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Electrochemical Techniques Corrosion Rate Measurement of Reinforcing Steel Using Half-Cell Corrosion Potential and Concrete Resistivity

Kpegara Saana N.[1], Agbeb Nornu Stephen[2] , Charles Kennedy[2]

[1,2]School of Engineering, Department of Electrical/ Electronics Engineering,
Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria.

[3]Faculty of Engineering, Department of Civil Engineering,
Rivers State University, Nkpolu, Port Harcourt, Nigeria.

Authors E-mail: [1]sankpe@gmail.com, [2]agbeb_nornu@yahoo.com ,[3]ken_charl@yahoo.co.uk

Abstract- Corrosion of steel reinforcement in concrete reduces the strength of the interaction between steel and concrete and thus affects the durability and usability of the concrete structure. This study investigated the potential of Terminalia tomentosa exudates/resin as an inhibitory material to prevent corrosion of steel bars embedded in concrete structures an exposed to high salinity media. The hardened concrete slab is fully immersed in a 5% aqueous sodium chloride (NaCl) solution and accelerated by routine 90-days, 180-days, 270-days, and 360-days intervals with routine inspections and tests to ascertained varying surface modifications and effects. The results of corrosion potential maximum calculated percentile controlled sample value is -66.67% compared to the corroded and coated values of 265.08% and -64.48% and the controlled potential difference value is 6.8%, corroded 83.55% and coated 8.13% . The maximum yields of controlled and coated samples were -106.57mV and -113.97mV, which showed the relationship between corrosion potential and probability as a $E_{corr} > -200\text{mV}$ as a reference range. For non-coated (corroded) samples, the maximum calculated value is -330.02mV, the result is within the reference value of the dependence between corrosion potential and probability of the value $-350\text{mV} \leq E_{corr} \leq -200\text{mV}$ indicating a high range of values, which corresponds to 10% or possible unsafe corrosion. The comparative results from the reference range (controlled) show that the corroded samples exhibited corrosion as a result of the induced corrosion acceleration compared to the coated samples which showed no corrosion/Resin has inhibitory properties against corrosion attack on reinforcing steel mounted on horses on step plates, corrosive media through the formation of an exposed Resistance layer. The maximum calculated value of the controlled sample concrete resistivity is 105.86% compared to the corroded and coated values of -57.78% and 154.88% and the maximum percentile difference in control are 19.34% compared to the corroded and coated values of 2.99% and 18.0 %. The results of the controlled and coated concrete resistance samples obtained an average maximum value of 14.33 kΩcm and 18.23 kΩcm with a data value of 10 <ρ <20 (low) compared to a corrosion value of 7.63 kΩcm with a specification of 5 <ρ < 10 (high) and with a reference range of dependence between concrete resistance and corrosion probability significant corrosion probability. 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 calculated maximum percentile value of the controlled yield strength was 7.79% compared to the corroded values of -6.49% and coated 7.59% and the possible difference values of 0.65% controlled 0.57% and 0.65% coated. The maximum calculated percentile of controlled ultimate tensile strength is 1.33% relative to corrosion and the coated value is -1.58% and 1.61%, respectively, and the difference value is possible from 0.00% controlled, 0.00% corroded and 0.01% coated. The maximum calculated percentile for comparison controlled -5.42% against corroded 5.93% and coated -5.0%, and differential peak controlled 0.59%, corroded 0.67 and coated 0.59%. The observed mean values for the coated samples were traced back to the potential for corrosion resistance to penetrate the reinforcing steel with the formation of a protective membrane; these attributes indicate the efficiency and effectiveness of exudates / resins as inhibitors against the corrosive effects of reinforced concrete structures exposed to strong severe, high salinity marine areas. The maximum calculated percentile is checked with 0.05% against -0.91% corroded and 0.93% coated, the difference in corrosion percentile is 0.01% against 0.01% coated. For comparison, the results obtained of

unit weight show a reduction of the mean and percentile values for the corroded from 0.070 kg to 0.050 kg and 35.19% to -26.03%. The summary results show that the corrosion effect causes a decrease in weight/reduction of the corroded sample compared to coatings with percentile loading and an increase in mean values, which leads to a slight increase in volume with coating thickness. This study demonstrated the efficacy and effectiveness of exudate/resin as a corrosion inhibitor for reinforcement embedded in a sample of concrete slabs exposed to induced corrosion

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

1.0 INTRODUCTION

Reinforced concrete structures are expected to have a long service life with minimal maintenance. Corrosion of reinforcing steel is a major factor in reducing lifespan. Corrosion products occupy a larger volume than that of the reinforcing steel, generating tensile stresses that crack the concrete cover ([1]; [2]). Dense impermeable concrete provides physical protection, while the alkalinity of the pore solution provides chemical protection. The alkaline environment of the concrete (pH 12-13) implies the formation of a passive film on the surface of the reinforcing strip, which provides corrosion protection of the steel [3]. However, two main phenomena such as carbonization and chloride attack can lead to the destruction of the iron hydroxide surface layer covering steel in alkaline concrete media [4]. Carbonization is characterized by the reaction of atmospheric carbon dioxide and water in the pores of the concrete to form insoluble carbonates, which causes corrosion of reinforcing steel because the pH value of the concrete pore solution decreases. On the other hand, chloride ions, such as sodium chloride in seawater and salt used in defrosting transport networks, and calcium chloride still present in concrete contaminants, can cause chloride ions to freely pass through the concrete layer and weaken the reinforcing steel. Corrosion products occupy a much larger volume than the original steel and ultimately cause a large tensile strength on the surrounding concrete, which can cause the cracking and disintegration of concrete cover damage in the adhesion between the steel and the concrete interface [5]. Half-cell potential measurements are an indirect method for estimating potential bar corrosion, but there is recent interest in developing tools for conducting perturbative electrochemical measurements to obtain a direct corrosion rates and are related to electrochemical measurements based on data first reported [6]. If the potential measurements indicate that there is a high likelihood of active corrosion, then the concrete resistivity measurement is then used to estimate the corrosion rate. This is also said from practical experience ([7] and [8]).

[9] Conducted research on inhibitors in solvents extracted from alkaline and cement. Substances extracted from the cement experiment revealed that corrosion was prevented by using sodium nitrate in the presence of chlorides, whereas sodium benzoate did not. Furthermore, corrosion initiation with sodium nitrate is delayed, increasing with delayed inhibition content.

Novokshcheov [10] has shown that calcium nitrate is not harmful to concrete properties, as seen in the problem of inhibition based on sodium or potassium. Subsequent studies by Schottink [11] and Slater [12] have shown that calcium nitrate has a good quality in terms of strength when considering long-term rapid testing.

[13] Investigated the corrosion potential, concrete resistivity and tensile strength of the control, the non-coated and coated reinforcement steel of concrete slab member. Direct application of corrosion inhibitor of dacryodes edulis resins thicknesses of 150μm, 250μm and 350μm. Coated with a 12 mm diameter reinforcement, embedded in a concrete slab and pooled for rapid corrosion testing using half-cell potential measurements, exposed to concrete for 119 days under severe corrosive conditions. In

Comparative, corroded specimen has an increased efficiency of 70.1% and decreased values of concrete resistivity by 38.8%.

[14] Investigated the effects of the chloride attack on reinforcing steel embedded in reinforced concrete structures built in the marine environment. An experimental work simulated the acceleration process by the acceleration process on the non-coated and coated reinforcement of the acardium occidental l. Resins of 150µm, 250µm and 350µm polished thickness were embedded in a concrete slab and immersed in sodium chloride (NaCl) and accelerated for 119 days using the Wenner Four Probes method. The mean percentile results of potential E_{corr}, mV and concrete resistivity were 27.45% and 68.45%, respectively. Compared to coated specimens, corroded increased by 75.4% values of potential E_{corr}, mV, and decreased by 33.54% of concrete resistivity, recorded 43.98% weight loss and 51.45% cross-sectional diameter reduction.

[15] Conducted an exploratory study on the potential application of resin extract of inorganic resistant natural exudates / grocia. The corrosion potential results show that the values of the depleted specimens are high with the range, indicating an uncertain probability of 10% or corrosion. The range of values for corroded specimen indicates a significant corrosion potential for high, low, moderate, and low. The results showed a high ultimate yield of corroded specimens to control and coated 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 percentile of values against the control and coated specimens due to the effect of corrosion on the mechanical properties.

[16] studied the level of corrosion of reinforcing steel coated and non-coated members embedded in concrete slab structures and submerged in corrosive medium and evaluation of corrosion potential using Wenner four-probe acceleration method. Due to the effect of corrosion on the mechanical properties of steel reinforcement, the results showed a high ultimate yield of the non-coated specimens to control and the coated samples. 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 the steel.

[17] Evaluated the use of environmentally friendly exudates/adhesives that can be extracted from cola accumineta. Half-cell potential, concrete resistivity, and tensile strength tests were used to analyze the mechanical properties of the non-coated and exudates/resin coated specimens by immersion in sodium chloride for 150 days, with a scan rate of 1mV / s, and currents of 1200mV-200 mV. The mean value of the mechanical properties corroded sample against the control and coated specimens was 107.6483% and the percentile difference was 7.648311%, -7.10491% and -6.67339%. The average mechanical properties of the corroded models are "steel weight loss" percentile average value 180.4375% and percentile difference 80.43747%, -44.5791% and -45.1857% for control and coated specimens. Cross-sectional reduction results showed higher percentile reduction values due to the impact of corrosion on the mechanical properties of steel.

[18] Evaluated the application of an environmentally friendly inorganic natural exudates/resins extract of Olibanum, coated to reinforcing steel and that of non-coated members, embedded in a concrete slab and pooled in a corrosive environment for 150 days and compared with controlled samples with a potential flow rate of 1mV / s with a potential test rate of 1200mV to -200 mV. High yield results recorded for non-coated (corroded) samples against coated samples due to the attack on the mechanical properties of steel reinforcement. The results of the weight loss of the steel indicated a high percentile of

values against the control and coated model, which resulted from the reduction of the fiber / ribbed properties of the steel and modifications of reinforcing steel surface. The cross-sectional expansion of the corroded sample results was due to the effect of corrosion on the mechanical properties of the steel that showed high percentile reduction values.

[19] Investigated the deterioration trend of passive loss of reinforcing steel with the use of natural inorganic exudates/resins paste of varying coated thickness. Coated and non-coated members were embedded in a concrete slab and submerged in a partially corrosive medium with fast application currents of 1200mV through -200 mV, with a scan rate of 1mVs to examine half-cell corrosion potential, concrete resistivity and tensile strength properties for non-coated and coated concrete samples. The results of the non-coated sample cross-sectional area reduction results showed higher percentile reduction values due to the effect of corrosion on the mechanical properties of reinforcing steel. Non-coated members showed high percentile values against control and coated specimens due to surface attack and fiber/ribbed removal from the effect of corrosion on the mechanical properties of steel. High ultimate yields of non-coated specimens with low load application to control and coated specimens resulted in corrosion attack on the mechanical properties of steel reinforcement

2.1 Materials and Methods

2.1.1 Aggregate

Fine and coarse aggregates are purchased at the landfill. Both met the requirements of [20]

2.1.2. Cement

For all concrete mixes, limestone cement 42.5 grade is used. The cement meets the requirements of [21]

2.1.3. Water

Water samples met the requirements of [22], gotten from Kenpoly, Civil Engineering Department, Bori, Rivers State

2.1.4 Structural Steel Reinforcement

Reinforcement was purchased directly from the market, it met [23] requirements.

2.1.5 Corrosion Inhibitors (Resins / Exudates) Terminalia tomentosa

The gum exudate/resins were obtained from the tree barks in Amachara Village, in Mpu District, Aninri Local Government Area of Enugu State 2.2 Experimental procedure

2.2.1 Experimental Method

2.2.2 Preparation of a Sample Reinforced with Exudate / Coated Resin

This study investigated the potential of Terminalia tomentosa exudates/resin as an inhibitor material to prevent corrosion of steel bars in high salinity areas. Corrosion behavior is an aging process over many years until it is fully produced. The corrosion induction process has shown that the introduction of sodium chloride and other related substances has shown that the phenomena will occur in a short time, and the reinforced concrete structure exposed to it will suffer great damage and degradation. The level of corrosion can be estimated by the degree of quantification of the current density and the corrosion rate obtained by the polarization curve. The slab studied is designed with a concrete mix of standard ratio 1.2.4 and a water-cement ratio of 0.65. By gradually adding cement, aggregates (fine and coarse), and water to obtain a uniform color, concrete standards were obtained. A concrete slab of 100 mm × 500 mm × 500 mm (thickness, width, and length) is cast in a metal mold, compacted without gaps, and with a 10 mm concrete cover, and reinforced with 10 quantities of 12 mm diameter steel bars at 100mm c / c spacing (top and bottom), de-molded after 72 hours, cure at standard room temperature for 28 days. The hardened concrete slab is fully immersed in a 5% aqueous sodium chloride (NaCl) solution and accelerated by routine 90-days, 180-days, 270-days, and 360-day interval inspections and tests.

2.3 Accelerated Corrosion Test

The corrosion process is a natural phenomenon, it takes decades to realize. This is a long-term process, but the rapid induction and accelerated corrosion process using sodium chloride (NaCl) solution causes steel bars embedded in concrete to corrode and can accelerate the increase in corrosion that it occurs in a short period of decades. To test the corrosion resistivity of concrete, an experimental method was developed to accelerate the corrosion process and maximize the corrosion resistivity of

concrete. Accelerated corrosion testing is

an impressive technique, it is an effective technique that can be used to check the corrosion process of steel in concrete and assess damage to the protective concrete layer of steel bars. The laboratory acceleration process helps distinguish the effects of various factors that can affect chloride ion corrosion. Therefore, for the design of structural members and durability against corrosion as well as the selection of suitable material and appropriate protective systems, it is useful to perform accelerated corrosion tests for obtaining quantitative and qualitative information on corrosion. The classification of steel reinforcement corrosion severity is shown in Table 2.1. If the potential measurement results show that the possibility of corrosion is high, the degree of corrosion can be assessed by measuring the resistivity of the concrete. However, care must be taken when using this data because it is assumed that the corrosion rate is constant over time. Practical experience has also proved this point [Figg and Marsden [5], Gower and Millard [6]. The measurement of average potential is an indirect method to estimate the likelihood of corrosion. Recently, there has been great interest in developing tools for electrochemical measurements of steel perturbations to obtain direct estimates of corrosion rates (Stem and Geary [7]). Corrosion rate refers to electrochemical measurements, first based on data.

Table 2.1: Dependence between potential and corrosion probability[25]

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 Tests for Measuring the Resistivity of Concrete

The test is used to measure the resistivity of concrete and obtained different readings at different positions on the concrete surface. After the water is applied to the surface of the board, the resistivity of the concrete is measured at a reference point daily to determine its saturation state. This location is chosen on the side of the panel because special resistivity measurements can be made with water on the top of the panel. In this study, the reading aid was recorded as the final resistivity measurement. The saturation of the slab is monitored by measuring the resistivity of the concrete. The resistivity is directly related to the moisture content of the concrete. Once one plate reaches saturation, water will flow out while the other plate remains closed. Time limitation is the main challenge for all experimental measurements because the saturation state of concrete will change over time. This study used the Wenner method with four probes. To this end, the four probes directly contact the concrete of the reinforced rail. Because each board has a different water-cement ratio, the time required to saturate each board is different. Before pouring water on the slab, measure the resistivity of the concrete at certain locations in the dry state. After the concrete reaches a saturated state, the resistivity will be constant.

Table 2.2: Dependence between concrete resistivity and corrosion probability[26]

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 Steel Bars

To determine the elastic limit of the steel bars and the maximum value of the ultimate tensile strength, 10 reinforced concrete slabs with coated and uncoated steel bars with a diameter of 12 mm were pressure to failure state on the Instron Universal Testing Machine (UTM).

The digital and computerized system records the results of yield strength, maximum tensile strength, and strain ratio. To ensure stability, the remaining cut part is used to check the diameter of the bar before the test, the diameter of the bar after corrosion, the reduction/increase of the cross-section, and the weight of the bar, steel weight loss/increase

3.0 Test Results and Discussion

The results of the half-cell potential measurement are plotted against the resistivity for ease of interpretation. It is used to represent the significant corrosion probability of extremely high, extremely high, extremely low to moderate and extremely low corrosion probability (ρ 20). At another measurement point, the correction potential is very high (–350mV≤Ecorr≤–200mV),

indicating that the probability of corrosion is 10% or uncertain. The measurement results of the concrete resistivity are shown in Table 2. Facts have proved that if the corrosion potential is low (<-350 mV) within a certain range, the probability of corrosion is 95%. The electrical resistivity of concrete is usually measured using the four-electrode method. The data from the resistivity study indicates whether certain conditions will lead to less ion movement, leading to increased corrosion.

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

	Control Concrete slab Specimens											
Sample Numbers	TTS	TTS1	TTS2	TTS3	TTS4	TTS5	TTS6	TTS7	TTS8	TTS9	TTS10	TTS11
	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	-110.9	-111.6	-107.8	-105.9	-108.9	-105.3	-113.8	-109.4	-105.0	-107.5	-111.4	-112.5

Concrete Resistivity ρ, kΩcm	14.21	14.20	14.19	14.19	14.18	14.35	14.34	14.33	14.33	14.32	14.26	14.18
Yield Strength, fy (MPa)	457.65	460.65	456.65	456.95	457.65	456.88	459.88	460.18	458.88	460.27	456.78	460.61
Ultimate Tensile Strength, fu (MPa)	624.66	622.61	624.29	620.07	623.60	624.02	623.82	624.62	623.22	624.77	624.27	624.13
Strain Ratio	1.36	1.35	1.37	1.36	1.36	1.37	1.36	1.36	1.36	1.36	1.37	1.36
Rebar Diameter Before Test (mm)	11.98	11.96	11.97	11.99	11.96	11.98	11.98	11.96	11.97	11.97	11.96	11.97
Rebar Diameter at 28 days(mm)	11.98	11.96	11.97	11.99	11.96	11.98	11.98	11.96	11.97	11.97	11.96	11.97
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	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.88	0.87	0.87	0.87	0.87
Rebar Weights- After at 28 days (Kg)	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.88	0.87	0.87	0.87	0.87
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	-322.5	-335.5	-332.3	-324.7	-334.5	-341.4	-375.4	-382.6	-386.4	-409.8	-415.6	-423.3
Concrete Resistivity ρ, kΩcm	**6.66**	**6.79**	**7.62**	**7.93**	**7.71**	**7.26**	**7.08**	**7.44**	**7.47**	**7.07**	**6.45**	**7.26**
Yield Strength, fy (MPa)	423.51	424.51	427.51	427.81	426.51	425.74	428.74	429.04	427.74	429.13	425.64	429.47
Ultimate Tensile Strength, fu (MPa)	616.46	614.41	616.09	611.87	615.40	615.82	615.62	616.42	615.02	616.57	616.07	615.93
Strain Ratio	1.46	1.45	1.44	1.43	1.44	1.45	1.44	1.44	1.44	1.44	1.45	1.43
Rebar Diameter Before Test (mm)	11.99	11.97	11.98	12.00	11.97	11.99	11.99	11.97	11.97	11.97	11.97	11.98
Rebar Diameter- After Corrosion(mm)	11.94	11.92	11.93	11.95	11.92	11.94	11.94	11.92	11.92	11.92	11.92	11.93
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)	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.88	0.87	0.87	0.87	0.87
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 Terminalia tomentosa 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	-115.3	-118.5	-117.9	-117.2	-114.3	-118.4	-116.6	-120.3	-116.9	-111.5	-112.5	-118.7
Concrete Resistivity ρ, kΩcm	17.63	17.78	18.06	18.19	17.88	18.17	18.12	18.27	18.30	17.77	17.66	17.51

Yield Strength, fy (MPa)	456.78	459.78	455.78	456.08	456.78	456.01	459.01	459.31	458.01	459.40	455.91	459.74
Ultimate Tensile Strength, fu (MPa)	626.33	624.28	625.96	621.74	625.27	625.69	625.49	626.29	624.89	626.44	625.94	625.80
Strain Ratio	1.37	1.36	1.37	1.36	1.37	1.37	1.36	1.36	1.36	1.36	1.37	1.36
Rebar Diameter Before Test (mm)	11.99	11.97	11.98	12.00	11.97	11.99	11.99	11.97	11.98	11.98	11.97	11.98
Rebar Diameter- After Corrosion(mm)	12.05	12.03	12.04	12.06	12.03	12.05	12.05	12.03	12.03	12.03	12.03	12.04
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Rebar Weights- Before Test(Kg)	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.88	0.87	0.87	0.87	0.87
Rebar Weights- After Corrosion(Kg)	0.95	0.94	0.95	0.94	0.95	0.95	0.95	0.95	0.95	0.94	0.95	0.95
Weight Loss /Gain of Steel (Kg)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07

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				Terminalia tomentosa 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 Terminalia tomentosa Exudate / Resin Coated Specimens			
Potential Ecorr,mV	-110.3	-106.5	-109.4	-110.3	-330.2	-333.6	-381.1	-416.8	-117.2	-116.9	-117.9	-113.7
Concrete Resistivity ρ, kΩcm	14.20	14.24	14.33	14.25	7.02	7.63	7.33	6.92	17.82	18.08	18.23	17.65
Yield Strength, fy (MPa)	458.31	457.16	459.64	459.22	425.17	426.68	428.50	428.08	457.45	456.29	458.78	458.35
Ultimate Tensile Strength, fu (MPa)	623.85	622.56	623.89	624.39	615.65	614.36	615.69	616.19	625.52	624.23	625.55	626.06
Strain Ratio	1.36	1.36	1.36	1.36	1.45	1.44	1.44	1.44	1.37	1.37	1.36	1.37
Rebar Diameter Before Test (mm)	11.97	11.98	11.97	11.97	11.98	11.99	11.98	11.97	11.98	11.99	11.98	11.98
Rebar Diameter- After Corrosion(mm)	11.97	11.98	11.97	11.97	11.93	11.94	11.93	11.93	12.04	12.05	12.04	12.04
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06
Rebar Weights- Before Test(Kg)	0.876	0.878	0.881	0.879	0.877	0.881	0.87	0.879	0.876	0.879	0.87	0.877
Rebar Weights- After Corrosion(Kg)	0.876	0.878	0.881	0.879	0.825	0.826	0.829	0.828	0.952	0.957	0.953	0.959
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				Terminalia tomentosa 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 Terminalia tomentosa Exudate / Resin Coated Specimens			
Potential Ecorr,mV	-66.67	-68.05	-71.32	-73.47	181.53	185.41	223.42	265.08	-64.48	-64.96	-69.08	-72.61
Concrete Resistivity ρ, kΩcm	102.18	86.52	95.53	105.86	-60.60	-57.78	-59.79	-60.77	153.79	136.88	148.72	154.88

Yield Strength, fy (MPa)	7.79	7.14	7.27	7.27	-7.06	-6.49	-6.60	-6.61	7.59	6.94	7.07	7.07
Ultimate strength (N/mm2)	1.33	1.33	1.33	1.33	-1.58	-1.58	-1.58	-1.58	1.60	1.61	1.60	1.60
Strain Ratio	-6.01	-5.42	-5.57	-5.49	5.93	5.26	5.35	5.34	-5.59	-5.00	-5.08	-5.07
Rebar Diameter Before Test (mm)	0.03	0.05	0.03	0.04	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.04
Rebar Diameter- After Corrosion(mm)	0.36	0.36	0.36	0.37	-0.91	-0.91	-0.91	-0.92	0.92	0.92	0.92	0.93
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-15.79	-14.04	-15.79	-14.04	18.75	16.33	18.75	16.33
Rebar Weights- Before Test(Kg)	6.601	6.479	6.484	6.802	6.481	6.563	6.482	6.481	6.499	6.305	6.5	6.599
Rebar Weights- After Corrosion(Kg)	6.59	6.59	6.71	6.59	-13.42	-13.33	-13.41	-13.42	15.51	15.38	15.49	15.51
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	-26.03	-26.03	-26.03	-26.03	35.19	35.19	35.19	35.19

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

The damage to concrete structures due to corrosion of reinforcement is not uncommon and can be quite large [27]. The durability problems associated with chlorides shorten the life of concrete structures [28]. The durability of concrete materials including chloride [29] requires special attention. However, the corrosion of reinforcement is not easy to see. Identification and measurement of reinforcement corrosion in reinforced concrete structures is still a major problem in studying the strength of concrete. A common approach for non-destructive measurement is the half-cell potential method [30], and specific resistance methods of Wenner four electrode method [31], which is been used in this studies to ascertain the degree and rate of corrosion and the effects on reinforced concrete structures wholly immersed in corrosive media. The existing methods have their own advantages because they are used in the assay field is easy to use with simple detection equipment. The results of "Corrosion Potential E_{corr}, mV and Concrete Resistivity ρ, kΩcm" as 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 3.1-3.7b, are the results of controlled samples, un-coated (corroded), and coated for 36 concrete slabs, divided into 3 sets of 12 controlled samples, which are the determining reference range, 12 samples without coating (corrosion) and 12 samples with exudates/resin coated.

The mean and minimum, maximum and differential values of the calculated measurements of the half-cell potential of the controlled sample were -110.39mV and -106.57mV (-73.47% and -66.67%) with a potential difference (3.82mV and 6.8%), the corroded samples were -416.08mV and -330.02mV (181.53% and 265.08%) and the difference values were 86.06mV and 83.55%, and the coated samples were -117 .99mV and -113.97mV (-72.61% and -64.48%), and the potential difference is 4.02mV and 8.13%, respectively. The maximum calculated percentile control value is -66.67% compared to the corroded and coated values of 265.08% and -64.48% and the controlled potential difference value is 6.8%, corroded 83.55% and coated 8.13% . The maximum yields of controlled and coated samples were -106.57mV and -113.97mV, which showed the relationship between corrosion potential and probability as a $E_{corr} > -200$mV as a reference range. The results of these corrosion potential E_{corr} results indicate that the values of controlled samples and exudates/resin coated samples are low with a 90% probability that no corrosion of the reinforcement is currently observed during measurements (10% corrosion risk, indicated.) 10% or corrosion probability uncertain. For non-coated (corroded) samples, the maximum calculated value is -330.02mV, the result is within the reference value of the dependence between corrosion potential and probability of the value $-350\text{mV} \leq E_{corr} \leq -200\text{mV}$ indicating a high range of values, which corresponds to 10% or possible unsafe corrosion. The comparative results from the reference range (controlled) show that the corroded samples exhibited corrosion as a result of the induced corrosion acceleration compared to the coated samples which showed no corrosion presence. Exudates/resin has inhibitory properties against corrosion attack on reinforcing steel embedded in concrete structures exposed to corrosive media.

The average value and the minimum and maximum percentile of concrete resistance with controlled sample potential difference are 14.2 kΩcm and 14.33 kΩcm (86.52% and 105.86%) and the difference value is 0.13kΩcm and 19.34%. The corroded samples were 6.92 kΩcm and 7.63kΩcm (-60.77% and -57.78%) and the difference values were 0.71 kΩcm and 2.99%. The coated sample valleys were 17.65 kΩcm and 18.23kΩcm (136.88% and 154.88%) and the difference values were 0.58 kΩcm and 18.0%, respectively. The maximum calculated value of the controlled sample concrete resistance is 105.86% compared to the corroded and coated values of -57.78% and 154.88% and the maximum percentile difference in control are 19.34% compared to the corroded and coated values of 2.99% and 18.0 %. The results of the controlled and coated concrete resistance samples obtained an average maximum value of 14.33 kΩcm and 18.23 kΩcm with a data value of 10 <ρ <20 (low) compared to a corrosion value of 7.63 kΩcm with a specification of 5 <ρ < 10 (high) and with a reference range of dependence between concrete resistance and corrosion probability significant corrosion probability (ρ < 5, 5 < ρ < 10, 10 < ρ < 20, ρ > 20) for very high, high, low to moderate and low, for the probability of occurrence corrosion. From the comparative results obtained with the coated and corroded samples, the maximum values obtained for the two samples clearly indicate that the value of the coated samples lies in the range of 10 < ρ < 20, which classifies the range of values from lowest to moderate, with information as significant corrosion probability. The maximum value of the corroded sample is in the range of 5 < ρ < 10, which indicates high, signs indicating the possibility of corrosion, as in the studies of ([16];[13];[15];[18];[19]). 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.

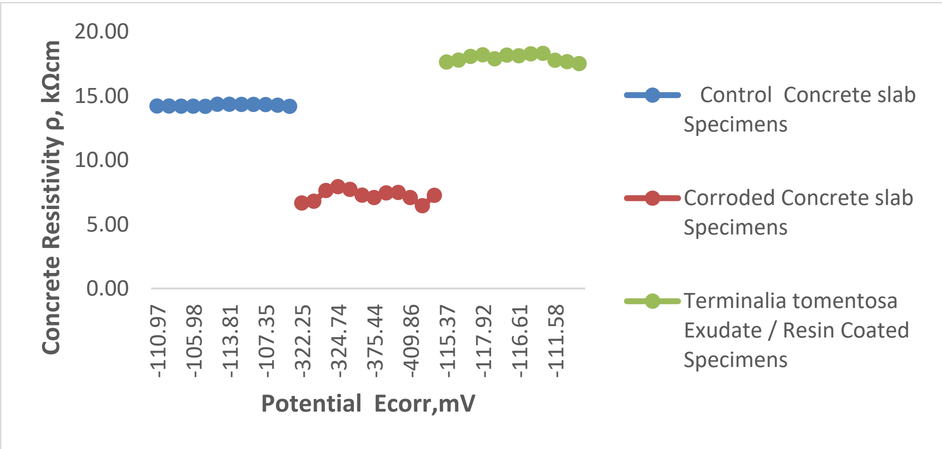

Figure 3.1 : Concrete Resistivity ρ, kΩcm versus Potential Ecorr,mV Relationship

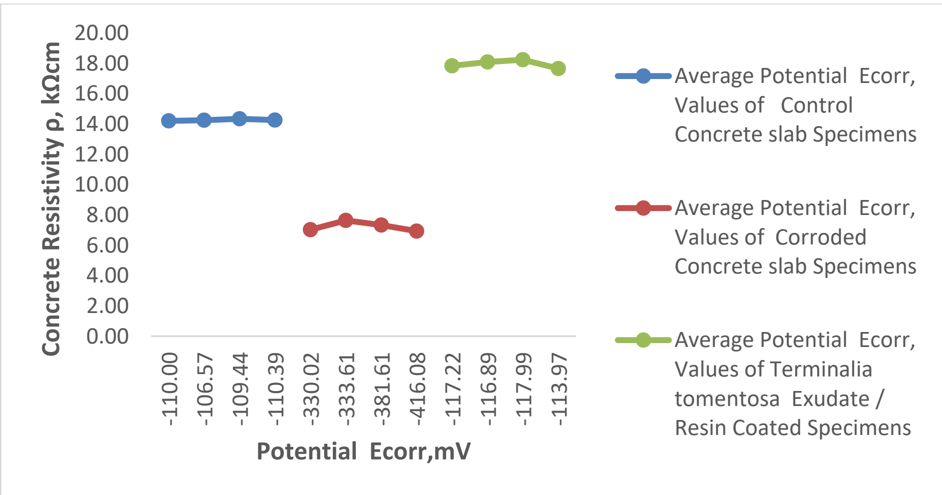

Figure 3.1A: Average Concrete Resistivity versus Potential Relationship

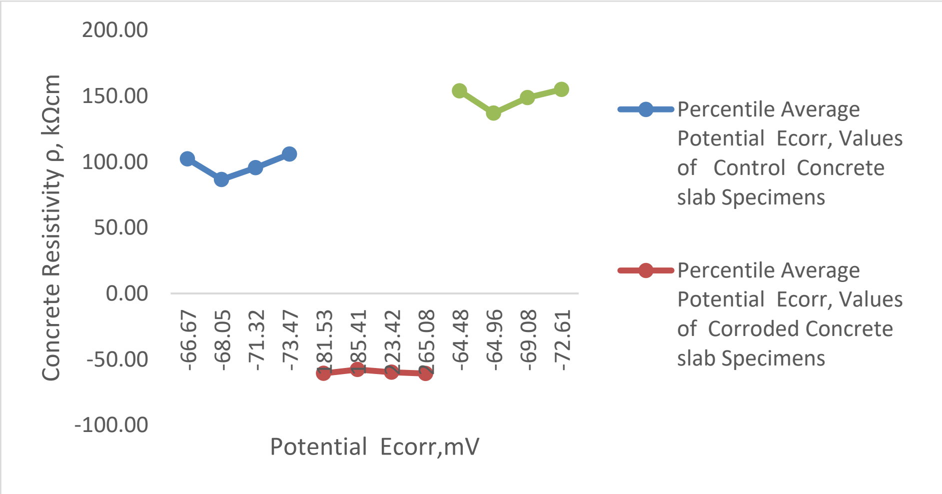

Figure 3.1B : Average Percentile Concrete Resistivity versus Potential Relationship

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

Stability is the ability of a structure to comply with safety and operational criteria during its design. The resistance depends on the condition of the concrete and reinforcement. Reinforcement corrosion is one of the main factors that can affect durability. Corrosion can be caused by the ingress of chlorides or by the action of carbonization. The chemical composition of the reinforcement plays an important role here. The mechanical properties of reinforcement, the minimum values usually given in most specifications, are tensile strength, maximum strength (or maximum tensile strength) and elongation as parameters for characterization.

The results of the mean, percentile and the value of the difference between the minimum and maximum yield strength limits, fy (MPa) of the controlled sample were 457.16MPa and 459.64MPa (7.14% and 7.79%) and the difference values were 2.48MPa and 0. 65%, the corroded samples were 425.17MPa and 428.5MPa (-7.06% and -6.49%) and the potentially differential values were 3.33MPa and 0.57%, the coated sample values were 456.29MPa and 458.78MPa (6.94% and 7.59%) and the potentially differential value is 2.49MPa and 0.65%. The calculated maximum percentile value of the controlled yield strength was 7.79% compared to the corroded values of -6.49% and coated 7.59% and the possible difference values of 0.65% controlled 0.57% and 0.65% coated.

The mean, percentile, and the difference between the minimum and maximum ultimate tensile strength, fu (MPa) of the controlled sample were 622.56MPa and 624.39MPa (1.33% and 1.33%) and the difference value was 1.83MPa and 0.00%, corroded 614.36MPa and 616.19MPa (-1.58MPa and -1.58%) and the difference between 1.83MPa and 0.0%, coated of 624.23MPa and 626.06MPa (1 .6% and 1.61% and the difference value is 1.83MPa. The maximum calculated percentile of controlled ultimate tensile strength is 1.33% relative to corrosion and the coated value is -1.58% and 1.61%, respectively, and the difference value is possible from 0.00% controlled, 0.00% corroded and 0.01% coated.

The strain ratio of the mean minimum and maximum deformation, percentile and difference values of the controlled samples were 1.36 and 1.36 (-6.01% and -5.42%) with a difference value of 0.00 and 0.59%, the value of the corrosion samples were 1.44 samples and 1.45 (5.255 and 5.93%) and the difference values were 0.01 and 0.67%, the coated samples were 1.36 and 1.37 (-5.59% and -5 .0%) and the difference between 0.01 and 0.59%.

The maximum calculated percentile for comparison controlled -5.42% against corroded 5.93% and coated -5.0%, and differential peak controlled 0.59%, corroded 0.67 and coated 0.59% as in the studies of ([16];[13];[15];[18];[19]). From the calculation results obtained, which are summarized in Tables 3.4 and 3.5 and shown graphically in Figures 3.1 - 3.8, the yield strength, ultimate tensile strength and strain ratio mean, percentile and controlled differential potential, non-coated (corroded) and layered concrete slab samples , coated samples had higher breaking loads compared to corroded samples with reduced breakdown loads and low load bearing capacity and with mean and percentile values for the reference range, whereas non-coated (corroded) samples had lower load bearing capacities and the reduced value is 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 non-coated (corroded) elements, which damage reinforcing steel fibers, ribs and passive formation and surface modification. The observed mean values for the coated samples were traced to have no corrosion with properties of corrosion resistance to penetration into the reinforcing steel with the formation of a protective membrane; these attributes indicate the efficiency and effectiveness of exudates / resins as inhibitors against the corrosive effects of reinforced concrete structures exposed to strong severe, high salinity marine areas.

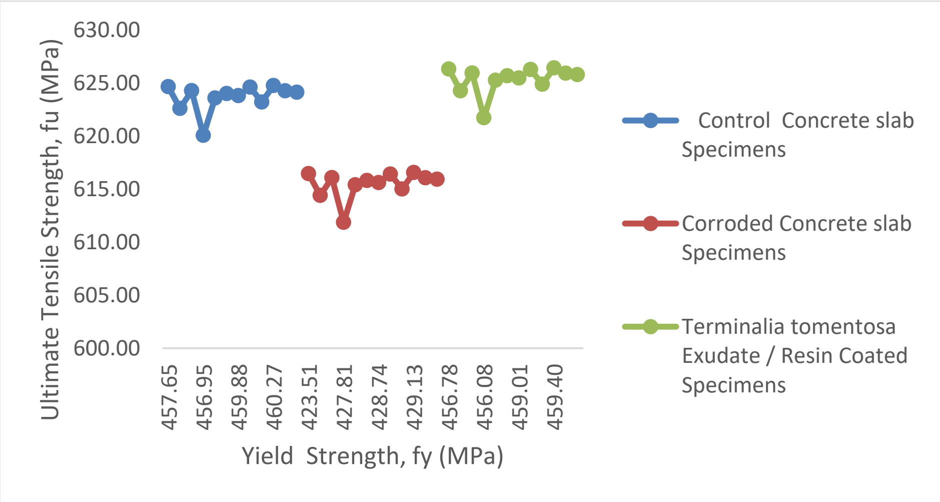

Figure 3.2 : Yield Strength versus Ultimate strength

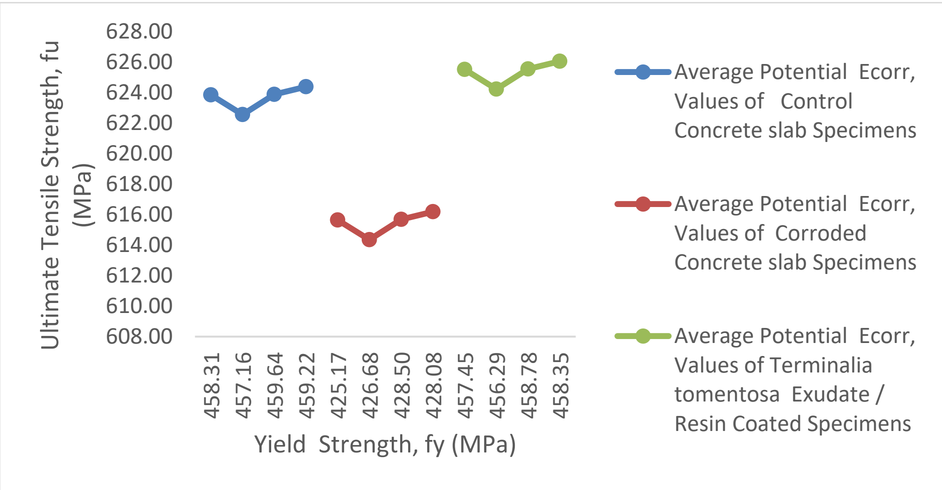

Figure 3.2A: Average Yield Strength versus Ultimate Tensile Strength

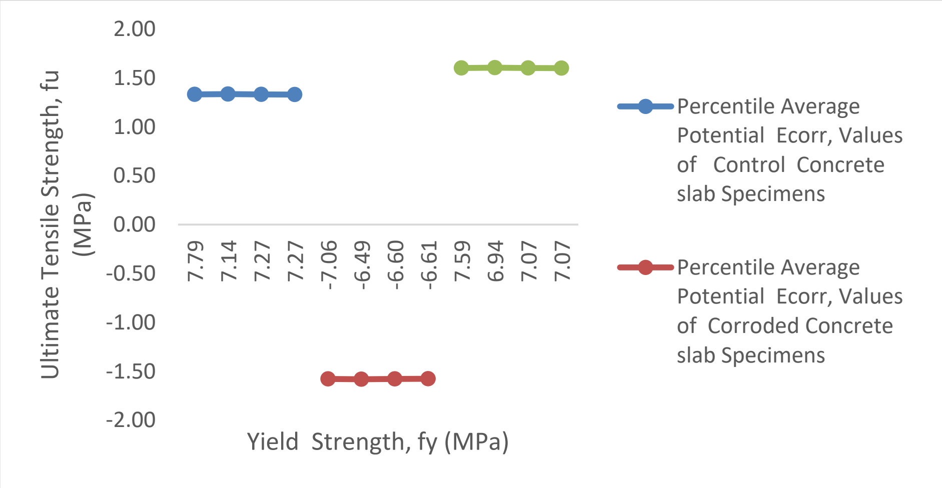

Figure 3.2B: Average Percentile Yield Strength versus Ultimate Tensile Strength

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

Corrosion of reinforced steel leads to a reduction in the cross-sectional area of the steel bar and the accumulation of corrosion products, which in turn reduces the ductility and strength of the steel. Corrosion products occupy a volume 2 to 6 times greater than that of the original reinforced steel (Liu and Weyers, 1998). The initial corrosion products on the surface of the steel bar cause longitudinal cracking, peeling and delamination of the concrete shell/cover. The loss of the concrete layer in turn leads to a loss of tightness by reducing the joint strength in the area between the steel rail and the concrete. The soft layer obtained from the accumulation of corrosion products on the surface of the rod succeeded in reducing the friction component of the bond strength. In this way, fracture of the ribs by deformed bars reduces the locking force between the bars and the surrounding concrete structure. This breaks the basic bond strength mechanism between the deformed bar and the concrete and significantly reduces bonding.

The diameter of the reinforcing steel before testing (mm), the average, minimum and maximum percentile values were 11.97mm and 11.98mm (0.03% and 0.05%) with the difference values, the controlled 0.01 mm and 0.02%, the corroded values of the samples were 11.97mm and 11.99mm (0.03% and 0.04%) and the difference values were 0.02 mm and 0.01% and the sample values coated were 11.98mm and 11.99mm (0.03% and 0.04 mm) and the calculated values were differentially 0.01mm and 0.01%. The unit weight of the values of reinforcing steel before corrosion test showed a small difference based on the product and The form of the company and by-products are used in the manufacturing process.

The minimum and maximum mean values obtained, percentiles and the value of the difference in diameter of reinforcement after corrosion (mm) for the controlled sample are 11.97 mm and 11.98 mm%) with a difference of 0.01 mm and 0.02%, with 100% reference values maintained, the corroded sample values were 11.93 mm and 11.94 mm (-0.92% and -0.91%) and the difference values were 0.01 mm and 0 0.01%, coated sample values are 12.04 mm and 12.05 mm (0.92% and 0.93%) and the difference is 0.01 mm and 0.01%. The maximum calculated percentile is checked with 0.05% against -0.91% corroded and 0.93% coated, the difference in corrosion percentile is 0.01% against 0.01% 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 and exposed to activity-induced corrosion acceleration. For comparison, the results of corroded samples showed a decrease and decrease in value compared to the diameter of the reinforcement before and after the induction accelerated corrosion test with a percentile decrease in value from 0.03% to -0.903% and an average value in the range from 11.97mm to 11. 93mm.

The decrease/increase (diameter) in cross-sectional area, minimum and maximum mean and percentile values were controlled 100%, with no decrease or increase after 360 days of immersion in fresh water. Corroded sample values were 0.05mm and 0.05mm (-15.79% and -14.04%) and the difference between 0% and 1.75% for the corroded, coated sample values were 0.06mm and 0.06 mm (16.33% and 18.75%) and 0.00 mm and 2.42% difference. The relative mean and difference in percentile values between coated and corroded samples ranged from 39.02% to -28.07%. The reduction in mean and percentile values indicates that the corrosion effect causes a reduction in diameter and cross-sectional area, fiber degradation, rib rib and surface modification, whereas exudate/resin coated elements show an increase in volume due to different coating thickness as in the studies of ([16];[13];[15];[18];[19]). 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.

The values of reinforcing steel weight - before test (kg), the minimum, maximum, and differential mean and percentile of controlled samples were 0.876 kg and 0.881 kg (7.69% and 8.85%) and the difference was 0.005% and 1.16%, respectively. Corroded samples weighed 0.87 kg and 0.881 kg (-18.96% and -16.64%) and the difference was 0.011% and 2.32%, coated samples were 0.87 kg and 0.879 kg (12.89% and 16, respectively). 09%) with a difference of 0.009% and 3.2%.

The average and percentile of reinforcement weight after corrosion (Kg) and the difference in the aggregate values of the minimum and maximum values of the controlled samples were 0.876 kg and 0.881 kg (7.69% and 8.85%), and the difference was 0.005% and 1, 16%, samples corroded was 0.825 kg and 0.829 kg (-13.42% and -13.33%) and the difference was 0.004% and 0.09%, the value of the coated sample was 0.952 kg and 0.959 kg (15.38% and 15.51%) and the difference between 0.007% and 0.13%. Average and percentile of minimum and maximum unit loss/gain steel (Kg) and percentile difference in comparator are values maintained at 100% as a result of aggregation in fresh water tanks with no trace of corrosion potential compared to a corrosion controlled sample value of 0.05 kg and 0.05 kg (-26.03% and -26.03%) and coated of 0.07kg and 0.07kg (35.19% and 35.19%). The computed results from Tables 3.1-3.3 and in 3.4 - 3.5 are summarized and plotted graphically in Figure 3.7-3.7b, and enumerated the effects of corrosion on uncoated (corroded) and coated reinforcing steel before and after corrosion tests. For comparison, the results obtained show a reduction of the mean and percentile values for the corroded from 0.070kg to 0.050kg and 35.19% to -26.03%, as related in the studies as in the studies of ([16];[13];[15];[18];[19]). The summary results show that the corrosion effect causes a decrease in weight/reduction of the corroded sample compared to coatings with percentile loading and an increase in mean values, which leads to a slight increase in volume with coating thickness. This study demonstrated the efficacy and effectiveness of exudate/resin as a corrosion inhibitor for reinforcement embedded in a sample of concrete slabs exposed to induced corrosion..

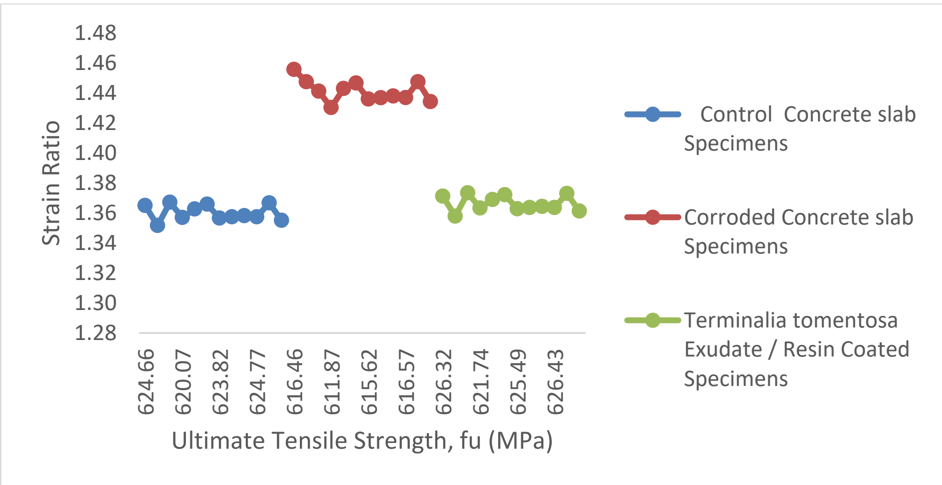

Figure 3.3: Ultimate Tensile Strength versus Strain Ratio

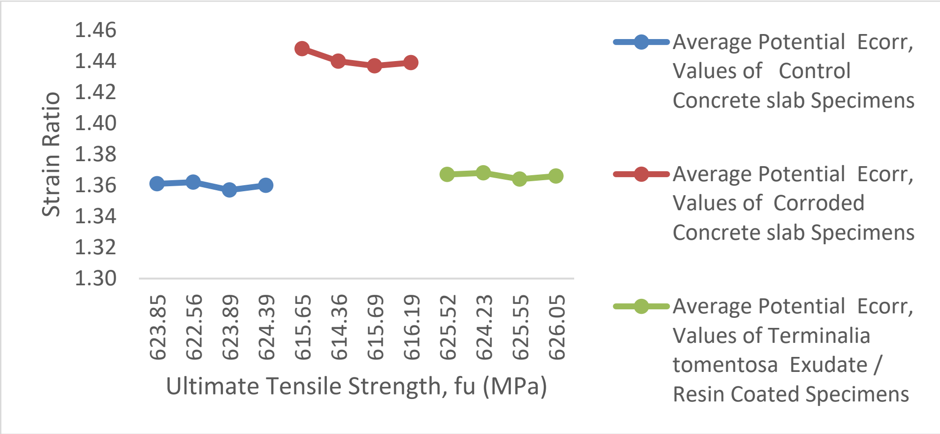

Figure 3.3A: Average Ultimate Tensile Strength versus Strain Ratio

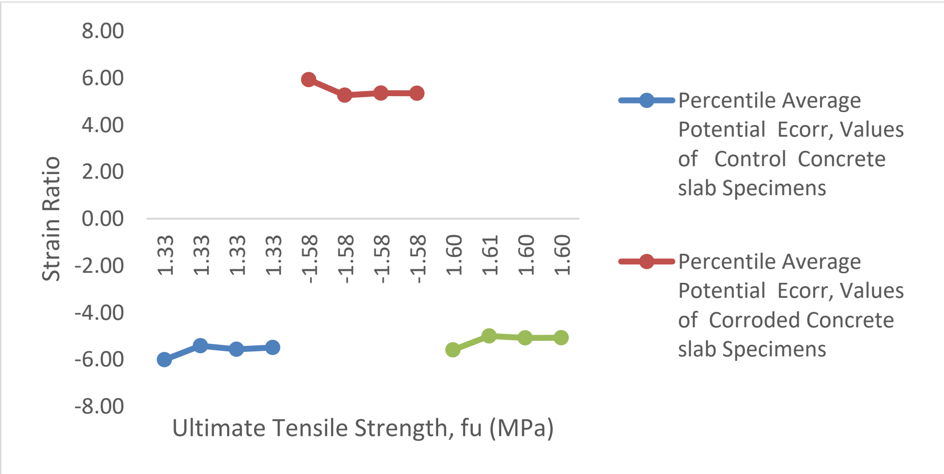

Figure 3.3B: Average percentile Ultimate Tensile Strength versus Strain Ratio

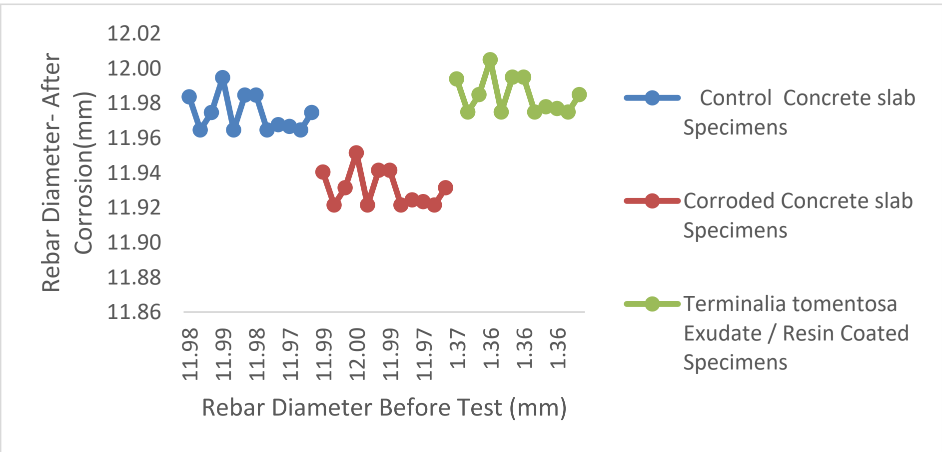

Figure 3.4: Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

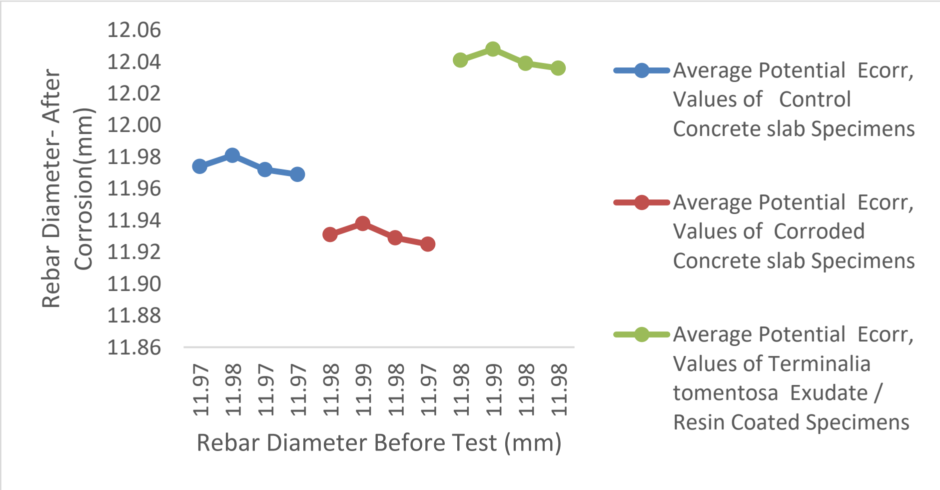

Figure 3.4A: Average Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

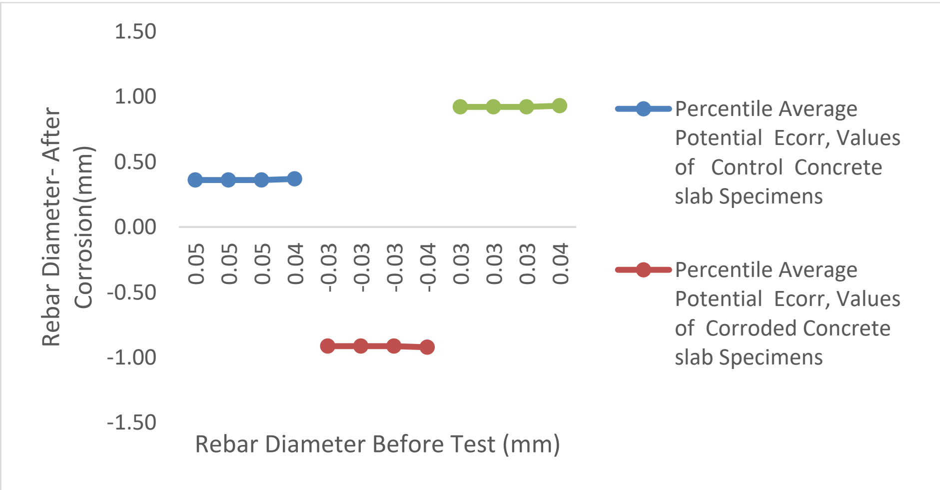

Figure 3.4B: Average Percentile Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

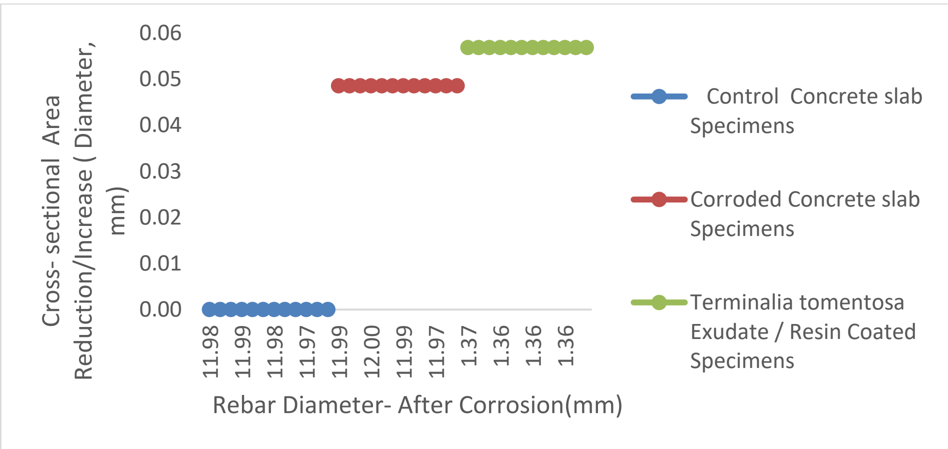

Figure 3.5: Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

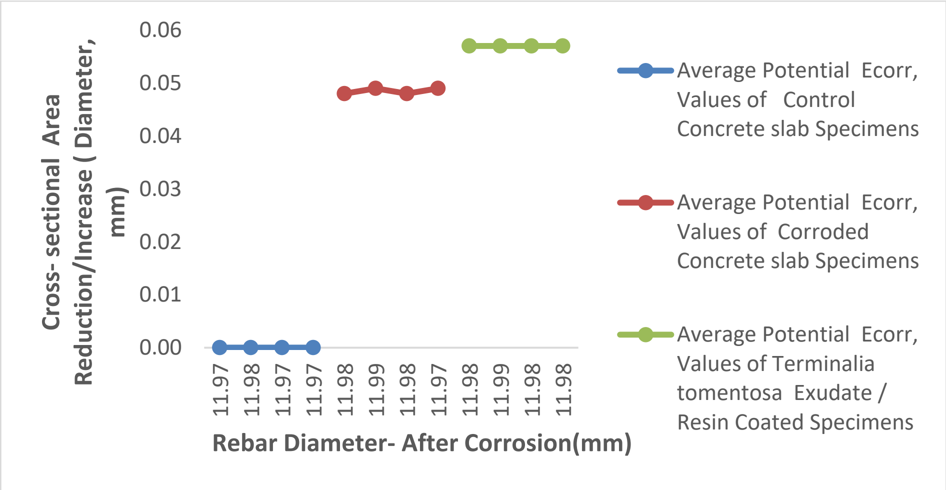

Figure 3.5A: Average Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

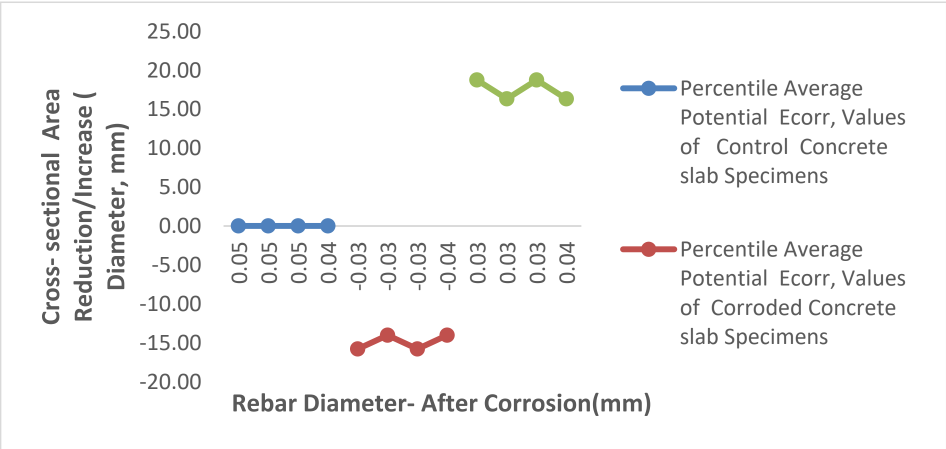

Figure 3.5B: Average Percentile Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

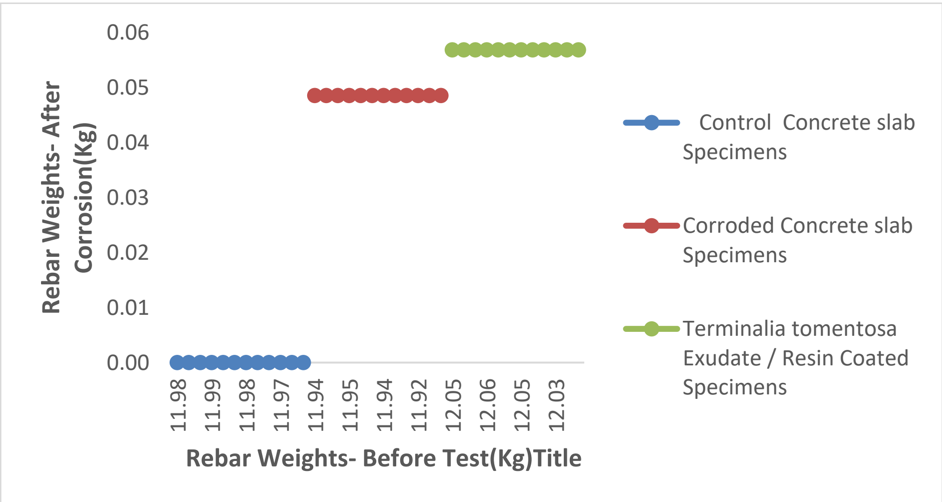

Figure 3.6: Rebar Diameter - After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

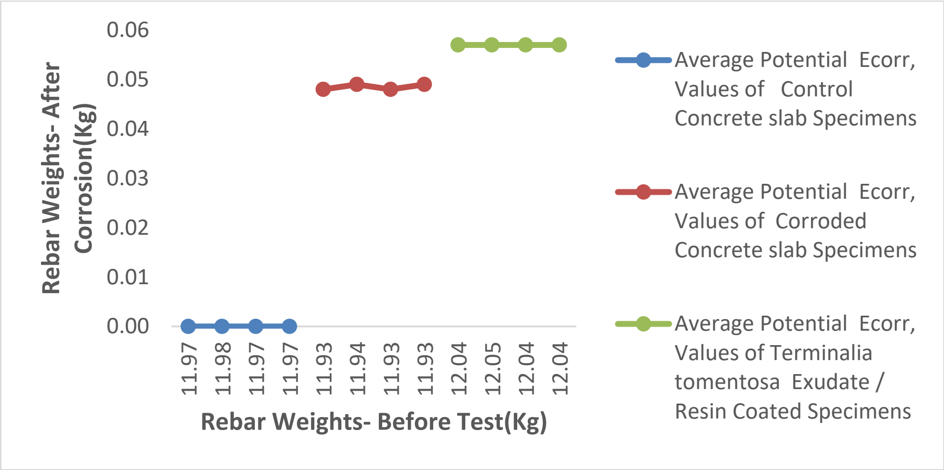

Figure 3.6A: Average Rebar Diameter - After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm

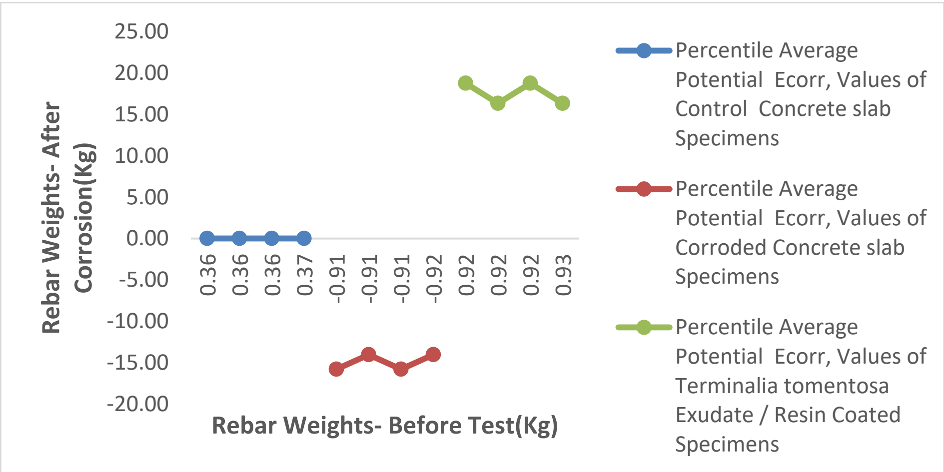

Figure 3.6B: Average Percentile Rebar Diameter - After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

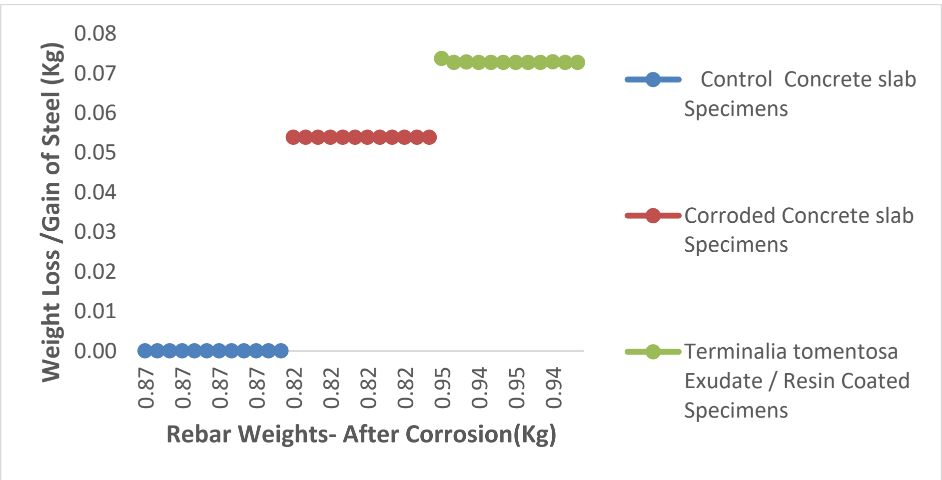

Figure 3.7: Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

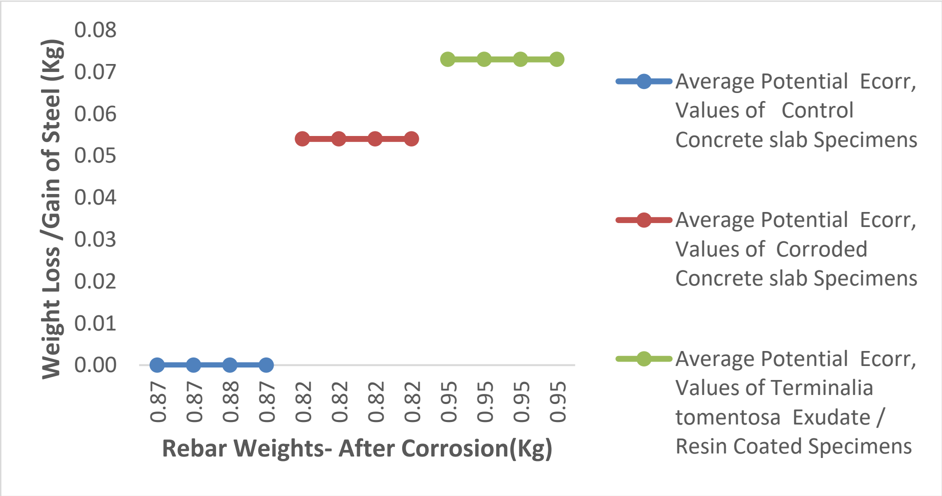

Figure 3.7A: Average Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

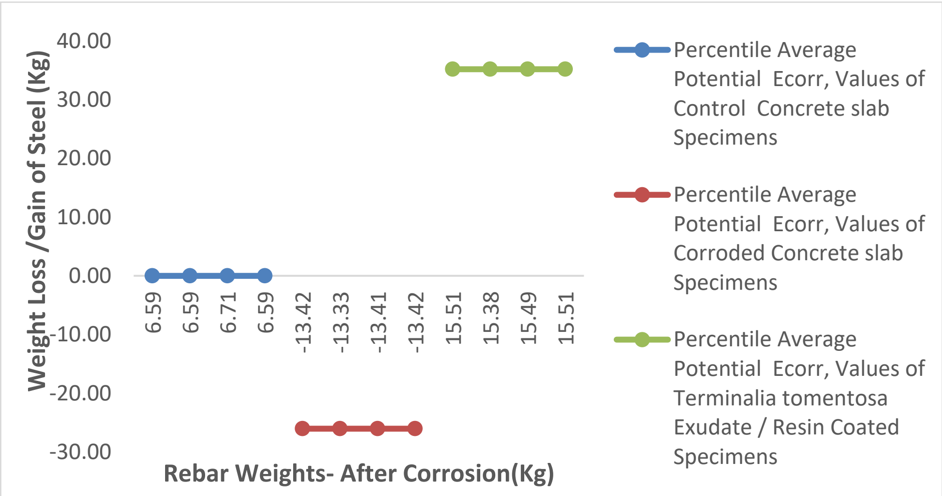

Figure 3.7B: Average Percentile Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

4.0 CONCLUSION

Experimental results showed the following conclusions:

1. The comparative results show that the low load carrying capacity is caused by the effect of corrosion attack on the non-coated (corroded) elements, which damage reinforcing steel fibers, ribs and passive formation and surface modification.
2. The observed mean values for the coated samples were traced to have no corrosion with properties of corrosion resistance to penetration into the reinforcing steel with the formation of a protective membrane
3. Exudates/resin showed attributes of efficiency and effectiveness of inhibitors against the corrosive effects of reinforced concrete structures exposed to strong severe, high salinity marine areas.
4. 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
5. The summary results show that the corrosion effect causes a decrease in weight/reduction of the corroded sample compared to coatings with percentile loading and an increase in mean values, which leads to a slight increase in volume with coating thickness.
6. This study demonstrated the efficacy and effectiveness of exudate/resin as a corrosion inhibitor for reinforcement embedded in a sample of concrete slabs exposed to induced corrosion.

7. 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

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