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Reinforcing Steel Corrosion Potential Probability Evaluation using Electrochemical Hall-Cell Measurement

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ABSTRACT

The investigative work examined the use of raphia hookeri exudate/resin, extracted from tree trunk and inhibited it to reinforcing steel, embedded to concrete slab of dimensions as described the test procedures, wholly immersed in an accelerated corrosive media for 360days with routinely checked and tested at 3 months intervals and observed the resulting surface modifications and changes. The corrosion potential maximum yields of the controlled and coated samples were -101.88mV and -116.26mV, which indicates the relationship between corrosion potential and probability as $E_{corr} > -200$mV as the reference range. The results of the potential E_{corr} results indicate that the values of controlled samples and exudate/resin coated samples are low with a 90% probability that no corrosion of the reinforcement is observed at the time of measurement (10% corrosion risk, 10% or indicates an uncertain corrosion probability For uncoated samples, the maximum calculated value is -345.43 mV, the result is within the reference value of the relationship between corrosion potential and probability of $-350\text{mV} \leq E\text{corr} \leq -200\text{mV}$ indicates a high range of values, indicating a corrosion probability of 10% or uncertain. Comparison 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 did not show corrosion attack on reinforcing steel embedded in a concrete slab, exposed to a corrosive environment due to formation resistive layer. The calculated maximum value of the controlled sample concrete resistance is 96.43% compared to the corroded and coated values -40.8% and 73.59% and the maximum controlled difference percentage is 5.38% compared to the corroded and coated value of 1.58% and 4.65%. The results of the controlled and layered concrete resistance samples obtained an average maximum value of 17.14kΩcm and 15.15kΩcm with a description of the value $10 < \rho < 20$ (low) compared to the corrosion value of 8.95kΩcm with specifications $5 < \rho < 10$ (high) and with the reference range of the relationship between concrete resistance and corrosion probability, the corrosion probability was significant ($\rho < 5$, $5 < \rho < 10$, $10 < \rho < 20$, $\rho > 20$) for very high, high, low to moderate and low, for possible corrosion. The maximum percentile values calculated from the controlled yield point were 2.06% relative to the corrosion and coating values of -1.9% and 1.79% and potential difference value 0.09% controlled, 0.06% corroded and 0.15% coated. The comparison results show that the low load carrying capacity is caused by the effect of corrosion attack on the uncoated (corroded) elements, which interfere with reinforcing steel fibers, ribs, and passive formation and surface modification. Comparatively, the results of corroded samples showed reduction and decreased values in comparison of rebar diameter before and after induced accelerated corrosion test with values reduction percentile range from 0.344% to -1.12% and average ranges values from 11.99mm to 11.93mm. Summarized results showed that the effect of corrosion caused weight reduction/decreased in corroded samples as compared to coated with an exhibition of percentile and average value increase resulting in a volumetric minute increase from coating thicknesses. The

investigated study showed the effectiveness and efficiency of exudates/resin as an inhibitory material against corrosion effects on reinforcing steel embedded in concrete slab samples exposed to the induced corrosion.

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

1.0 Introduction

When reinforcing steel corrodes the first rust product is produced and can slightly improve the bond, but increasing the saturation often leads to a decrease and decrease of bond at the reinforcement / concrete interface (Cabrera [1], Chung et al. [2]). The formation of the rust includes a large volume increase causing cracking, sliding and plastering, and reduces the effective area of the reinforcement section as well and reduces the bond between the reinforcements and concrete, which significantly affects the durability, and structural service life [Almusalla et al.[3]). The basic idea of the corrosion barrier is the production of a soft structure with a metal oxide and the formation of an adsorption structure with iron oxide. Anodic inhibitors work by binding the reaction to the anode. In favorable conditions, they react with existing corrosion products to form a non-corrosive film that adheres perfectly to the metal surface. This film can act as a barrier to metal dissolution by protecting the metal surface from contact with the corrosive electrolyte. Corrosion creates tensile stresses in the steel reinforcement around the concrete, which causes initial cracking. It is known that chloride is introduced into concrete through various sources [Morris et al.[5], [Ann and Song, [6], found that concrete, which contains chloride ions from seawater and aggregates, can be used as an accelerator. The salt mixture penetrates the concrete through various mechanisms. The low water/cement ratio resists chloride penetration in reinforcing steel, also offers a barrier against oxygen penetration and thus ensures better corrosion resistance of concrete [Canul et al.[7], [Chia and Zhang [8], [Du and Folliard [9].

Goto and Roy [10], (Guneyis et al. [11]). The use of organic compounds to prevent corrosion of mild steel and iron is important because of their use to prevent corrosion in various corrosive environments. Ali et al. [8]. The development of corrosion inhibitors is based on organic compounds with nitrogen, oxygen, sulfur atoms and double bonds in the molecule that facilitate adsorption on metal surfaces. Cruz et al. [12].

Charles et.al [13] Investigated the electrochemical process that led to the transfer of electrons in the corrosion process of steel reinforcement in aggressive seawater with high chloride levels. Corrosion experiments were carried out on a 12mm thick steel reinforcement surface, surface samples treated with symphonia globulifera linn resin extracts with layered thickness of 150µm, 250µm, 350µm. Control, non-inhibited and resin inhibited specimens were cured for the first 28 days and the Sodium Chloride accelerated process for 119 days and 14 days for study readings. A reduced rate of concrete resistivity, yield stress compared with against ultimate strength as the average yield stress decreased.

Charles et.al [14] studied the corrosion potential, concrete resistance and tensile test of reinforcing steel, corroded and coated made of concrete elements. The allowable stress based on the total final strength and the average condition of the corroded plate with a nominal value of 100% and the maximum strength reduced from 100.68% to 96.12%, the weight loss compared to the reduction of the cross-sectional diameter was reduced from 67.1 in each case due to sodium chloride attack % to 48.5% and 98.2% to 94.82%. Compared with the corroded sample, the corroded has a potential value of 70.1% increased and reduces the concrete resistance value by 38.8%, the limit stress at the boundary limit is compared to corrosion, because 100% of the nominal stress sis reduced from 100.95% to 96.12% and respectively, a weight reduction of 67.5% compared to 48.5% and 98.7% to 94.82%, a reduction in cross-sectional diameter, both of which show reduced corrosion values compared to the coated samples.

Macdonald [15] conducted an investigation of inhibitors on alkaline solutions and extracts from cement. The extract from the cement test yielded unrestricted rust using sodium nitrite in the presence of chlorides while sodium benzoate was not. In addition, the onset of corrosion is delayed by sodium nitrite, with the delay increasing with

Charles et al. [16] The experimental work measured the rapid process with the acceleration process of the uninhibited and inhibited acardium occidentale l. with thicknesses 150μm, 250μm, 350μm, mounted on a concrete slab and immersed in sodium chloride and accelerated for 119 days using the Wenner method, compared with the corroded specimen increased in corrosion potential Ecorr, mV, reduction in reinforcement cross sectional diameter, both showed reduced corroded values compared to coated specimen.

Novokshcheov [17] studied and showed that calcium nitrite does not permanently damage concrete structures as seen in the case of sodium or potassium-based inhibitors. Latter studies by Skotinck [18] and Slater [19] showed that considering a long-standing fast test, calcium nitrite was at its best in terms of intensity.

Charles et.al [20] investigated the probability of a possible breakdown of the cell deformity, the evaluation of concrete strength and durability of materials for corrosion, non-corroded, corroded and inhibited with moringa oleifera lam resin paste. Reinforced concrete specimens were immersed in aqueous solution and accelerated at an average period of 119 days. The average percentage results for potential, Ecorr, mV and concrete composition are 29.9% and 68.74%, respectively. Compared with the corroded samples, the corroded values have reduced values of concrete initiation. The effects of average yield stress versus tensile strength, compared with corroded as decreased by 100% yield stress from 105.75% to 96.12% and weight loss 67.5% compared to 48.5% and 48.34% to 94.82%, diameter reduction, both showed reduced corroded values compared to the coated specimens.

Charles et.al [20] investigated the use of inorganic inhibitors and Greener path inhibitors to evaluate potential corrosion studies using mangifera indica resins paste residues coated to stabilize the reinforcing steel. Compared with the corroded samples, the corroded values appear to contain Ecorr, mV and reduced values of concrete resistivity and diameter reduction, both showing reduced corroded values compared to the coated specimens. When compared to corroded samples, corroded has decreased values of concrete resistivity, yield stress against ultimate strength at summary and average state of corroded slab with nominal values and decremented in ultimate strength.

Charles et al [22] investigated corrosion potential probability rate of three different resins inorganic extracts of dacryode edulis, mangifera indica and moringa oleifera lam using half-cell potential corrosion rate, concrete resistivity and tensile strength. The arbitrary calculated percentage values of the ultimate stress versus yield stress reduced the nominal yield stress and corrosion reduction of the coated sample cross-sectional diameter and reduced the shear.

Terence et al. [23] evaluated the effect of saltwater on reinforced concrete structures in a coastal marine environment. Simulations of the accelerated corrosion process were carried out on uncoated samples and resin-coated Senegalese Kaya extract for 150 days and evaluated the potential effects of half-cells, concrete resistance and tensile strength of steel embedded in concrete and corrosion risk.The results of specific resistance, kΩcm versus Ecorr potential, mV binding showed the average potential value of the Ecorr control percentile was 30.33% and the percentile difference was -69.66% compared to 235.19% of the corroded sample. The mechanical properties of the "maximum strength" control sample value is 93.71% and the percentage difference is -6.28% compared to the corroded sample 7.131%. Mechanical Properties "Reduction of cross-sectional area" of the control sample with an average percentile value of 118.50% and a percentage difference of 18.50% versus the corroded sample of 15.61%. The results of the control samples showed no potential for corrosion due to the presence of exudate/resin inhibitors that acted as insulators from reinforcing steel embedded in a corrosive environment.

Letam et al [24] studied the level of corrosion embedded in concrete slab structures and submerged in corrosive medium and evaluated the corrosion efficiency using four-probe methods that Wenner accelerated. The range of values for the depleted samples indicates the likelihood of significant corrosion (ρ <5, 5 <ρ <10, 10 <ρ <20, ρ> 20) for most, high, low to moderate and low, corrosion potentials. Due to the effect of corrosion on the mechanical properties of steel reinforcement, the results showed high ultimate yield and coating patterns of the samples to control. 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.

Daso et al. [25]) evaluated the use of ecologically inorganic exudates/resin from cola-acuminate trees as a preventive measure against the corrosive effects of saltwater attack on reinforcing steel embedded in a concrete structure in a marine area using an experimental application of the half-cell potential of concrete resistance and tensile strength to investigate state changes. surface of reinforcement, mechanical properties of uncoated samples and exudate/resin immersed in a corrosive medium accelerated by immersion in sodium chloride for 150 days and with a current potential of - 200 mV to 1200 mV, with a scanning speed of 1 mV/s. The mechanical properties of the “maximum strength” of the corroded samples averaged the 107.64% percentile and the difference of the 7.64% percentile versus the -7.10% and -6.67% of the control sample and the coated sample. The average mechanical properties of "weight loss of steel" corroded samples had an average percentage of 180.43% and a difference of 80.43747% compared to -44.57% and -45.18% of the control and coated samples. The result of the reduction of the cross section shows a higher percentage of reduction due to the effect of corrosion on the mechanical properties of the steel.

Nelson et al. [26] Studied the application of environmentally inorganic exudates/resins extracted from Invincia gabonensis, layered to reinforcing steel with various thickness and on non-layered members, and immersed in sodium chloride for 150 days for rapid corrosion testing with 200 mV by 1200mV with a scan rate of 1mV / s. The overall results of the exudates/resins coated samples showed no signs of corrosion potential and the results showed that Invincia gabonensis exudates/resins were good corrosion inhibitors, while the non-layered ones showed signs of corrosion. 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.

Kanee et al. [27] examined steel reinforcement with the introduction of milicia excelsa exudates/resins to reduce surface changes and mechanical properties of reinforcing steel in concrete structures formed in saltwater environments through assessment period of 150 days corrosion process. Spalling and fracture corrosion properties in non-coated members showed that overall experimental results were indicative of lower relief failure loads; The effect of corrosion on the mechanical properties of steel reinforcement on rusted (controlled) members has not been observed.

Gregory et al. [28] evaluated the changes in the reinforcement of steel and the mechanical properties of exposure to aqueous media of exudates/resins paste coated and non-coated samples. The result of corrosion effects was recorded in non-coated over coated samples due to corrosion attack on the mechanical properties of steel reinforcement. The weight loss results of the steel showed higher percentage values against the control and coated samples.

Philip et al. [29] examined the use of acacia senegal exudates/resins tree extract as corrosion inhibitors. Various thicknesses of the exudates/resins paste and non-coated were embedded concrete members and immersed in corrosive media for 150 days in an accelerated process. The potential Ecorr results ($-350mV \leq E corr \leq -200mV$) showed that the values of the corroded specimens with the range are high, indicating an uncertain probability of 10% or corrosion. Concrete resistivity ρ, kΩcm percentage -48.9081%, 95.72572%, and 114.8917% average value of control and coating samples. The range of values of corrosion models indicates significant corrosion (moderate).

2.1 Materials and Methods

2.1.1 Aggregates

Fine and coarse aggregates are purchased. Both meet the requirements of BS 8821[30]

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[31]

2.1.3 Water

Water samples were taken from the Department of Civil Engrg. laboratory at Kenule Beeson Polytechnic, Bori, Rivers State. Water meets BS 12390[32] requirements

2.1.4 Structural steel reinforcement

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Reinforcement purchased directly from the market at Port Harcourt. It conformed to **B**S4449: 2005 + A3 [33] requirements

2.1.5 Corrosion Inhibitors (Resins / Exudates) Raphia hookeri

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

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 Raphia hookeri exudate/resin, extracted from tree trunks, and has the potentiality of environmentally stable properties of non-hazardous. The resulting exudate/resin is coated directly to 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 dosed 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 metal plate mold measuring 100 mm × 500 mm × 500 mm (thickness, width, and length), and the specimen was cast into a metal mold, compacted to void free of air, having a concrete cover of 10mm and reinforced with 10 pieces of reinforcing steel of diameter 12 mm steel bar, spaced at 100 mm c / c (top and bottom) and displaced after 72 hours, cured for 28 days at standard room temperature to harden. The hardened concrete slabs are completely immersed in a 5% sodium chloride (NaCl) solution mixed with water and accelerated for a rapid corrosion process for 360 days with interval checks and routine tests at 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) plastic 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 impressive 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 [34], Gower and Millard [35]. 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 [36]). Corrosion rate refers to electrochemical measurements, the first based on data.

Table 2.1: Dependence between potential and corrosion probability *ASTMC876-91,* 1999.) [37]

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 ≤ Ec$_{orr}$ ≤ −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 ofmeasurement (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(ASTM Standard C876, 2012) ([38]

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 Results of Testing and Discussion

The results of the half-cell potential measurements in Table 1 are plotted against the resistance 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 moderate and low probability of corrosion. At another measurement point, the potential for correction is high (–350 mV E Ecorr ≤ –200 mV), which indicates a corrosion probability of 10% or uncertain. The results of concrete resistance measurements are shown in Table 2. It has been proven that with a low corrosion potential (<-350 mV) within a certain range, there is a 95% chance of corrosion. Concrete resistance is usually measured using the four-electrode method. Resistance study data show whether some conditions result in less ionic motion, leading to greater 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	RHS	RHS1	RHS2	RHS3	RHS4	RHS5	RHS6	RHS7	RHS8	RHS9	RHS10	RHS11
	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	-102.93	-106.61	-102.34	-100.94	-103.35	-100.32	-108.77	-104.45	-103.00	-102.31	-106.30	-100.46
Concrete Resistivity ρ, kΩcm	17.11	17.10	17.10	17.09	17.09	17.25	17.24	17.24	17.23	17.23	17.17	17.09
Yield Strength, fy (MPa)	458.58	461.58	458.08	457.88	458.58	457.81	460.81	461.11	459.81	461.20	457.71	461.54
Ultimate Tensile Strength, fu (MPa)	642.49	640.44	642.12	637.90	641.43	641.85	641.65	642.45	641.05	642.60	642.10	641.96
Strain Ratio	1.40	1.39	1.40	1.39	1.40	1.40	1.39	1.39	1.39	1.39	1.40	1.39
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	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Rebar Weights- After at 28 days (Kg)	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
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	-330.38	-354.50	-351.40	-343.79	-353.59	-360.59	-394.49	-401.69	-405.79	-408.91	-413.11	-411.34
Concrete Resistivity ρ, kΩcm	**8.34**	**8.52**	**9.35**	**8.36**	**9.13**	**8.69**	**8.31**	**8.86**	**8.90**	**8.50**	**8.67**	**8.68**
Yield Strength, fy (MPa)	438.09	441.09	437.09	437.39	438.09	437.32	440.32	440.62	439.32	440.71	437.22	441.05
Ultimate Tensile Strength, fu (MPa)	629.82	627.77	629.45	625.23	628.76	629.18	628.98	629.78	628.38	629.93	629.43	629.29
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)	11.98	11.99	11.99	12.00	12.00	12.00	12.00	11.99	11.99	11.99	11.99	11.99
Rebar Diameter- After Corrosion(mm)	11.93	11.94	11.93	11.94	11.95	11.94	11.94	11.93	11.93	11.94	11.93	11.94
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	0.05
Rebar Weights- Before Test (Kg)	0.82	0.81	0.81	0.81	0.82	0.82	0.81	0.81	0.81	0.81	0.80	0.80
Rebar Weights- After Corrosion (Kg)	0.77	0.75	0.75	0.75	0.76	0.76	0.76	0.76	0.76	0.76	0.75	0.75
Weight Loss /Gain of Steel (Kg)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06

Table 3.3: Potential Ecorr, after 28 days curing and 360days Accelerated Periods of Raphia hookeri 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	-115.23	-118.91	-114.64	-113.24	-115.65	-112.62	-121.07	-116.75	-112.30	-114.61	-118.60	-109.88
Concrete Resistivity ρ, kΩcm	14.70	14.85	15.13	15.26	14.95	15.24	15.19	15.34	15.37	14.84	14.73	14.58
Yield Strength, fy (MPa)	451.71	454.71	450.71	451.01	451.71	450.94	453.94	454.24	452.94	454.33	450.84	453.67
Ultimate Tensile Strength, fu (MPa)	640.66	638.61	640.29	636.07	639.60	640.02	639.82	640.62	639.22	640.77	640.27	640.13
Strain Ratio	1.42	1.40	1.42	1.41	1.42	1.42	1.41	1.41	1.41	1.41	1.42	1.41
Rebar Diameter Before Test (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
Rebar Diameter- After Corrosion(mm)	12.08	12.07	12.08	12.08	12.07	12.09	12.08	12.07	12.08	12.08	12.07	12.08
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Rebar Weights- Before Test (Kg)	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.87	0.88	0.89
Rebar Weights- After Corrosion (Kg)	0.94	0.95	0.95	0.95	0.94	0.94	0.94	0.95	0.94	0.93	0.94	0.95
Weight Loss /Gain of Steel (Kg)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.05	0.06	0.06

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

Sampling and Durations	Control Concrete slab Specimens				Corroded Concrete slab Specimens				Raphia hookeri 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 Raphia hookeri Exudate / Resin Coated Specimens			
Potential Ecorr, mV	-103.96	-103.30	-102.21	-101.54	-345.43	-349.90	-349.59	-352.66	-116.26	-115.60	-114.51	-113.84
Concrete Resistivity ρ, kΩcm	17.10	17.10	17.09	17.14	8.74	8.74	8.95	8.73	14.89	15.08	15.11	15.15
Yield Strength, fy (MPa)	459.42	459.18	458.18	458.09	438.75	438.52	437.52	437.60	452.38	452.14	451.14	451.22
Ultimate Tensile Strength, fu (MPa)	641.68	640.15	640.48	640.39	629.01	627.48	627.81	627.72	639.86	638.33	638.66	638.57
Strain Ratio	1.40	1.39	1.40	1.40	1.43	1.43	1.44	1.43	1.41	1.41	1.42	1.42
Rebar Diameter Before Test (mm)	11.90	11.90	11.90	11.90	11.99	11.99	12.00	12.00	11.99	11.99	11.99	11.99
Rebar Diameter- After Corrosion(mm)	11.89	11.89	11.89	11.89	11.93	11.93	11.94	11.94	12.07	12.07	12.07	12.08
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	0.06	0.06	0.06	0.06	0.09	0.09	0.09	0.09
Rebar Weights- Before Test (Kg)	0.85	0.85	0.85	0.85	0.82	0.81	0.81	0.82	0.88	0.88	0.88	0.88
Rebar Weights- After Corrosion (Kg)	0.85	0.85	0.85	0.85	0.76	0.75	0.76	0.76	0.95	0.95	0.95	0.95
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	0.06	0.06	0.06	0.06	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				Raphia hookeri 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 Raphia hookeri Exudate / Resin Coated Specimens			
Potential Ecorr,mV	-69.90	-70.48	-70.76	-71.21	197.12	202.69	205.30	209.80	-66.34	-66.96	-67.25	-67.72
Concrete Resistivity ρ, kΩcm	95.81	95.60	91.05	96.43	-41.35	-42.03	-40.81	-42.39	70.50	72.51	68.94	73.59
Yield Strength, fy (MPa)	4.71	4.71	4.72	4.68	-3.01	-3.01	-3.02	-3.02	3.11	3.11	3.11	3.11
Ultimate strength (N/mm2)	2.02	2.02	2.02	2.02	-1.70	-1.70	-1.70	-1.70	1.73	1.73	1.73	1.73
Strain Ratio	-2.58	-2.59	-2.58	-2.51	1.41	1.35	1.34	1.34	-1.40	-1.33	-1.32	-1.33
Rebar Diameter Before Test (mm)	0.344	0.342	0.339	0.342	0.3482	0.346	0.339	0.346	0.344	0.336	0.341	0.344
Rebar Diameter- After Corrosion(mm)	0.345	0.363	0.394	0.404	-1.195	-1.169	-1.145	-1.126	1.211	1.172	1.158	1.138
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-34.09	-31.03	-31.82	-32.96	51.72	45.00	46.67	49.15
Rebar Weights- Before Test(Kg)	6.583	6.461	6.545	6.287	6.463	6.466	6.464	6.463	6.481	6.784	6.482	6.581
Rebar Weights- After Corrosion(Kg)	11.99	12.60	12.30	12.15	-19.77	-20.30	-20.09	-19.89	24.64	25.46	25.13	24.84
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	-17.39	-17.14	-15.94	-14.71	21.05	20.69	18.97	17.24

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

Reinforced concrete structures in marine environments are most susceptible to chloride-induced corrosion of reinforcement due to the presence of high chloride concentrations and humid or saturated conditions. However, the passivity of steel can be exacerbated by the loss of alkalinity due to chloride attack or carbonization of the concrete; this phenomenon causes an increase in the susceptibility to corrosion of reinforcing steel, Domone et al., [39] Approaches to controlling these factors have used inhibitors, electrochemical protection processes, cleaners, buffers, and coatings.

The potential E_{corr},mV and concrete resistance, kΩcm, results obtained from Tables 3.1 - 3.3 and summarized into average and percentile values in Tables 3.4 and 3.5, plotted graphically in Figures 3.1-3.8b, are the results of controlled samples, uncoated (corroded) and coated samples of36 concrete slabs, divided into 3 sets of 12 controlled samples, which are the determining reference range, 12 uncoated (corroded) samples and 12 exudate/resin coated samples.

The average and percentile of minimum, maximum, and differential of the calculated potential measurements from the half-cell controlled samples were -103.96 mV and -101.88 mV (-71.2% and -69.9%) with a potential difference of 2.08 mV and 1.31%), the corroded samples were -352.66 mV and -345.43 mV (-197.12% and -209.8%) and the difference values were 7.23 mV and 12.68 %, and the coated samples were -116.26 mV and -113.844 mV% and -66.34%) and the potential differences were 2.42 mV and 1.387%, respectively. The maximum controlled percentile value calculated was -69.9% compared to the corroded and coated values of 209.8% and -66.3% and the controlled potential difference value was 1.31%, corroded 12.68%, and coated 1.378%. The maximum yields of the controlled and coated samples were -101.88mV and -116.26mV, which indicates the relationship between corrosion potential and probability as $E_{\text{corr}} > -200$mV as the reference range. The results of the potential Ecorr results indicate that the values of controlled samples and exudate/resin coated samples are low with a 90% probability that no corrosion of the reinforcement is observed at the time of measurement (10% corrosion risk, 10% or indicates an uncertain corrosion probability For uncoated samples, the maximum calculated value is -

345.43 mV, the result is within the reference value of the relationship between corrosion potential and probability of $-350\text{mV} \leq E\text{corr} \leq -200\text{mV}$ indicates a high range of values, indicating a corrosion probability of 10% or uncertain[23]. Comparison 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 did not show corrosion attack on reinforcing steel embedded in a concrete slab, exposed to a corrosive environment due to formation resistive layer.

The average value and the minimum and maximum percentage of concrete resistance with controlled sample potential difference are 17.09kΩcm and 17.14kΩcm (91.05% and 96.43%) and the difference value is 0.05kΩcm and 5.38%. The Corroded samples were 8.73kΩcm and 8.95kΩcm (-42.4% and -40.8%) and the difference values were 0.22kΩcm and 1.58%. The closed sample valleys were 14.89 and 15.15kΩcm (68.94% and 73.59%) and the difference values were 0.26 mV and 4.65%. The calculated maximum value of the controlled sample concrete resistance is 96.43% compared to the corroded and coated values -40.8% and 73.59% and the maximum controlled difference percentage is 5.38% compared to the corroded and coated value of 1.58% and 4.65%. The results of the controlled and layered concrete resistance samples obtained an average maximum value of 17.14kΩcm and 15.15kΩcm with a description of the value $10 < \rho < 20$ (low) compared to the corrosion value of 8.95kΩcm with specifications $5 < \rho < 10$ (high) and with the reference range of the relationship between concrete resistance and corrosion probability, the corrosion probability was significant ($\rho < 5$, $5 < \rho < 10$, $10 < \rho < 20$, $\rho > 20$) for very high, high, low to moderate and low, for possible corrosion[29]. 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 $10 < \rho < 20$ 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 $5 < \rho < 10$, indicating high, signs suggesting possible corrosion, confirmed in the work ([18] [19] [17] [29] [28] [14] [12]). 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 reinforcement.

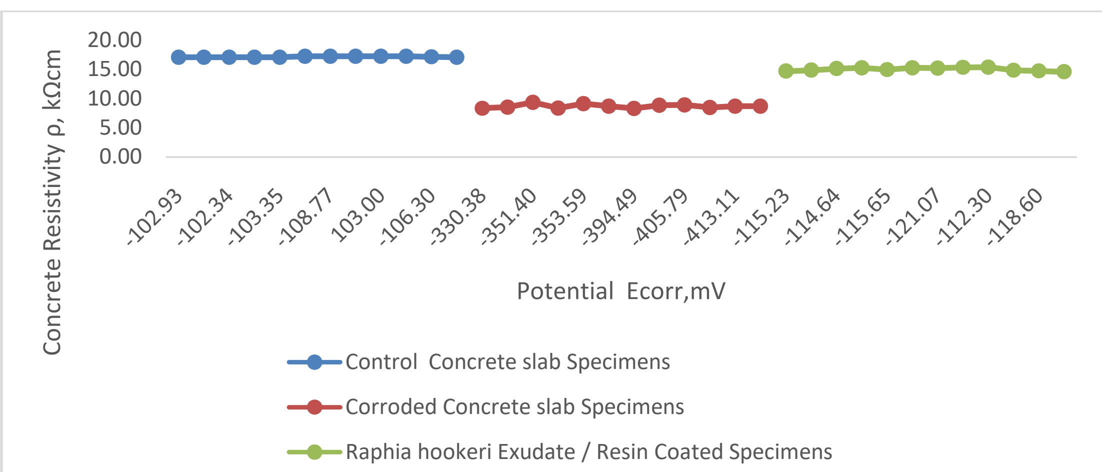

Figure 3.1 : Concrete Resistivity ρ, kΩcm versus Potential Ecorr,mV Relationship

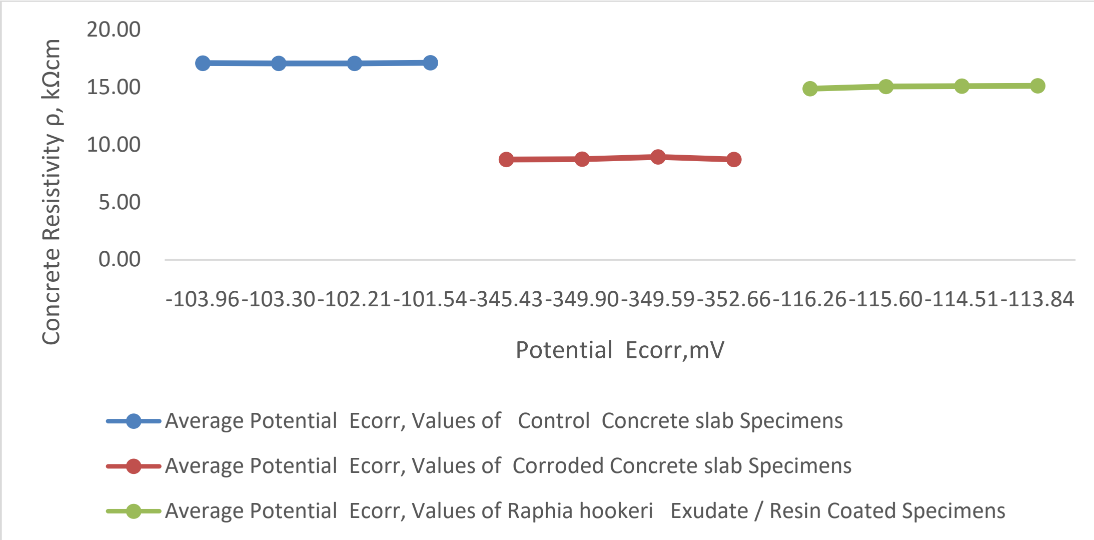

Figure 3.1A: Average Concrete Resistivity versus Potential Relationship

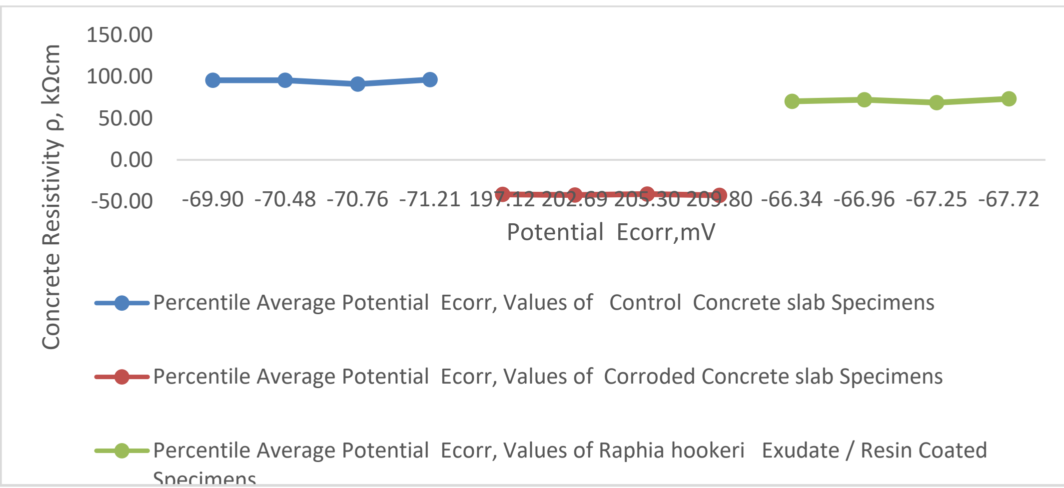

Figure 3.1B : Average Percentile Concrete Resistivity versus Potential Relationship

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

The corrosive effect of reinforcing steel embedded in raw and saltwater environments is protected by a passive layer. Corrosion tends to result in relatively even surface removal, but the specific surface properties of the metal can be attacked. The results of the mean, percentile, and the difference between the minimum and maximum yield strength, fy (MPa) of the controlled sample were 458.1 MPa and 459.4 MPa (4.68% and 4.72%) and the difference values were 1.33 MPa and 0.045%, the corroded samples were 437.5 MPa and 438.8 MPa (-3.02% and -3.01%) and the difference values were 1.23 MPa and 0.045%, the coated sample values were 451.1 MPa and 452.4 MPa (3.11% and 3.14%) and the difference value of 1.24 MPa and 0.045%. The calculated maximum percentage of the controlled yield strength was 4.72% compared to the corroded and coated values -3.01% and 3.14% and the possible difference values were 0.045% controlled, 0.045% corroded, and 0.045% coated. The mean, percentile, and difference in the values of the minimum and maximum tensile strength, fu (MPa) of the controlled samples were 640.2 MPa and 641.7 MPa (2.02% and 2.06%) and the difference values were 1.53MPa and 0. 05%, corrosion is 627.5 MPa and 629 MPa (-1.7 MPa and -1.9%) and the difference is 1.58 MPa and 0.06%, coated is 638.3 MPa and 639.9 MPa, 73 % and 1.79% and differential values of 1.53 MPa and 0.15% The maximum percentile values calculated from the controlled yield point were 2.06% relative to the corrosion and coating values of -1.9% and 1.79% and potential difference value 0.09% controlled, 0.06% corroded and 0.15% coated.

The ratio of the mean minimum and maximum deformation, percentile, and different values of the controlled samples were 1.39 and 1.4 (-2.59% and -2.51%) with different values of 0.03 and 0.08% being corroded. samples 1.43 and 1.44 (1.34% and 1.41%) and the difference values 0.01 and 0.07%, coated samples 1.41 and 1.42 (-1.4% and -1, 32%) and the difference value of 0.002 and 0.07%. Maximum percentage calculated for comparison controlled to -2.51% versus 1.41% corroded and -1.32% coated, and different peaks controlled to 0.08%, corroded 0.07% and coated 0.07% controlled as confirmed in the work ([18] [19] [17] [29] [28] [14] [12]).

The calculated results, which are summarized in Tables 3.4 and 3.5 and shown graphically in Figures 3.1 - 3.8b, were used to determine the yield point, tensile strength, and deformation ratio of the mean, percentile, and differential potential values of the control, unconfined concrete slab samples. coated (corroded) and coated, coated samples reported higher damage loads compared to rusted samples with reduced breakdown loads and low load-bearing capacities and with average and percentage values to the reference range, while uncoated low loads (corroded) - carrying capacity and 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 interfere with reinforcing steel fibers, ribs, and passive formation and surface modification. 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 effectiveness and effectiveness of exudates/resins as inhibitors against the corrosion effects of reinforced concrete structures, heavy marine areas with high salt content are exposed.

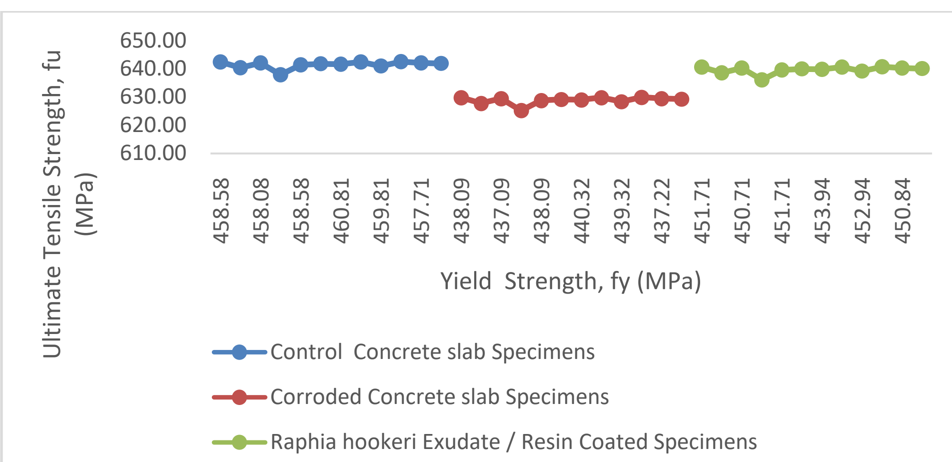

Figure 3.2 : Yield Strength versus Ultimate strength

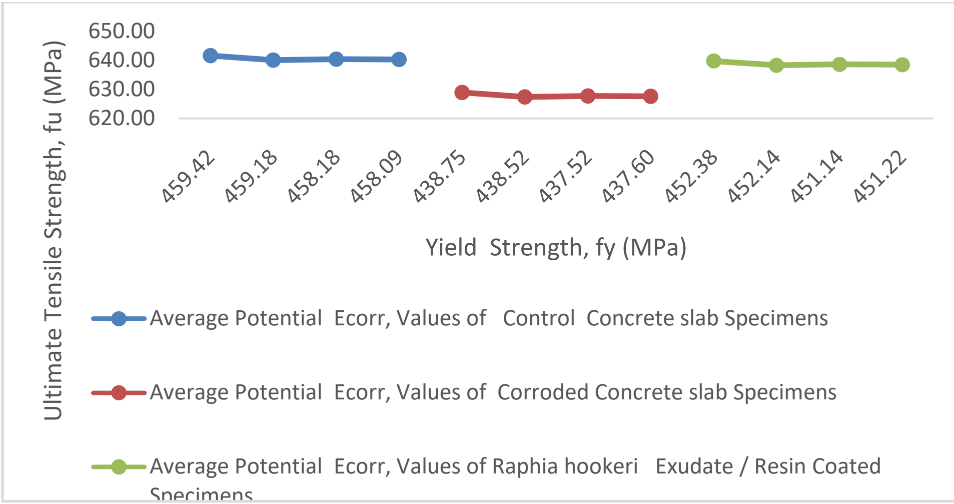

Figure 3.2A: Average Yield Strength versus Ultimate Tensile Strength

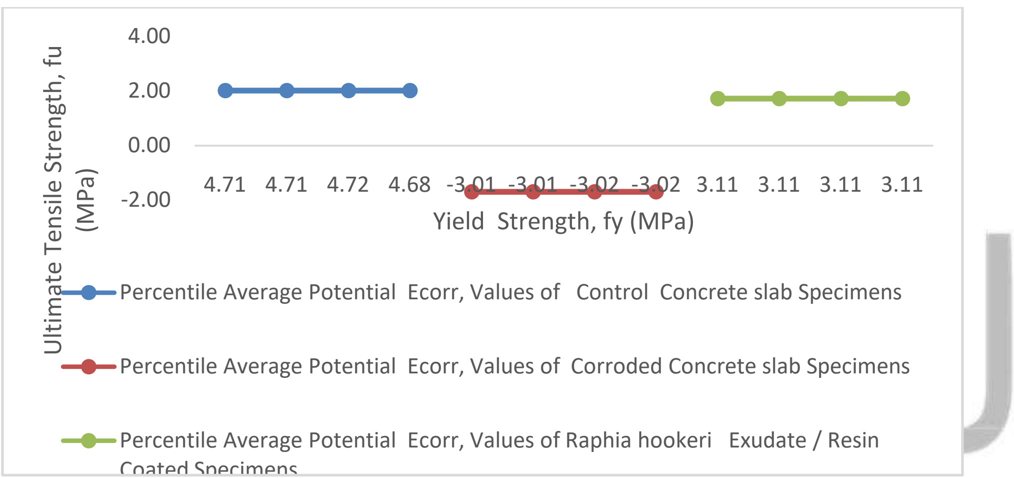

Figure 3.2B: Average Percentile Yield Strength versus Ultimate Tensile Strength

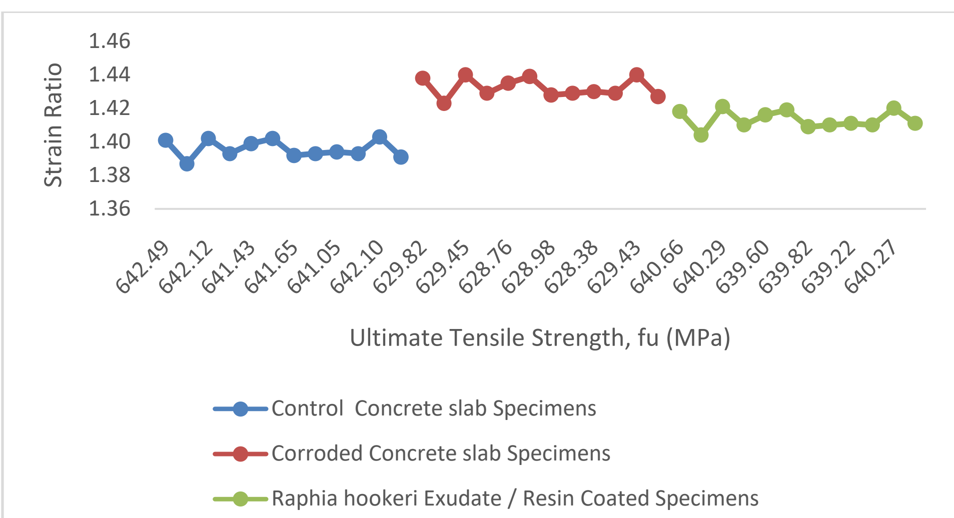

Figure 3.3: Ultimate Tensile Strength versus Strain Ratio

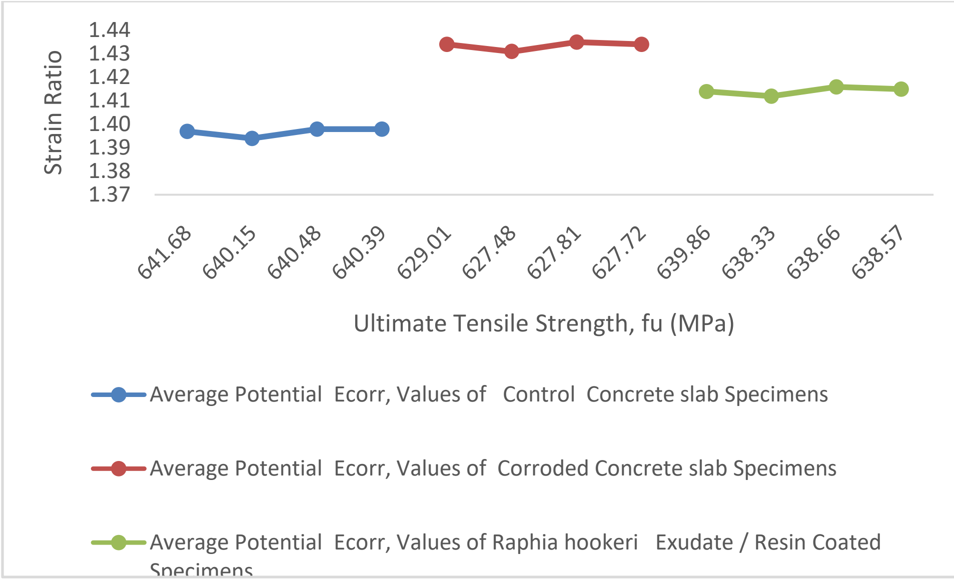

Figure 3.3A: Average Ultimate Tensile Strength versus Strain Ratio

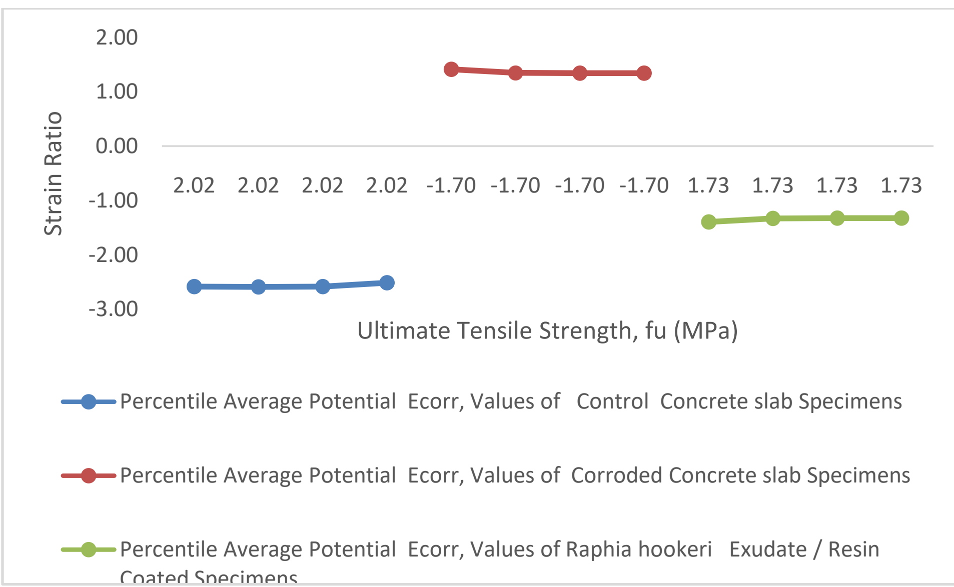

Figure 3.3B: Average percentile Ultimate Tensile Strength versus Strain Ratio

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

The rebar diameter before test (mm) minimum and maximum average and percentile values are controlled 11.9mm and 11.9mm (0.339% and 0.344%) with differential values of 0.04mm and 0.013%, the corroded sample values are 11.99mm and 12mm (0.339% and 0.348%) and differential values of 0.06mm and 0.013% and the coated sample values are 11.99mm and 11.99mm (0.336% and 0.344mm and differentially computed values of 0.05mm and 0.013%. The unit weight of rebar before the corrosion test exhibited infinitesimal differences based on product and company molds as well as the byproducts used in the manufacturing processes. The minimum and maximum obtained average, percentile and differential values of rebar diameter-after corrosion (mm) for controlled samples are 11.9mm and 11.9mm (0.339% and 0.344%), having 100% maintained reference value, the corroded sample values are 11.93mm and 11.94mm (-1.19% and -1.12%) and differentials of 0.01mm and 0.069%, the coated samples d values are 12.07mm and 12.08mm (1.13% and 1.21%) and differentials of 0.025mm and 0.080%. The maximum computed percentile values are controlled 0.344% against corroded -1.12% and coated 1.21%, the percentile difference is corroded 0.069% against 0.080% coated. The results obtained in tables 3.4 and 3.5 as summarized from tables 3.1, 3.2, and 3.3, and represented graphically in figures 3.3-3.6b showed the effects of corrosion attacks on the reinforcing steel embedded in the concrete slab and exposed to induced corrosion acceleration activities. Comparatively, the results of corroded samples showed reduction and decreased values in comparison of rebar diameter before and after induced accelerated corrosion test with values reduction percentile range from 0.344% to -1.12% and average ranges values from 11.99mm to 11.93mm.

Also, the cross-sectional area reduction/increase (diameter) minimum and maximum average and percentile values are controlled 100%, no reduction or increased notice after 360 days immersion in freshwater. The corroded sample values are 0.06mm and 0.06mm(-34.09% and -31.03%) and differentials of % at corroded, the coated sample values are 0.09mm and 0.09mm (45% and 51.72%) and differentials of 0.015mm and 6.72%. The comparatively average and percentile value differences between coated and corroded samples are with the ranges of 51.72% to -31.03%. The reduction in average and percentile values showed that corrosion effects caused diameter reduction and cross-sectional area, fibre degradation, ribs reduction, and surface modifications whereas, exudates/resin coated members showed volumetric increase resulting from varying coating thicknesses as validated in the works of (Kanee et al., 2019; Gregory et al., 2019; Philip et al., 2019; Nelson et al., 2019; Daso et al., 2019; Letam et al., 2019).

It can be summarized that exudates/resin exhibited inhibitive characteristics against corrosion influences on reinforcing steel embedded in concrete slab samples that were induced in a highly salinity environment. The rebar weights - before test (Kg) results of minimum, maximum and differential average and percentile values of controlled samples are 0.85kg and 0.85kg (6.29% and 6.8%) and differentials are 0% and 0.51%, the corroded sample are 0.81kg and 0.82kg (-7.31% and -6.85%) and differentials of 0.01% and 0.46%, the coated samples are 0.88kg and 0.88kg (7.35% and 7.88%) with differentials of 0% and 0.53%.

The rebar weights-after corrosion(Kg) average and percentile results and the summarized differential values of the minimum and maximum values of controlled samples are 0.85kg and 0.85kg (11.99% and 12.6%) and differential values of 0.01% and 0.61%, the corroded samples are 0.75Kg and 0.76Kg (-20.3% and -19.8%) and differentials of 0% and 0.53%, the coated sample values are 0.95kg and 0.95kg (24.64% and 25.46%) and differentials of 0% and 0.86%. The average and percentile minimum and maximum unit weight loss /gain of steel (Kg) and the percentile differences in comparison are controlled 100% maintained values resulting from pooling in a freshwater tank with no traces of corrosion potentials against the corroded sample values of 0.05kg and 0.06kg (-17.4% and -14.7%) and the coated are 0.06kg and 0.07kg (17.24% and 21.05%). The computed results obtained from tables 3.1-3.3 and summarized in 3.4 - 3.5, and graphically plotted in figures 3.7-3.87 enumerated the effect of corrosion on non-coated (corroded) and coated reinforcing steel and the examination of unit weight of rebar before and after corrosion test and as well as the weight loss/gain. Comparatively, obtained results showed average and percentile values reduction / decreased and increased with coated with 0.07kg to 0.70Kg and 21.05% to -14.7% corroded, as validated in the works of ([18] [19] [17] [29] [28] [14] [12]). Summarized results showed that the effect of corrosion caused weight reduction/decreased in corroded samples as

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compared to coated with an exhibition of percentile and average value increase resulting in a volumetric minute increase from coating thicknesses. The investigated study showed the effectiveness and efficiency of exudates/resin as an inhibitory material against corrosion effects on reinforcing steel embedded in concrete slab samples exposed to the induced corrosion.

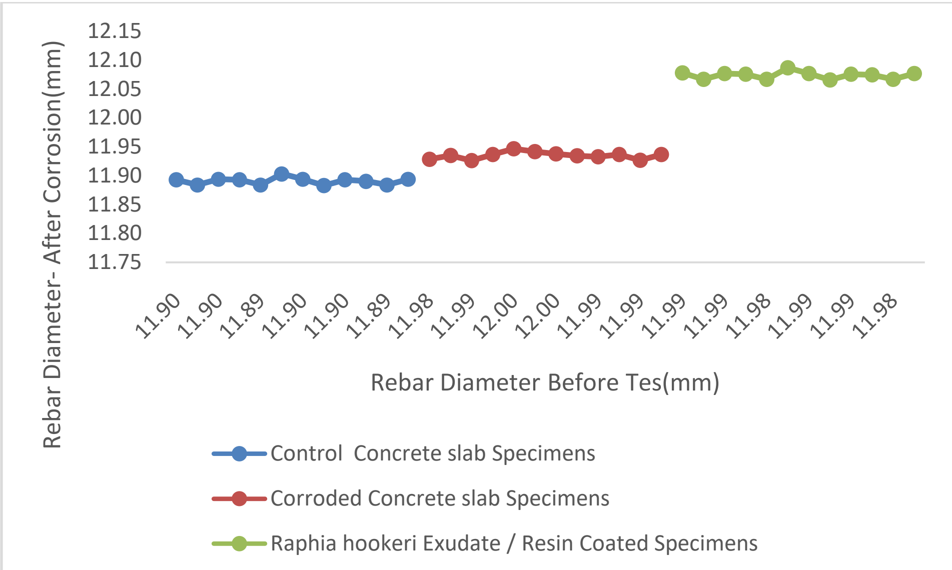

Figure 3.4: Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

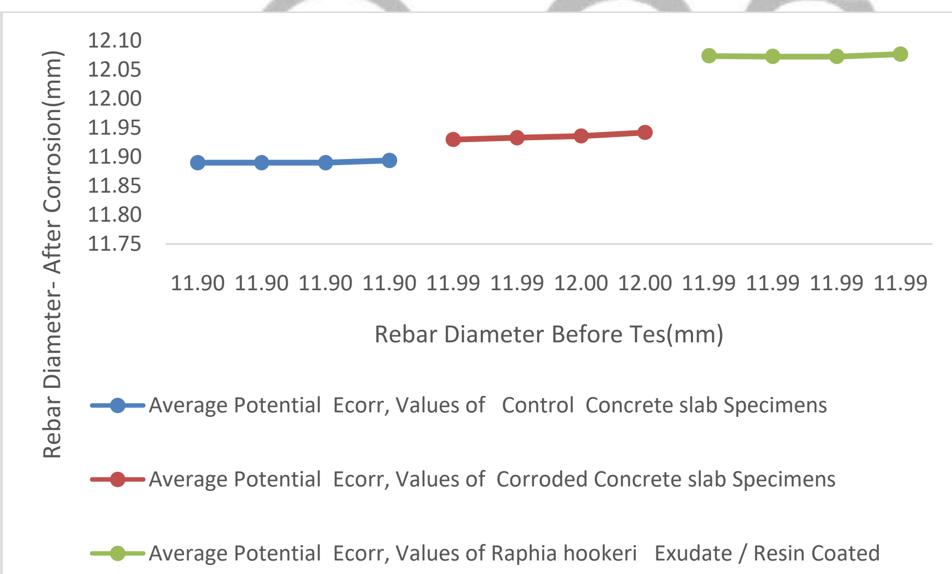

Figure 3.4A: Average Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

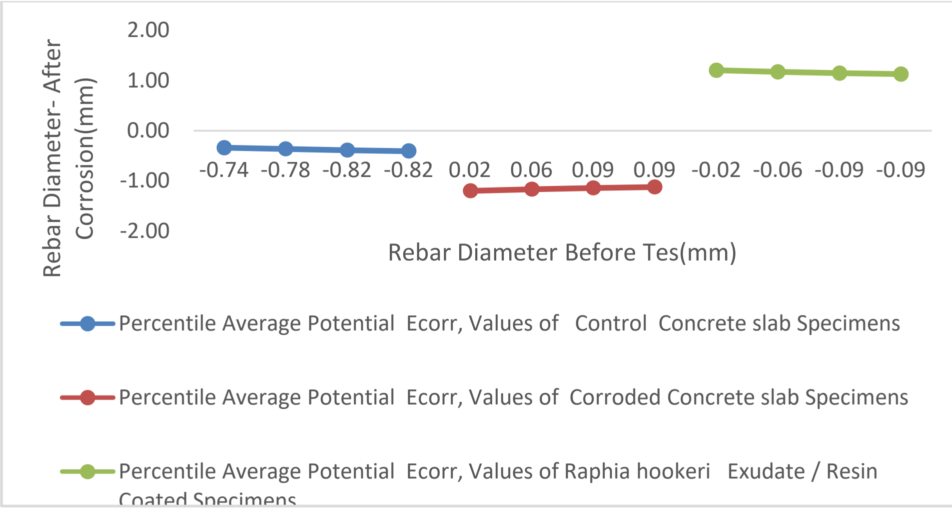

Figure 3.4B: Average Percentile Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

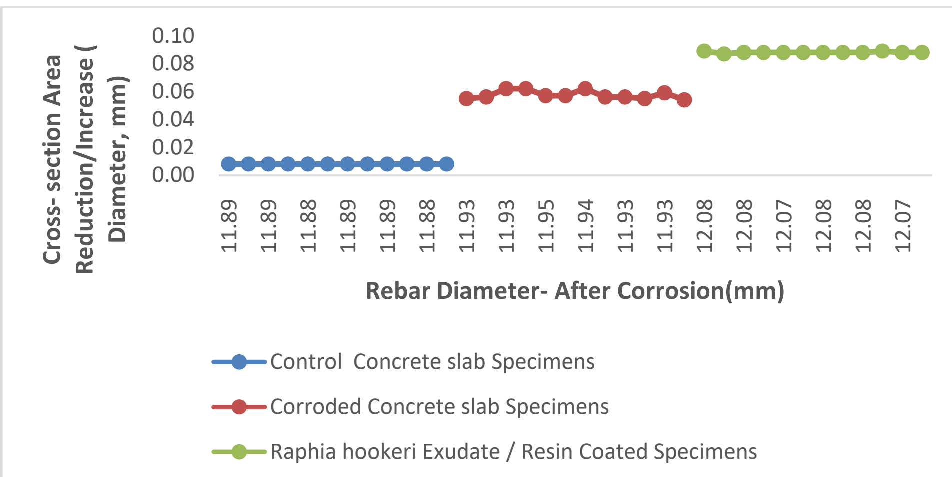

Figure 3.5: Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

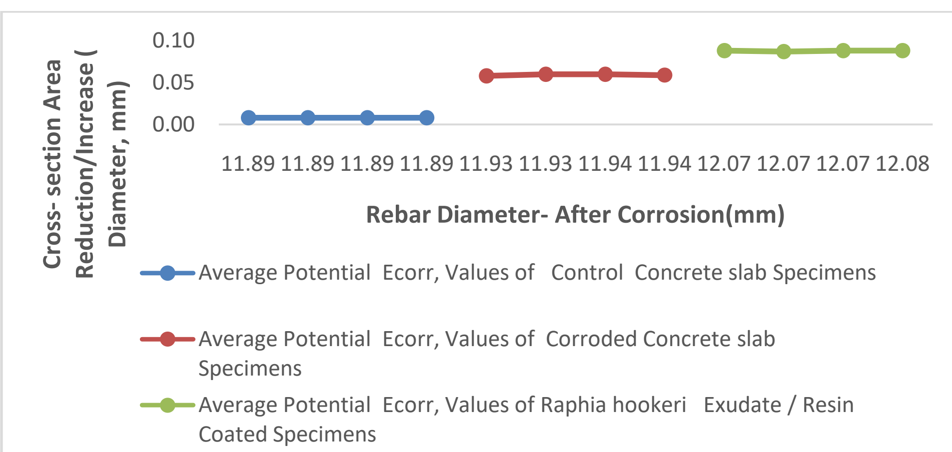

Figure 3.5A: Average Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

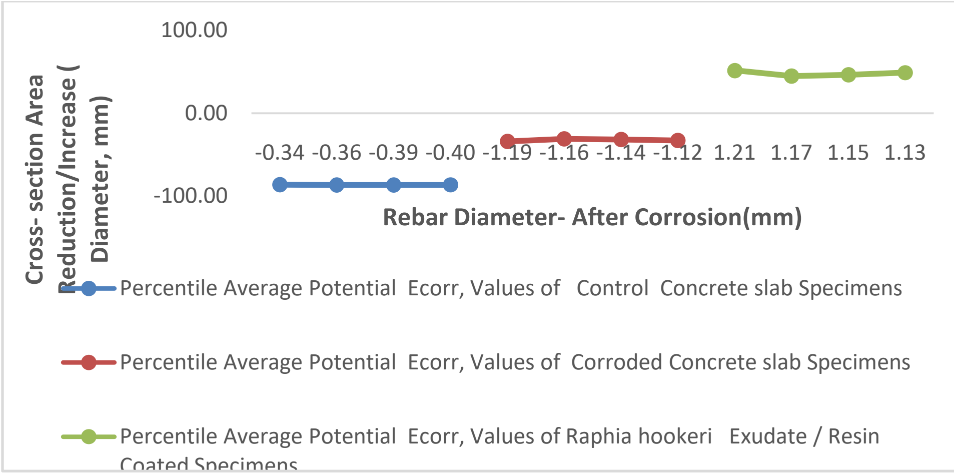

Figure 3.5B: Average Percentile Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

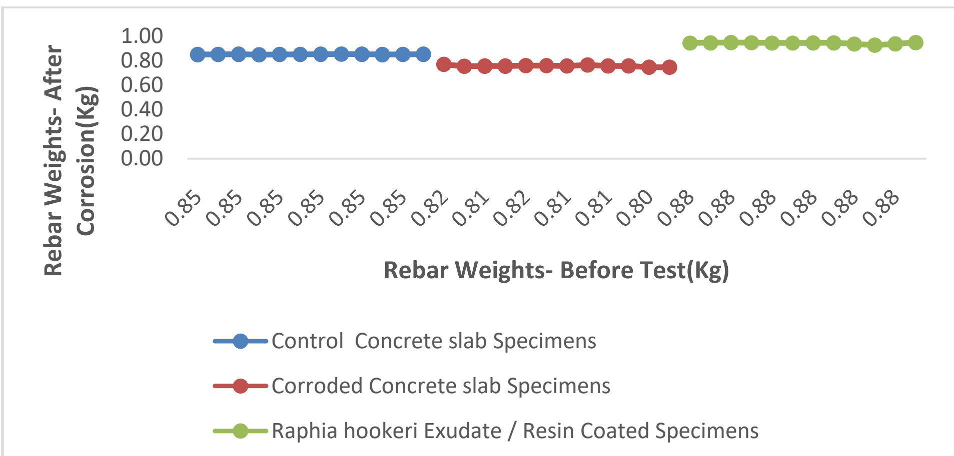

Figure 3.6: Rebar Weights- Before Test(Kg) versus Rebar Weights- After Corrosion(Kg)

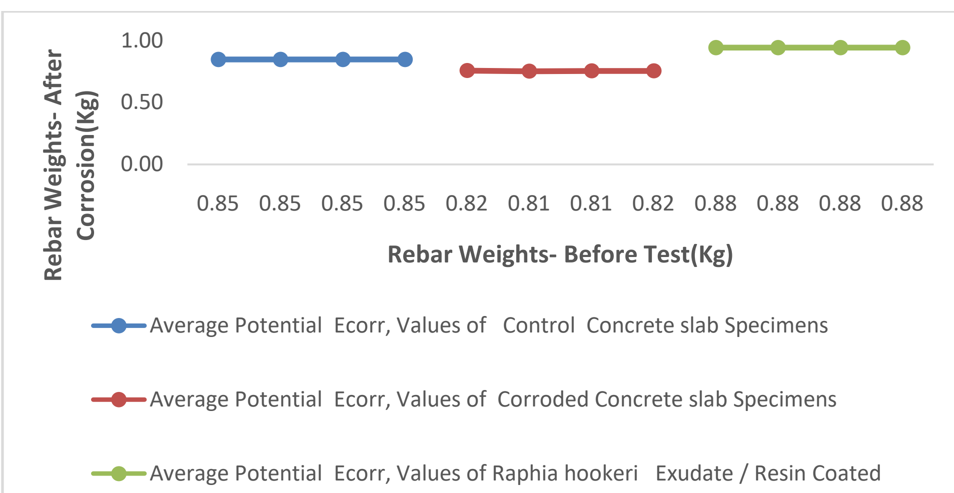

Figure 3.6A: Average Rebar Weights- Before Test(Kg) versus Rebar Weights- After Corrosion(Kg

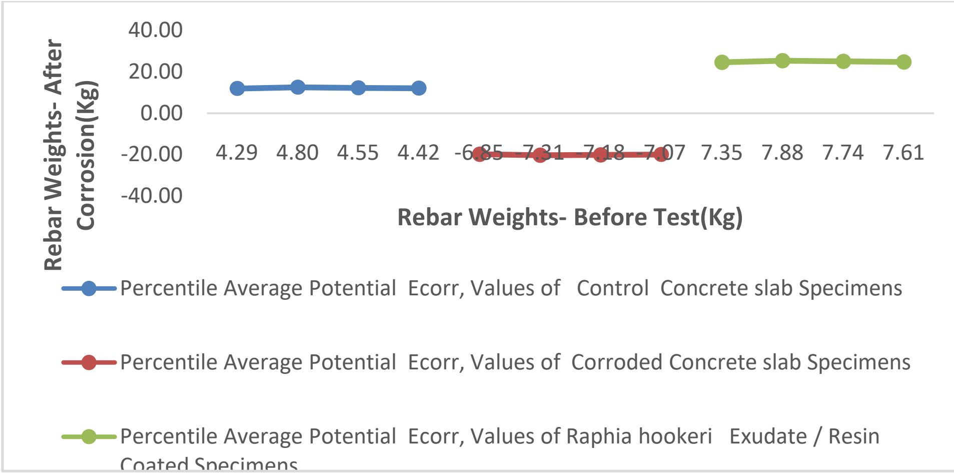

Figure 3.6B: Average Percentile Rebar Weights- Before Test(Kg) versus Rebar Weights- After Corrosion (Kg)

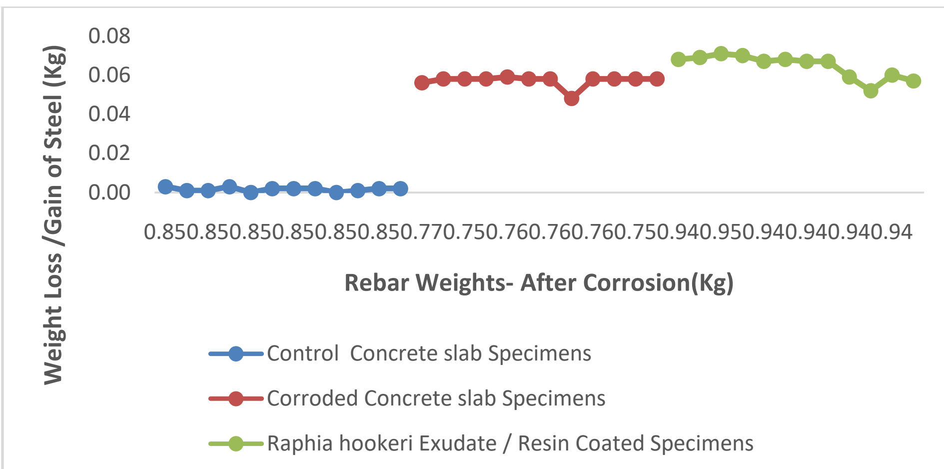

Figure 3.7: Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

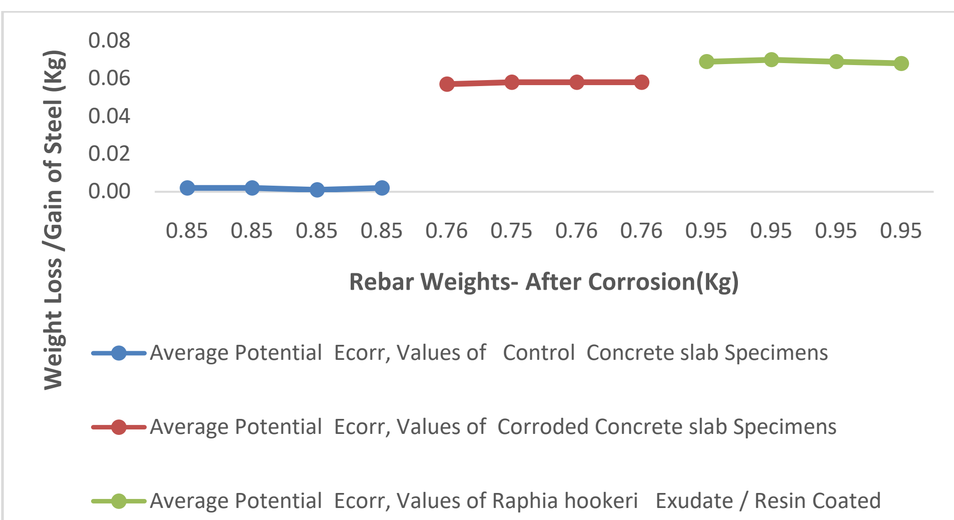

Figure 3.7A: Average Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

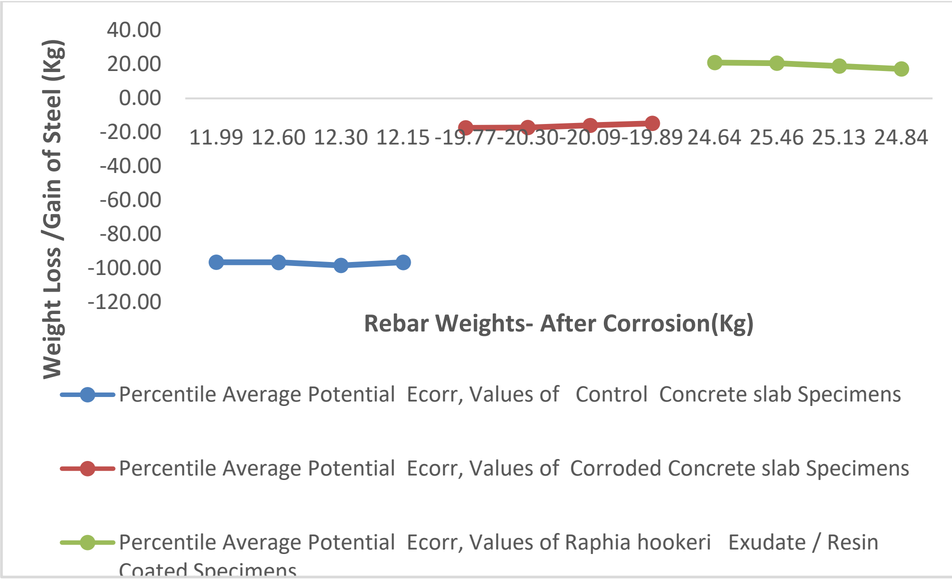

Figure 3.7B: Average Percentile Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

4.0 CONCLUSION

Experimental results showed the following conclusions:

1. 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 reinforcement.
2. The comparison results show that the low load carrying capacity was caused by the effect of corrosion attack on the uncoated (corroded) elements, which interfere with reinforcing steel fibers, ribs, and passive formation and surface modification.
3. 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 effectiveness and effectiveness of exudates/resins as inhibitors against the corrosion effects of reinforced concrete structures, heavy marine areas with high salt content are exposed.
4. Summarized results showed that the effect of corrosion caused weight reduction/decreased in corroded samples as compared to coated with an exhibition of percentile and average value increase resulting in a volumetric minute increase from coating thicknesses.
5. The investigated study showed the effectiveness and efficiency of exudates/resin as an inhibitory material against corrosion effects on reinforcing steel embedded in concrete slab samples exposed to the induced corrosion.

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