48.9081%, 95.72572%, and 114.8917% of control and coating samples. The range of values for corrosion models indicated significant corrosion (moderate).

2.1 Materials and Methods

2.1.1 Aggregates

Fine and coarse aggregates are purchased at landfills. Both meet the requirements of BS8821 [20]

2.1.2 Cement

For this study, quality cement lime 42.5 was used for all concrete mixtures. The cement meets the requirements of BS EN 196-6[21]

2.1.3 Water

Water samples were taken from the Department of Civil Engrg. Laboratory at Kenule Beeson Polytechnic, Bori, Rivers State. Water meets BS12390 [22] requirements

2.1.4 Structural steel reinforcement

Reinforcement purchased directly from the market at Port Harcourt. It conformed to [23] **B**S4449: 2005 + A3 requirements

2.1.5 Corrosion Inhibitors (Resins / Exudates) Treculia africana (African breadfruit)

The exuding sticky gummy cream was obtained from the tree bark through the tapping process. It was obtained from a plantation farm in Odiokwu Town in Ahoada-West Local Government of Rivers State at *Coordinates*: 5°05′N 6°39′E / 5.083°N 6.650°E / 5.083; 6.650.

2.2 Experimental Procedure

2.2.1 Experimental method

2.2.2 Prepare samples for reinforcement with coated exudate/resin

Investigative work examined the use of treculia africana exudate/resin, tapped from tree trunks, and has the potentiality of environmentally stable properties of non-hazardous. The resulting exudate/resin is coated directly with reinforcing steel of different thicknesses, embedded in concrete slabs, and exposed to territorial sea areas with high salt content. 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 corrosion rate value is calculated by estimating the current density obtained or obtained from the polarization curve and the degree of quantification of the corrosion rate. The concrete mixture was measured with the weight of the material using 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, gravel (fine and coarse), and water to achieve a consistent color. A concrete plate measuring 100 mm × 500 mm × 500 mm (thickness, width, and length) with a concrete cover of 10 mm is poured into a metal mold, covered with air removed, 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 molded after 72 hours, compacted for 28 days at standard room temperature to harden. The hardened concrete slabs are completely immersed in 5% sodium chloride (NaCl) solution in 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 calculations and record documentation for comparison.

2.3 Accelerated Corrosion Test

The corrosion process is a natural phenomenon that takes decades to materialize. This is a long-term process, but the fast and accelerated corrosion process using Sodium Chloride (NaCl) process allows reinforcement embedded in concrete to undergo corrosion and can simulate 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 accelerated 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 [23], Gower and Millard [24]. 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 [24]). Corrosion rate refers to electrochemical measurements, the first based on data.

Table 2.1: Dependence between potential and corrosion probability [26] **(***ASTMC876-91*, 1999.)

Potential E_{corr}	**Probability of Corrosion**
Ecorr < −350mV	Greater than 90% probability that reinforcing steel corrosion is occurring in that area at the time of measurement
−350mV ≤ E_{corr} ≤ −200mV	Corrosion activity of the reinforcing steel in that area is uncertain
E_{corr} > −200mV	90% probability that no reinforcing steel corrosion is occurring in that area at the time of measurement (10% risk of corrosion

2.5 Test 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 plate has a different W / C, the time required to saturate each plate is 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[27] (ASTM Standard C876, 2012)

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 are 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 ≤ Ecorr ≤ –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

	Time Intervals 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	-105.60	-109.28	-105.01	-103.61	-106.02	-102.99	-111.44	-107.12	-102.66	-104.98	-108.96	-103.13
Concrete Resistivity ρ, kΩcm	16.11	16.10	16.10	16.09	16.08	16.25	16.24	16.24	16.23	16.22	16.17	16.08
Yield Strength, fy (MPa)	458.58	456.58	456.08	457.88	458.58	457.81	457.81	458.11	459.81	457.20	457.71	457.54
Ultimate Tensile Strength, fu (MPa)	640.22	638.17	639.85	635.63	639.16	639.58	639.38	640.18	638.78	640.33	639.83	639.69
Strain Ratio	1.40	1.40	1.40	1.39	1.39	1.40	1.40	1.40	1.39	1.40	1.40	1.40
Rebar Diameter Before Test (mm)	11.90	11.89	11.90	11.90	11.89	11.91	11.90	11.89	11.90	11.90	11.89	11.90
Rebar Diameter at 28 days(mm)	11.89	11.88	11.89	11.89	11.88	11.90	11.89	11.88	11.89	11.89	11.88	11.89
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Rebar Weights- Before Test	0.86	0.86	0.86	0.86	0.86	0.86	0.87	0.87	0.86	0.86	0.86	0.87
Rebar Weights- After at 28 days (Kg)	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
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

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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	-326.42	-350.55	-347.45	-339.84	-349.64	-356.64	-390.54	-397.74	-401.84	-404.96	-409.16	-407.39
Concrete Resistivity ρ, kΩcm	6.73	6.91	7.74	6.74	7.52	7.08	6.70	7.25	7.29	6.89	7.06	7.07
Yield Strength, fy (MPa)	431.76	434.76	430.76	431.06	431.76	430.99	433.99	434.29	432.99	434.38	430.89	434.72
Ultimate Tensile Strength, fu (MPa)	620.93	618.88	620.56	616.34	619.87	620.29	620.09	620.89	619.49	621.04	620.54	620.40
Strain Ratio	1.44	1.42	1.44	1.43	1.44	1.44	1.43	1.43	1.43	1.43	1.44	1.43
Rebar Diameter Before Test (mm)	11.99	12.00	11.99	12.00	12.01	12.00	12.00	12.00	11.99	12.00	11.99	12.00
Rebar Diameter- After Corrosion(mm)	11.93	11.93	11.92	11.93	11.94	11.94	11.94	11.93	11.93	11.93	11.92	11.93
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.06	0.06	0.07	0.07	0.06	0.06	0.07	0.06	0.06	0.06	0.07	0.06
Rebar Weights- Before Test (Kg)	0.82	0.80	0.80	0.80	0.81	0.81	0.81	0.80	0.81	0.81	0.79	0.79
Rebar Weights- After Corrosion (Kg)	0.77	0.75	0.75	0.75	0.75	0.75	0.75	0.76	0.75	0.75	0.74	0.74
Weight Loss /Gain of Steel (Kg)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05

Table 3.3: Potential Ecorr, after 28 days curing and 360days Accelerated Periods of Treculia africana 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	-117.80	-121.48	-117.21	-115.81	-118.22	-115.19	-123.64	-119.32	-114.87	-117.18	-121.17	-112.44
Concrete Resistivity ρ, kΩcm	14.71	14.86	15.14	15.27	14.96	15.25	15.20	15.35	15.38	14.85	14.74	14.59
Yield Strength, fy (MPa)	454.14	457.14	453.14	453.44	454.14	453.37	456.37	456.67	455.37	456.76	453.27	456.10
Ultimate Tensile Strength, fu (MPa)	637.84	635.79	637.47	633.25	636.78	637.20	637.00	637.80	636.40	637.95	637.45	637.31
Strain Ratio	1.40	1.39	1.41	1.40	1.40	1.41	1.40	1.40	1.40	1.40	1.41	1.40
Rebar Diameter Before Test (mm)	11.90	11.90	11.90	11.90	11.89	11.91	11.90	11.89	11.90	11.90	11.89	11.90
Rebar Diameter- After Corrosion(mm)	11.99	11.98	11.99	11.99	11.98	12.00	11.99	11.98	11.99	11.99	11.98	11.99
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.09	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.09	0.08	0.08
Rebar Weights- Before Test (Kg)	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.89
Rebar Weights- After Corrosion (Kg)	0.93	0.94	0.94	0.94	0.93	0.93	0.93	0.94	0.93	0.92	0.93	0.94
Weight Loss /Gain of Steel (Kg)	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.05

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

Sampling	Control Concrete slab Specimens				Corroded Concrete slab Specimens				Tertulia Africana 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 Treculia Africana Exudate / Resin Coated Specimens			
Potential Ecorr, mV	-106.63	-105.96	-104.88	-104.2	-341.47	-345.94	-345.64	-348.7	-118.83	-118.16	-117.08	-116.4
Concrete Resistivity ρ, kΩcm	16.10	16.10	16.09	16.14	7.12	7.13	7.33	7.12	14.90	15.09	15.12	15.16
Yield Strength, fy (MPa)	457.08	456.85	457.51	458.09	432.43	432.20	431.20	431.27	454.81	454.58	453.58	453.65
Ultimate Tensile Strength, fu (MPa)	639.42	637.89	638.22	638.13	620.12	618.59	618.92	618.83	637.03	635.50	635.83	635.74
Strain Ratio	1.40	1.40	1.40	1.39	1.43	1.43	1.44	1.44	1.40	1.40	1.40	1.40
Rebar Diameter Before Test (mm)	11.90	11.90	11.90	11.90	11.99	12.00	12.00	12.01	11.90	11.90	11.90	11.90
Rebar Diameter- After Corrosion(mm)	11.89	11.89	11.89	11.89	11.93	11.93	11.93	11.94	11.99	11.99	11.99	11.99
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	0.07	0.07	0.07	0.07	0.09	0.08	0.08	0.08
Rebar Weights- Before Test (Kg)	0.86	0.86	0.86	0.86	0.81	0.80	0.81	0.81	0.87	0.87	0.87	0.87
Rebar Weights- After Corrosion (Kg)	0.86	0.86	0.86	0.86	0.76	0.75	0.75	0.75	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	0.06

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				Treculia africana 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 Treculia africana Exudate / Resin Coated Specimens			
Potential Ecorr,mV	-68.77	-69.37	-69.66	-70.12	187.37	192.77	195.22	199.56	-65.20	-65.84	-66.13	-66.62
Concrete Resistivity ρ, kΩcm	126.04	125.77	119.38	126.85	-52.19	-52.74	-51.49	-53.06	109.17	111.62	106.15	113.02
Yield Strength, fy (MPa)	5.70	5.70	6.10	6.22	-4.92	-4.92	-4.93	-4.93	5.18	5.18	5.19	5.19
Ultimate strength (N/mm2)	3.11	3.12	3.12	3.12	-2.65	-2.66	-2.66	-2.66	2.73	2.73	2.73	2.73
Strain Ratio	-2.44	-2.45	-2.79	-2.93	2.36	2.36	2.35	2.43	-2.30	-2.31	-2.30	-2.37
Rebar Diameter Before Test (mm)	0.405	0.304	0.313	0.309	0.315	0.305	0.303	0.302	0.305	0.304	0.305	0.303
Rebar Diameter- After Corrosion(mm)	0.33	0.345	0.387	0.392	-0.485	-0.468	-0.439	-0.413	0.485	0.466	0.432	0.418
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-23.53	-20.24	-20.24	-21.43	30.77	25.37	25.37	27.27
Rebar Weights- Before Test(Kg)	7.46	7.60	7.21	7.57	7.35	7.31	7.48	7.46	7.93	78.47	7.20	7.07
Rebar Weights- After Corrosion(Kg)	14.02	14.78	14.48	14.32	-19.23	-19.77	-19.55	-19.36	23.81	24.63	24.3	24.01
Weight Loss /Gain of Steel (Kg)	0	0	0	0	-21.54	-21.21	-20.23	-18.75	27.45	26.92	25.35	23.08

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

The corrosion results in tensile stresses in the steel reinforcement and the concrete, which leads to the appearance of the first crack. Chlorides are known to be absorbed into the concrete from a variety of sources Morris and Vazquez [1]; Ann and Song [2], stated that casted concrete contained chloride ions from seawater of salt content and aggregates that can be used as a catalyst. The salt in the mixture penetrates the concrete, according to the different mechanisms of action. Chlorine can be created from the elements of the structure itself, or as a result of the diffusion of chloride ions in the environment. The (E_{corr},mV) potential results, and concrete resistance, kΩcm, are obtained from Tables 3.1 - 3.3 and summarized into mean and percentile values in Tables 3.4 and 3.5, plotted graphically in Figures 3.1-3.8b, are the results of controlled samples, non-coated (corroded) and coated samples for 36 concrete slabs, divided into 3 sets of 12 control samples, which are the determining reference range, 12 non-coated (corroded) samples, and 12 exudate/resin coated samples. The average and percentile of minimum, maximum, and differential of the calculated potential measurements from the computed half-cell potential controlled samples were -110.49 mV and -107.33 mV (-72.4% and -67.19%) with a difference between the potential of 3.16 mV and 5.21%, the corroded samples were -400.23 mV and -334.53 mV (169.87% and 227.89%) and the difference values were 65.7 mV and 58.02% and the coated samples were -124.41 mV and -122.54 mV (-69.5% and -62.95%) and the potential difference is 2.8 mV and 6.55%, respectively. The maximum calculated percentile control value is -67.19% compared to the corroded and coated values of 227.89% and -62.95% and the controlled potential difference value is 5.21%, corroded 58.02%, and coated 6.55%. The maximum yield obtained from the controlled and coated samples were -107.33 mV and -122.54 mV, which indicates the relationship between corrosion potential and probability as a reference $E_{\text{corr}} > -200\text{mV}$ as a reference range. The results of this potential Ecorr result showed that the controlled sample values and exudates/resin coated are low with a 90% probability that no corrosion of the reinforcement is observed at the time of measurement (10% corrosion risk, 10% or shows an uncertain corrosion probability. For samples that non-coated, the calculated maximum value is -334.53 mV, the result is within the reference value of the relationship between corrosion potential and probability of $-350\text{mV} \leq E\text{corr} \leq -200\text{mV}$ indicating a high-value range, one 10% or uncertain corrosion probability [23]. The comparison result of the reference range (controlled) shows that the corrosion samples show corrosion as a result of accelerated corrosion-induced as compared to the coated samples which show no corrosion. The exudates/resin exhibits properties against the corrosive attack on the reinforcing steel embedded in the concrete slab, which then is exposed to a corrosive medium through the formation of a resistance layer.

The average value and the minimum and maximum percentage of concrete resistance with a controlled sample potential difference are 14.25kΩcm and 14.38kΩcm (60.75% and 63.55%) and the difference value is 0.13kΩcm and 2.8%. The corrosion samples were 8.75kΩcm and 8.86kΩcm (-45.83% and -44.16%) and the difference values were 0.1kΩcm and 1.67%. The closed sample valleys were 15.69kΩcm and 16.28 k cm (79.08% and 84.61%) and the difference values were 0.59 mV and 5.53%, respectively. The maximum calculated value of the controlled sample concrete resistance is 63.55% compared to the corroded and coated values of -44.16% and 84.61% and the maximum percentage difference in control is 2.8% compared to the corroded and coated values of 1.67% and 5, 53%. The results of controlled and coated samples with concrete resistance at the maximum average value are 14.38 kΩcm and 16.28kΩcm with a description of the value 10 <ρ <20 (low) compared to the corrosion value of 8.86kΩcm with specifications 5 <ρ < 10 (high) and with a reference range of dependence between concrete resistance and corrosion probability at significant corrosion probability (ρ < 5, 5 < ρ < 10, 10 < ρ < 20, ρ > 20) for very high, high, low to moderate and low, for corrosion probability [24]. From the comparison results of coated and corrosion samples, the maximum values obtained for both samples clearly show the value of coated samples with a range of 10 <ρ <20 which classifies the range of values as low to moderate, with information as a significant corrosion probability. The maximum value of the corroded sample was in the range of 5 < ρ < 10, indicating high, signs suggesting possible corrosion, confirmed in the studies of (Daso et al. [14], Charles et al. [13], Philip et al [19], [Kanee et al. [17]). From the results obtained, for comparison, it can be judged that the effect of corrosion attack was observed in the uncoated samples, whereas the samples with exudate/resin coating had anti-corrosion properties with a highly resistant and water-resistant membrane that prevented corrosion of the embedded reinforcement in the exposed concrete slab to an induced accelerated corrosion region.

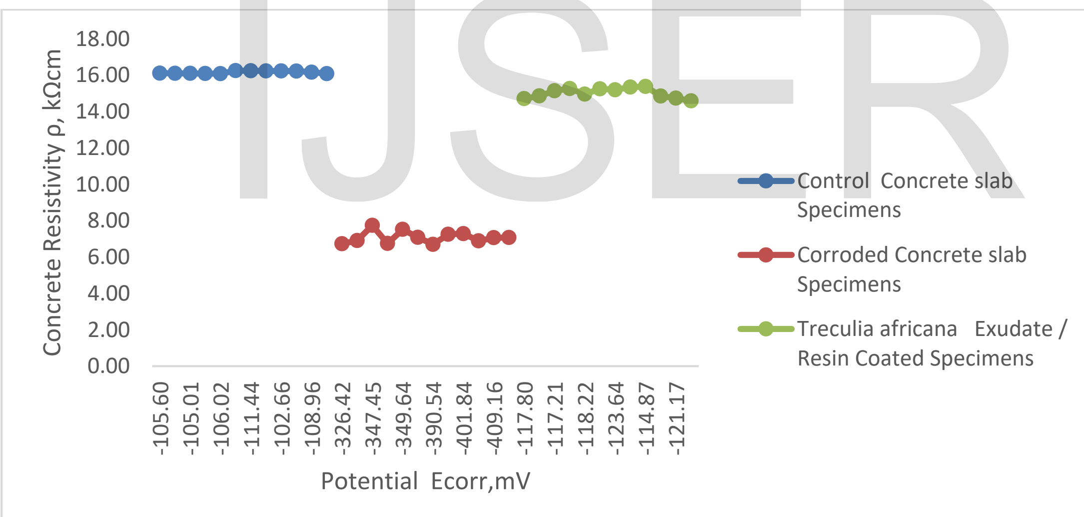

Figure 3.1 : Concrete Resistivity ρ, kΩcm versus Potential Ecorr,mV Relationship

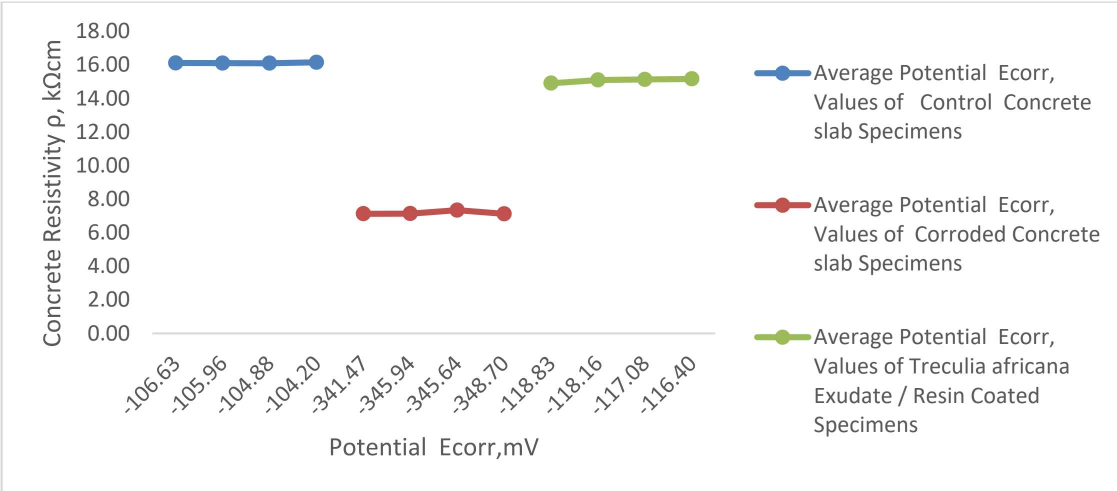

Figure 3.1A: Average Concrete Resistivity versus Potential Relationship

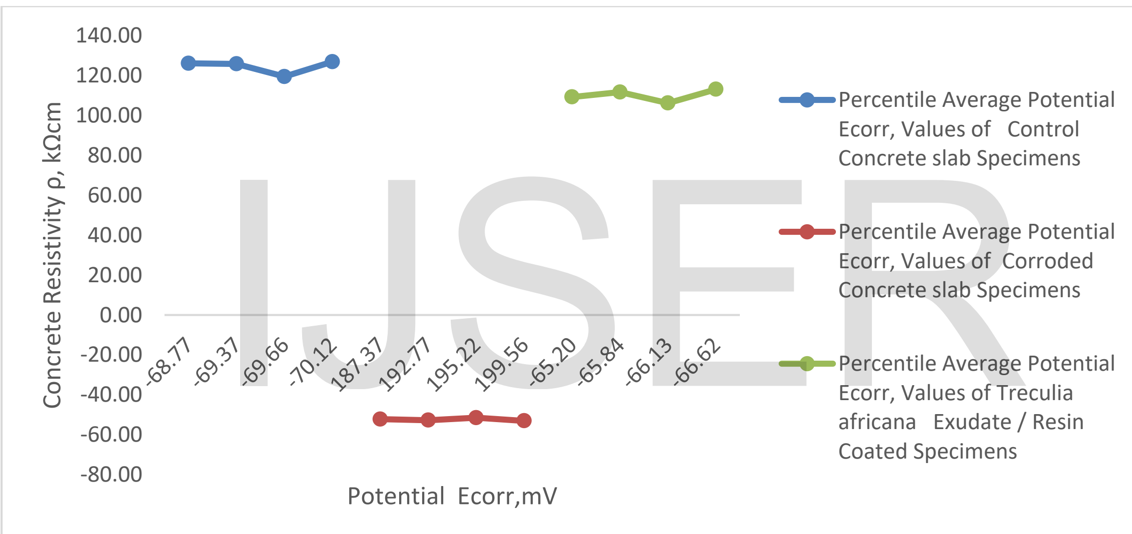

Figure 3.1B : Average Percentile Concrete Resistivity versus Potential Relationship

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

The results of the mean, percentile, and the difference between the minimum and maximum recovery limits, fy (MPa) of the controlled sample were 452.93 MPa and 455.41 MPa (8.23% and 8.28%) and the difference values were 2.48 MPa and 0.049%, the corroded samples were 418.2 MPa and 420.77 MPa (-7.65% and -7.61%) and the difference values were 2.479 MPa and 0.04%, the coated sample values were 452.92 MPa and 455 .41 MPa (8.23 MPa).)% and 8.28%) and the difference values of 2.49 MPa and 0.049%. The calculated maximum percentage value of the controlled yield strength was 8.28% compared to the corroded and coated values -7.61% and 8.28% and the possible difference values were 0.049% controlled, 0.04% corroded, and

0.049% coated. The mean, percentile, and the difference between the minimum and maximum tensile strength, fu (MPa) of the controlled samples were 626.8 MPa and 628.63 MPa (2.00% and 2.00%) and the difference values were 1.83MPa and 0 , 03%, corrosion is 614.49MPa and 616.32 MPa (-1.97MPa and -1.96%) and the difference is 1.83MPa and 0.01%, coverage is 627.82MPa and 629.64Mpa (2.00% and 2.0% and the difference value is 1.83 MPa and 0.00 The maximum calculated percentage of the maximum controlled tensile strength is 2.00% relative to the corrosion and coating values -1.97% and 2.00% and the potential difference value is 0.03% checked, 0.01% is corroded and 0.01% coated.

The minimum and maximum mean values of the deformation ratio, percentile, and difference values of the controlled samples were 1.38 and 1.38 (-5.81% and -5.73%) with a difference of 0.00 and 0.079%, corrosion values the samples were 1.46 and 1.467 (6.08% and 6.16%) and the difference values were 0.01 and 0.08%, the coated samples were 1.38 and 1.38 (-5.81% and -5, respectively). 73%) and the difference value of 0.002 and 0.07%. The maximum calculated percentage for the ratio controlled -5.73% against corrosion 6.16% and coated -5.73%, and differential peak controlled 0.079%, corroded 0.08% and coated 0.07%, as in the revealed in the studies of (Daso et al. [14], Charles et al. [13], Philip et al [19], [Kanee et al. [17]). From the calculation results obtained, summarized in Tables 3.4 and 3.5 and displayed graphically in Figures 3.1 - 3.8, the yield strength, tensile strength, and deformation ratio of the mean, percentile, and controlled differential potential values, uncoated (corroded) and layered concrete slab samples were determined. , coated samples had higher breaking loads compared to corroded samples with reduced failure load and low load-bearing capacity and with mean and percentile values with the reference range, whereas uncoated (corroded) samples, had load bearing capacity which is low and a reduced value compared to the reference range. The comparison results show that the low load carrying capacity is caused by the effect of corrosion attack on the uncoated (corroded) elements, which damage the reinforcing steel fibers, ribs, and passive formation and surface modification. The observed mean values for the coated samples were associated with the corrosion resistance potential to penetrate the reinforcing steel with the formation of a protective membrane; This attribute indicates the efficiency and effectiveness of the exudate/resin as an inhibitor against corrosive effects. of reinforced concrete structures exposed to the edges of strong, high salinity marine areas.

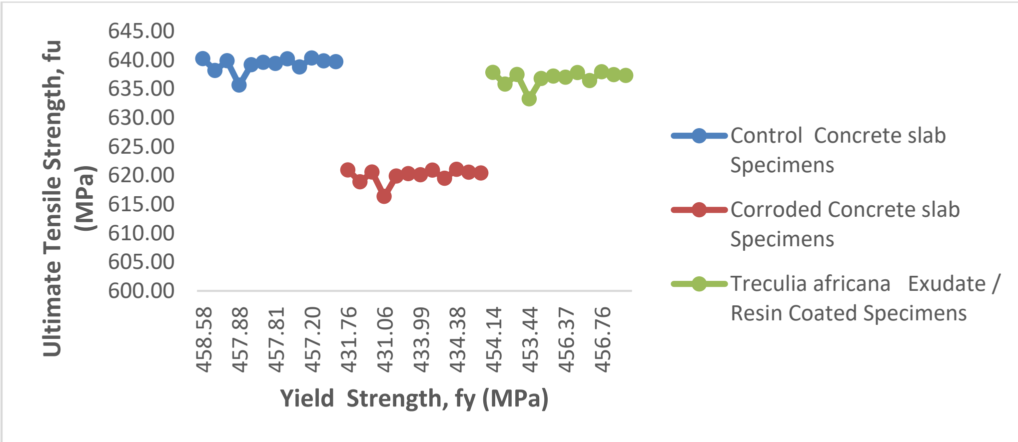

Figure 3.2 : Yield Strength versus Ultimate strength

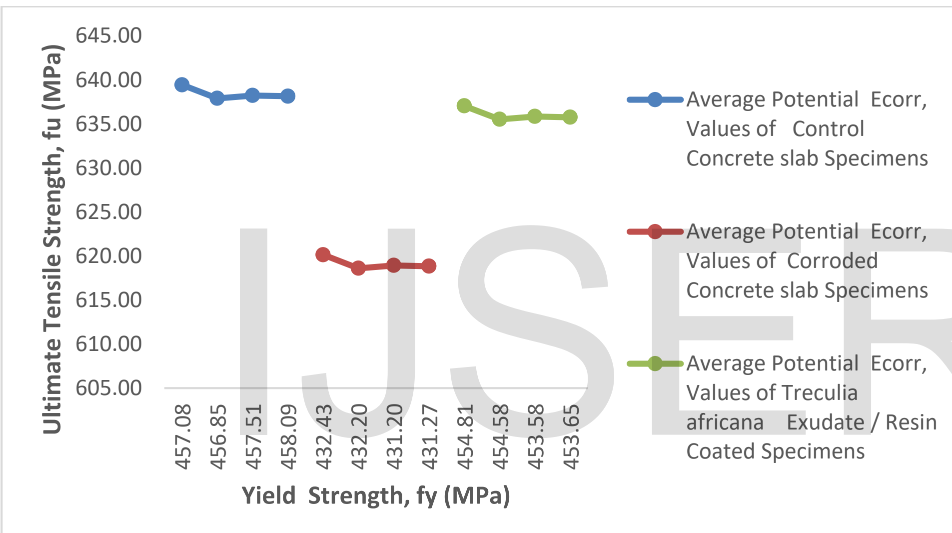

Figure 3.2A: Average Yield Strength versus Ultimate Tensile Strength

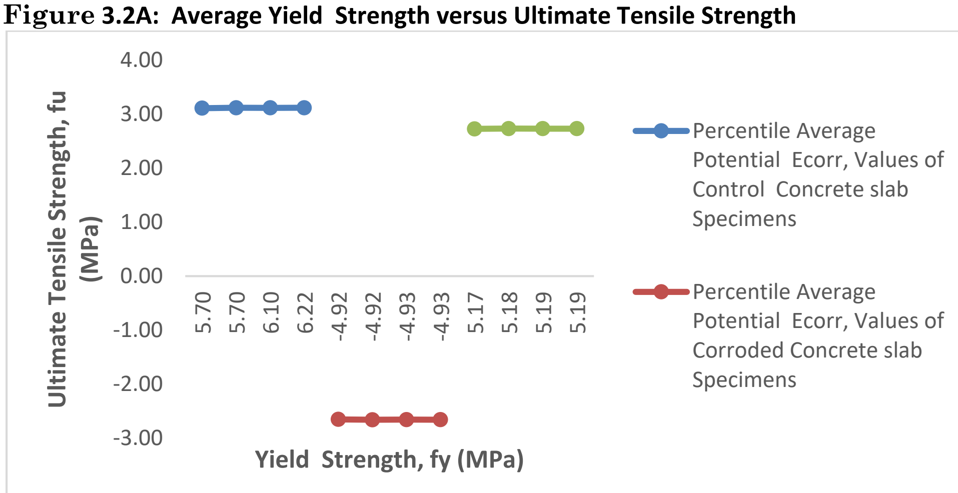

Figure 3.2B: Average Percentile Yield Strength versus Ultimate Tensile Strength

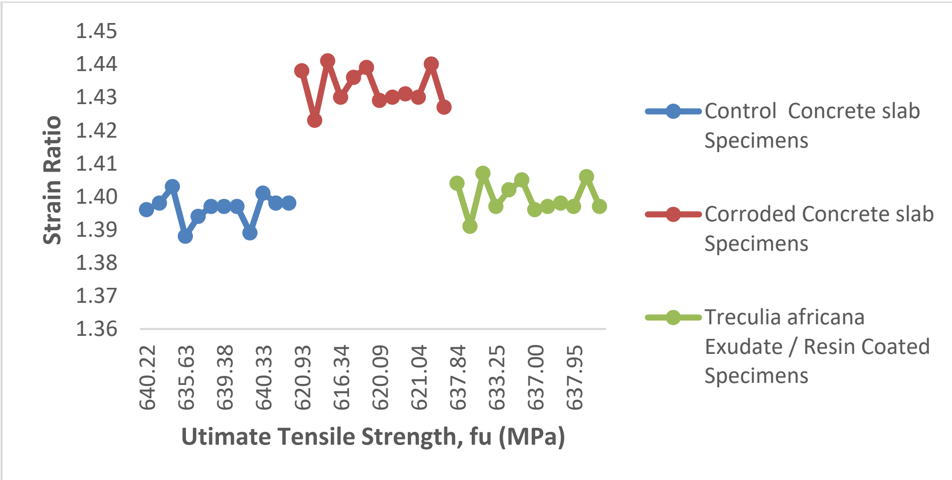

Figure 3.3: Ultimate Tensile Strength versus Strain Ratio

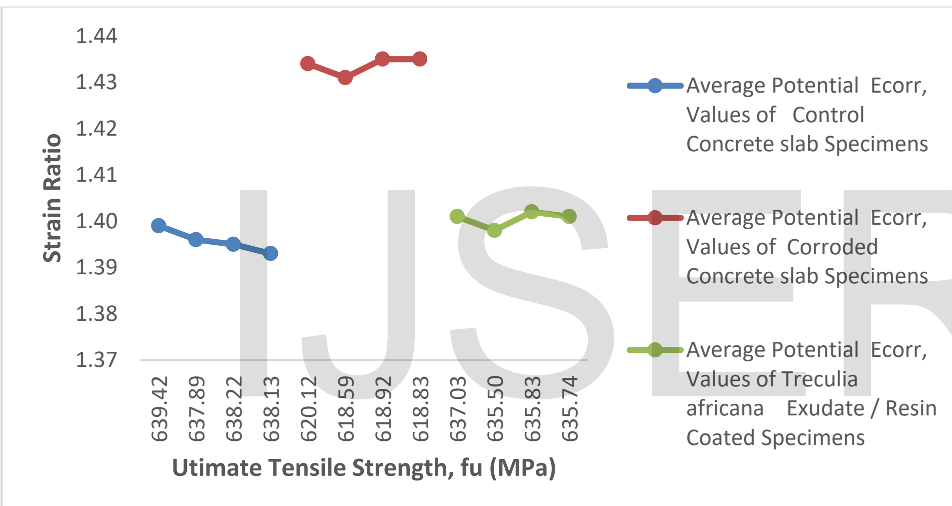

Figure 3.3A: Average Ultimate Tensile Strength versus Strain Ratio

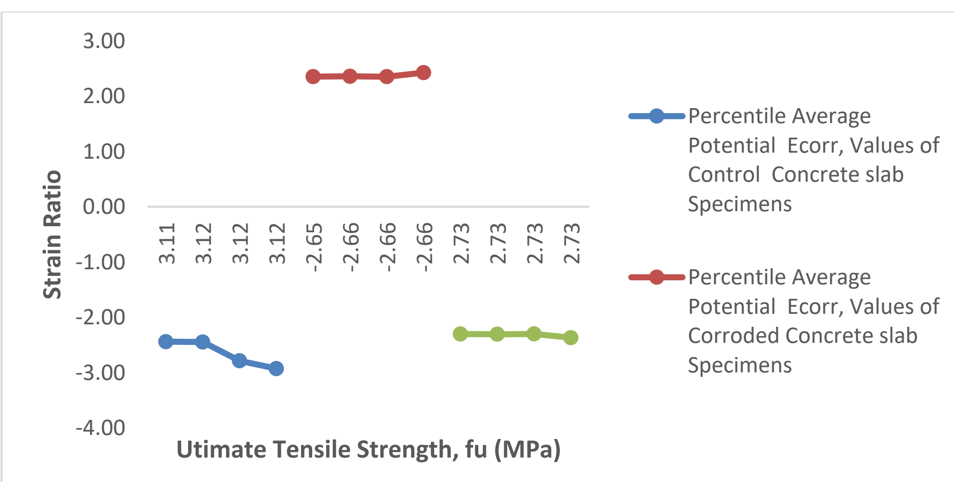

Figure 3.3B: Average percentile Ultimate Tensile Strength versus Strain Ratio

3.3 Results of Mechanical Properties of Rebar Diameter, Cross -Sectional Area and Weight Loss / Increase of Embedded Reinforcing Steel in Concrete Slab

The diameter of the rebar before the test (mm) has the values of controlled for the average and the minimum and maximum percentile values of 11.93 mm and 11.93 mm (0.348% and 0.348%) with a difference of 0.04 mm and 0.013%, the corrosion value of the controlled sample was 11 .93 mm and 11.93 mm (0.346% and 0.346%) and the difference values of 0.06 mm and 0.013% and the coated sample values are 11.95 mm and 11.95 mm (0.346% and 0.346 mm.) count 0.02 mm and 0.010% The unit weight of reinforcement before corrosion test shows small differences based on the shape of the product and company, as well as by-products used in the production process, the minimum and maximum average values obtained, percentiles and the value of the difference in diameter of reinforcement after corrosion (mm) for the controlled sample were 11.93 mm and 11.93 mm (0.348% and 0.348%), with 100% reference values maintained, the corroded sample values were 11.88 mm and 11.88 mm (-1.2 1% and -1.17%) and the difference of 0.01 mm and 0.0 3%, the coated d values were 12.02 mm and 12.02 mm (1.18% and 1.21%) and Difference 0.025 mm and 0.03%.

The calculated maximum percentile value is controlled 0.348% against -1.17% corroded and 1.21% coated, with a percentage difference of 0.03% corrosion against 0.03% 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 concrete slabs, which are exposed to induced corrosion-accelerating activities. For comparison, the results of the corroded samples showed the reduction and reduction values compared to the diameter of the reinforcement before and after the induction accelerated corrosion test with a percentage reduction in value from 0.344% to -1.17% and an average value in the range from 11.99 mm to 11. 88 mm.

The decrease/increase (diameter) in cross-sectional area, minimum and maximum mean and percentile values were controlled to 100%, with no decrease or increase after 360 days of immersion in freshwater. Corroded sample values are 0.05 mm and 0.05 mm (-20.9% and -20.9%) and the difference is 0.00% for corroded samples, coated sample values are 0.07 mm and 0.07 mm (26.42%). and 26.42%) and the difference between 0.00 mm and 3.26%. The relative mean and difference in percentage values between coated and corroded samples ranged from 26.42% to 20.9%. The reduction in mean and percentile values indicates that the corrosion effect causes a reduction in diameter and cross-sectional area, fiber degradation, rib reduction, and surface modification, while the exudate/resin-coated elements experience an increase in volume due to differences in layer thicknesses confirmed in the studies (Daso et al. [14], Charles et al. [13], Philip et al [19], [Kanee et al. [17]). In summary, it can be said that the exudate/resin has inhibitory properties against corrosive effects on reinforcing steel embedded in the concrete slab sample, which is induced in an environment with high salt content.

Th values of Weight - Before Test (kg), the minimum, maximum, and differential mean results and the percentage of controlled samples were 0.88 kg and 0.88 kg (6.199% and 6.495%) and the difference was 0% and 0.296%, Corroded samples were 0.88 kg and 0.88 kg (6.375% and 6.378%) and the difference was 0.00% and 0.003%, coated samples were 0.88 kg and 0.88 kg (6.393% and 6.696%) with a difference 0.00% and 0.303%.
The results of the average value and percentage of reinforcement weight after corrosion (Kg) and the generalized difference value from the minimum and maximum values of the controlled sample are 0.88 kg and 0.88 kg (13.81% and) 13.93%) and the difference value 0.00% and 0.119%, the samples corroded 0.82 kg and 0.82 kg (-12.63% and -12.55%) and the difference between 0% and 0.080%, the value of the coated samples was 0.94 kg and 0.94 kg (14.36% and 14.46%) and the difference between 0% and 0.10%.

The average and minimum and maximum unit weight of rebar loss/gain of steel percentages (Kg) and percentage difference ratios are values maintained at 100% as a result of aggregation in freshwater tanks with no trace of corrosion potential relative to corrosion. The controlled sample values were 0.05 kg and 0.05 kg (-16.92% and -16.92%) and coverage was 0.07 kg and 0.07 kg (20.37% and 20.37%). The computed results from Tables 3.1-3.3 and in 3.4 - 3.5 are summarized and plotted graphically in Figures 3.7-3.87 showing the effect of corrosion on uncoated (corroded) and coated reinforcing steel and an investigation of the unit weight of reinforcement before and after corrosion and decreasing/increasing tests. weight. For comparison, the results obtained showed a reduction and reduction in the mean and percentile values for coatings from 0.07 kg to 0.50 kg and corrosion 20.37% to -16.92%, see the studies of (Daso et al. [14], Charles et al. [13], Philip et al [19], [Kanee et al. [17]). The aggregate results show that the corrosion effect causes a reduction in weight/reduction of the corroded sample compared to the percentile layer and an increase in mean, resulting in a slight increase in volume around the layer thickness. This study demonstrated the efficacy and effectiveness of exudate/resin as an inhibitor against the effects of corrosion on reinforcement embedded in a sample of concrete slabs exposed to induced corrosion.

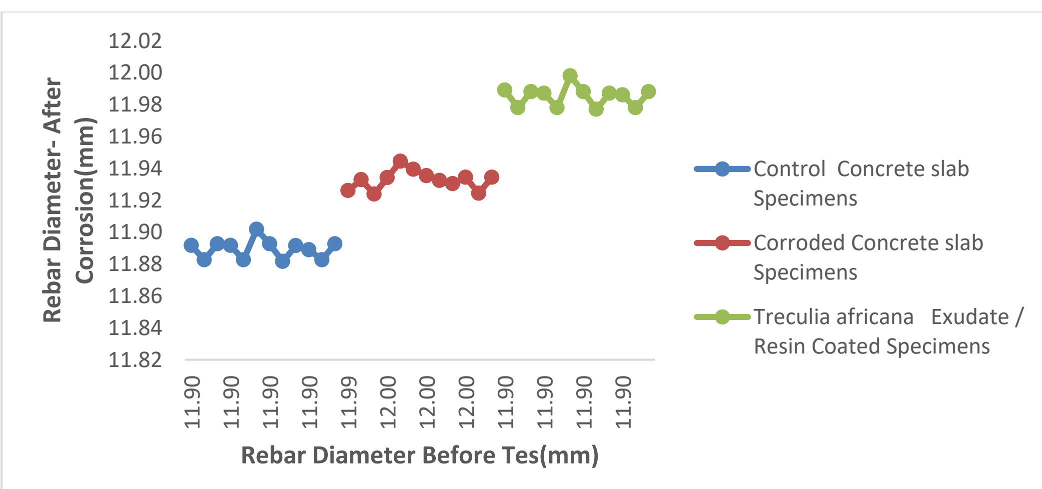

Figure 3.4: Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

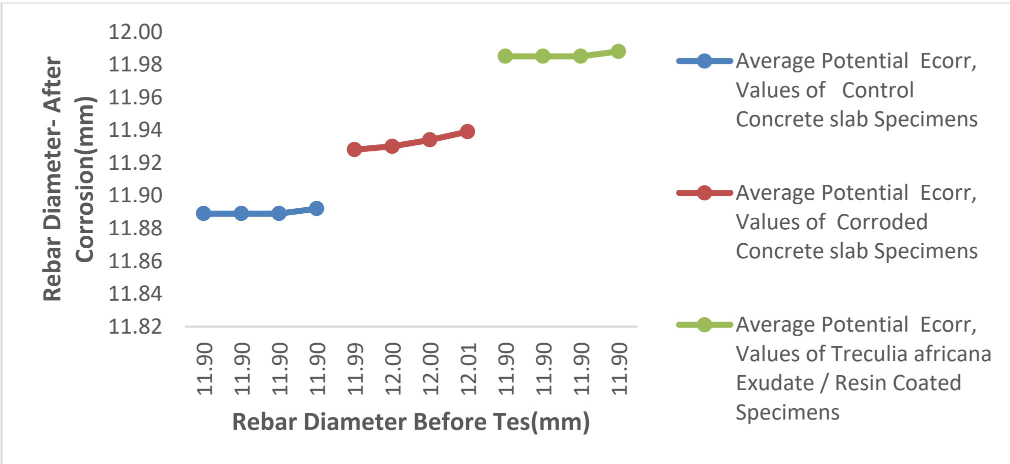

Figure 3.4A: Average Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

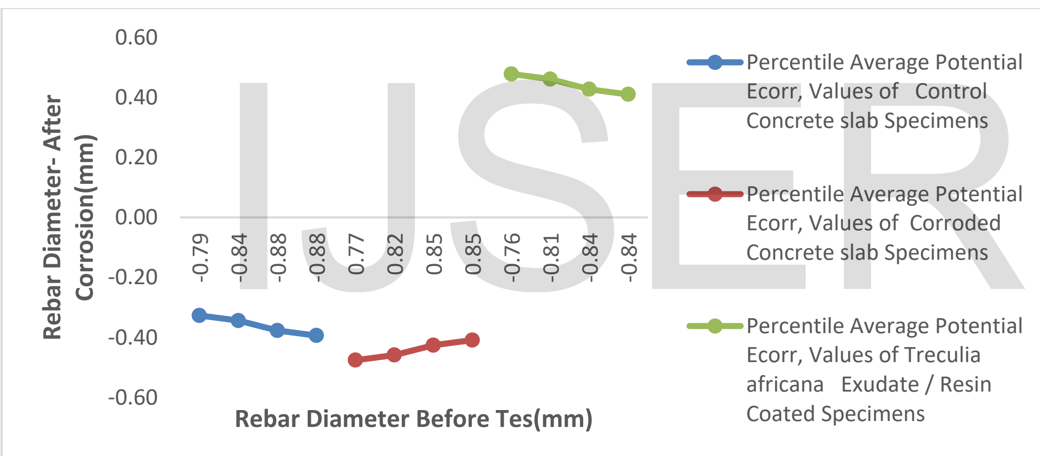

Figure 3.4B: Average Percentile Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

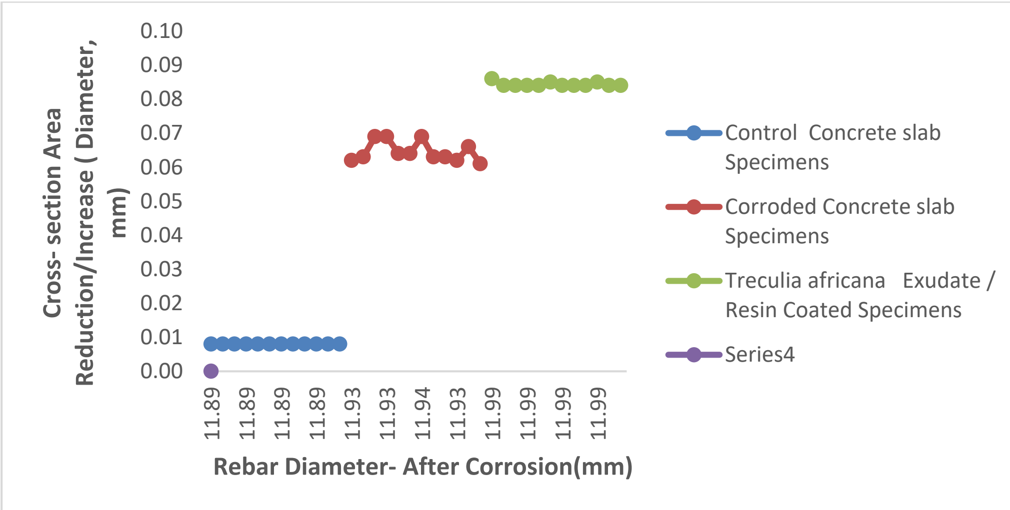

Figure 3.5: Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

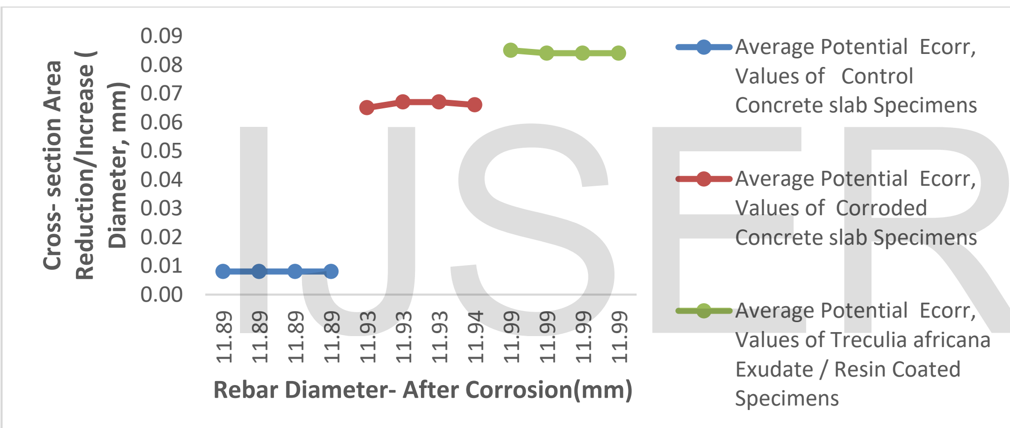

Figure 3.5A: Average Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

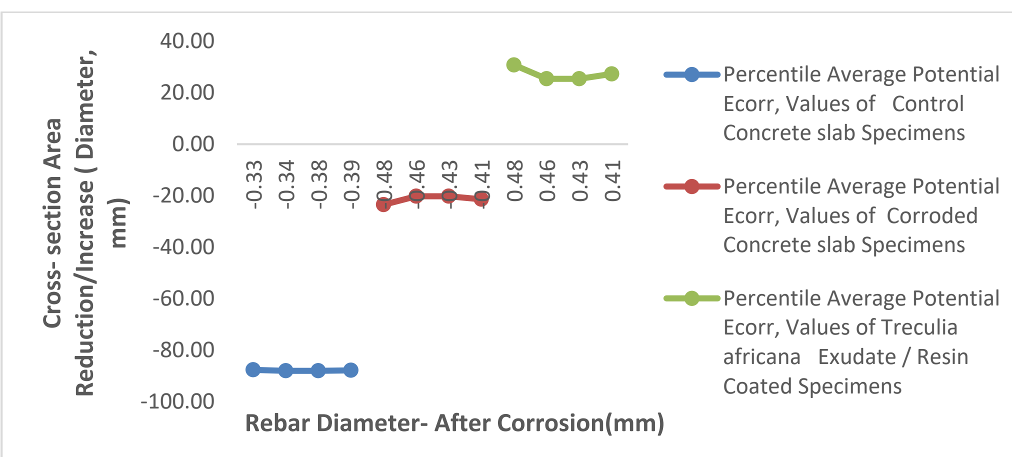

Figure 3.5B: Average Percentile Rebar Diameter- After Corrosion(mm) versus

Cross- section Area Reduction/Increase (Diameter, mm)

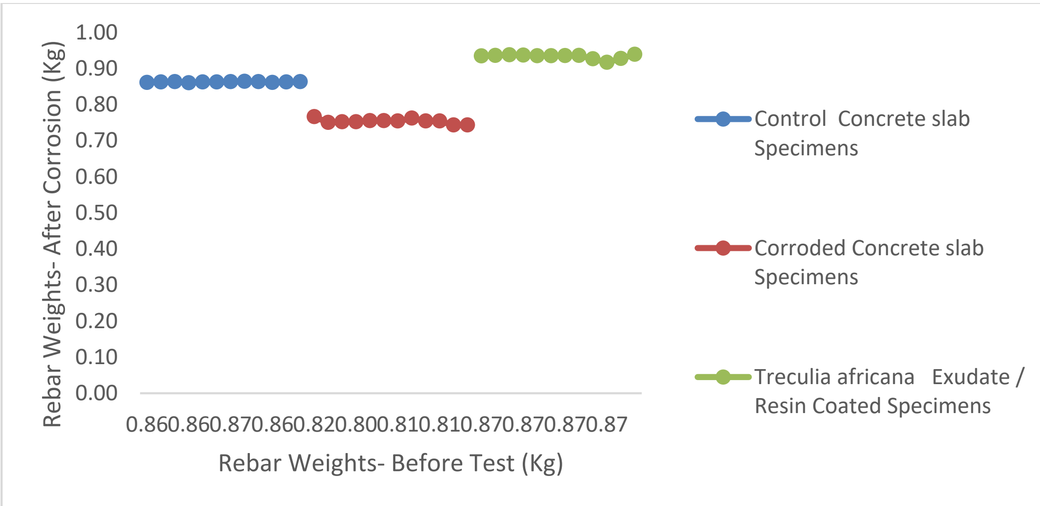

Figure 3.6: Rebar Diameter - After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

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

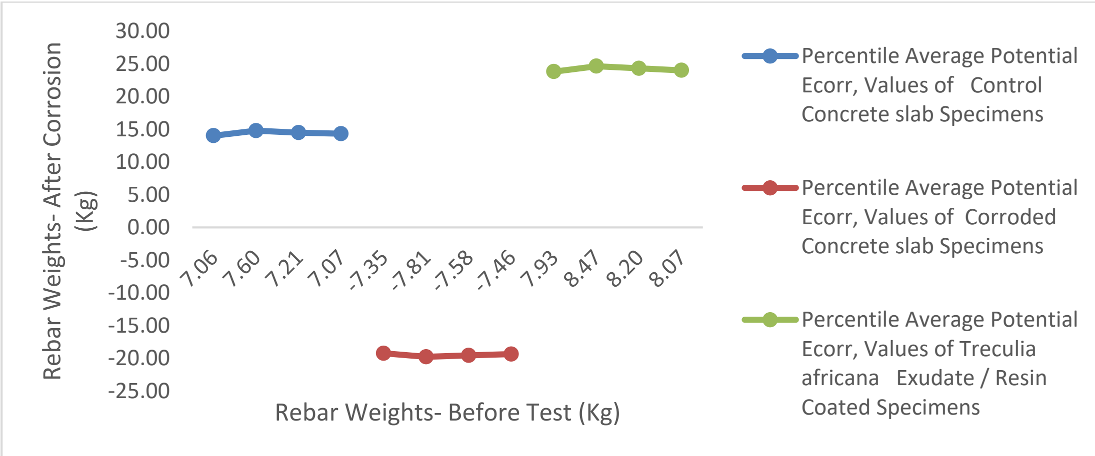

Figure 3.6B: Average Percentile Rebar Diameter - After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

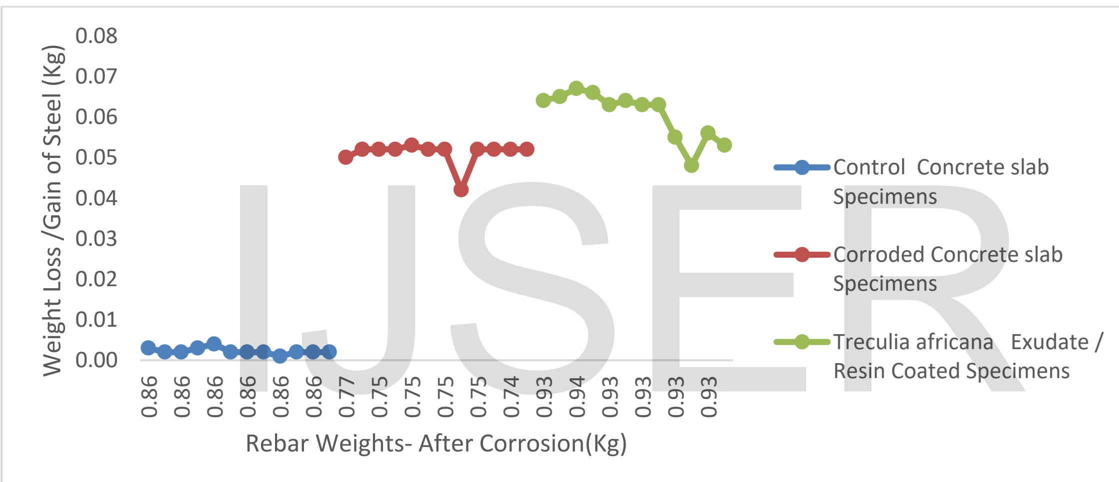

Figure 3.7: Rebar Weights- Before Test(Kg) versus Rebar Weights- After Corrosion(Kg)

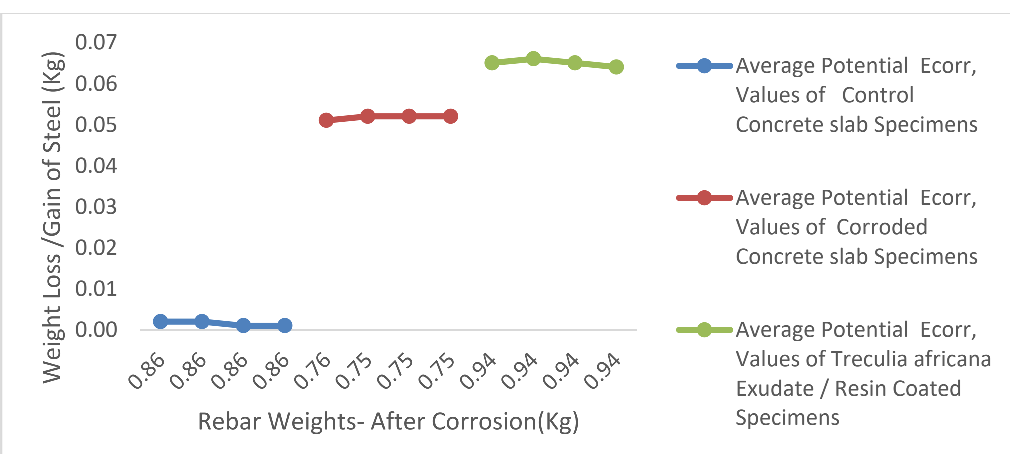

Figure 3.7A: Average Rebar Weights- Before Test(Kg) versus Rebar Weights- After

Corrosion(Kg)

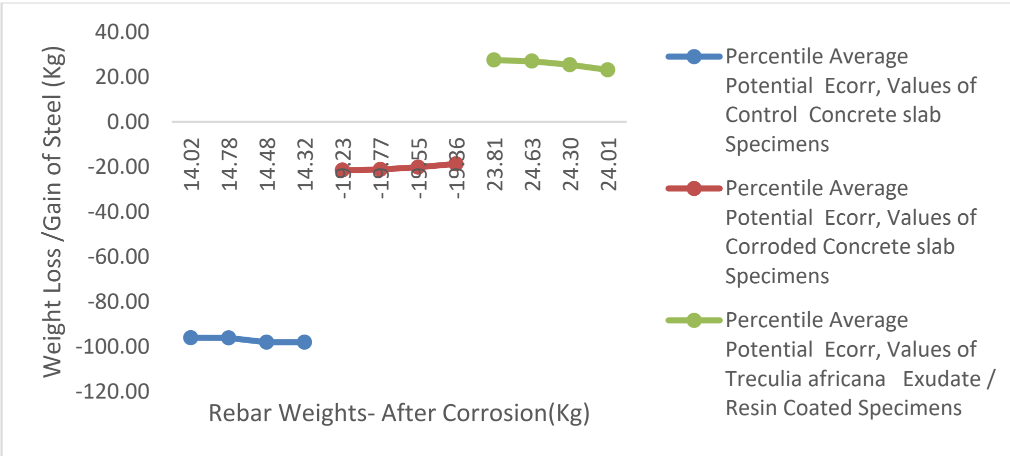

Figure 3.7B: Average Percentile Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

4.0 CONCLUSION

Experimental results showed the following conclusions:

i. Exudates/resin inhibited reinforcement did not indicate the presence of presence

ii. Treculia Africana exudates / resins showed an inhibitory properties against corrosion attacks

iii. Corroded samples showed reduction in diameter and cross-sectional areas

iv. Corroded samples exhibited weight loss 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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