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Corrosion Probability Assessment of Reinforced Steel Bar Using Wenner Technique

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ABSTRACT : *The research investigates the corrosion potential, concrete resistivity, and mechanical properties of reinforcing steel from samples of controlled, corroded, and coated concrete slabs. Direct application of corrosion inhibitors to exudate/resin anogeissus latifolia of different thicknesses coated on reinforcement with a diameter of 12 mm, embedded in a sample of concrete slabs, and exposed to strong corrosive media for 360 days for accelerated corrosion testing, corrosion potential measurement, concrete resistance measurement, and surface modification reinforcement steel..The corrosion potentials 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 results from this potential Ecorr result show that the controlled and exudate/resin-coated sample values are low with a 90% probability that no corrosion of reinforcing steel was observed at the time of measurement (10% corrosion risk, which means a 10% for uncoated samples the maximum value obtained is -345 mV, the results are within the reference value of the relationship between corrosion potential. The calculated maximum value of the controlled sample concrete resistivity was 105% compared to the corroded and coated values of -40.8% and 73.6% and the maximum controlled difference percentage was 5.6% compared to the corroded and coated value of 1.58% and 4.78%. The test results of controlled and coated samples with concrete resistance obtained a maximum average value of 17.9kΩcm and 15.2kΩcm with a description of the value 10 <20 <20 (low) compared to the corrosion value of 8.95kΩcm with specification 5 <ρ < 10 (high). The calculated maximum percentage value of the controlled yield strength is 5.32% compared to the corrosion and coating values of -5.39% and 5.72% respectively and the controlled potential difference value is 0.01%, corroded is 0.02%, and 0.02% coated. The maximum strain ratio percentage calculated for comparison is controlled -2.73% against corroded 2.51% and coated -2.38%, and the different peaks controlled for 0.08%, corroded 0.069% and coated 0.008%. The yield strength, tensile strength, and strain ratio of the mean, percentile, and controlled differential potential values, uncoated (corroded) and coated concrete slab samples were determined, coated samples had higher failure loads compared to corroded samples with reduced failure load and low load-bearing capacity and with mean and percentile values with the reference range, whereas uncoated (corroded) samples, had a load-bearing capacity which is low and a reduced value compared to the reference range. Comparatively, the results of corroded samples showed reduction and decreased values as compared to rebar diameter before and after induced accelerated corrosion test with values reduction percentile range from 0.344% to -0.99% and average ranges values from 11.99mm to 11.93mm. The cross-sectional area reduction/increase comparatively average and percentile value differences between coated and corroded samples are with the ranges of 24.1% to -16.7%. 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 leading to 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.*

KEYWORDS: *Corrosion, Corrosion inhibitors, corrosion potential, concrete resistivity and Steel Reinforcement*

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I. INTRODUCTION

The presence of cracks reduces the overall strength and rigidity of concrete structures and accelerates the entry of aggressive ions, which can lead to other types of concrete degradation and result in degraded reinforcement and stirrups surrounding the encoated concrete and as well can affect the anchorage and shear capacity of a beam.

If concrete is cracked with corrosion in the area, it has reached maximum tensile strength.

Cracked concrete not only affects the actual shear and anchorage capabilities but also reduces the load-bearing capacity of the long-term structure by providing less protection to the reinforcement and to the safety of the structures ([2], [3]). It is necessary to develop methods to increase the service life of structures with the method of proper design and the introduction of corrosion inhibitors. Corrosion inhibitors are widely used to delay the corrosion of reinforcing steel in concrete, either by creating an impervious film on the metal surface, or by interfering with anodic. Some insulators such as chromates and benzoates have been shown to reduce the corrosion rate of steel bar ([4], [5]), but they also reduce the compressive strength of concrete but inorganic resins / exudates are environmentally friendly and less expensive.

6] Proposed that the value of B in the Stern-Geary equation for the active state is 26mV, and that the passive state is 52mV.Using value of B = 26mV can be obtained if the two Tafel slopes are equal to 120mV / decade; and one of the Tafel slopes for B = 52mV is infinite and the other is 120mV / decade.

[7] Suggested that the B value for steel in concrete ranges from less than 8mV to infinity under different conditions

[8] Investigated the electrochemical processed that led to the electron transfer in corrosion process of steel reinforcement in the harsh marine environment with high level of chloride. Average results on comparison showed increased values against control of potential and decreased values in concrete resistivity, yield stress against ultimate strength at summary and average state of corroded slab with nominal values of 100% and decreased in ultimate strength, weight loss versus cross-section diameter reduction decremented due to attack from sodium chloride.

[9] Investigated the corrosion potential, tensile tests of concrete resistivity and control, and the degradation and coating of reinforcing steel of a concrete slab member. Compared to corroded specimens have an increased efficiency and decreased values of concrete resistivity. Overall results showed that dacryodes edulis has protective membrane that acts against corrosion attack to reinforcing steel exposed to corrosive media.

[10] Investigated the effects of the chloride attack on reinforcing steel embedded in reinforced concrete structures built in the marine environment. The mean percentage results of potential E_{corr}, MV and concrete resistivity were 27.45% and 68.45%, respectively. Compared to corroded specimens, an increased value of potential E_{corr}, MV, decreased concrete resistivity and cross-sectional diameter reduction, respectively. Both showed reduced values compared to coated samples.

[11] Investigated the use of inorganic inhibitors and green approach inhibitors to assess corrosion efficiency using paste extracts of mangifera indica resins. The mean percentage of corrosion potential, E_{corr}, MV and concrete resistivity are 26.57% and 61.25%, respectively.

Compared to the corroded models, the corrosion potential, E_{corr}, MV, and concrete resistivity values increased, weight loss and cross-section diameter reduction were reduced due to the attack from sodium chloride.

[12] Evaluated comparatively the application effect of celtis zenkeri coated paste reinforcing steel embedded into concrete slab with 150μm, 300μm and 450μm thicknesses and accessed the corrosion potential and mechanical properties. The results showed a high ultimate yield of corrugated specimens to control and coated specimens due to the effect of corrosion on the mechanical properties of steel reinforcement. The weight loss results of corroded steel showed high percentage of values against the control and coated members. Cross-sectional reduction results showed higher percentage reduction values due to the effect of corrosion on the mechanical properties of steel.

[13] Studied corrosion levels of reinforcement embedded in concrete slab structures and immersed in a corrosive medium using the Wenner accelerated four inspection methods in the assessment of coated and non-coated reinforcement. The estimated range of the corroded samples indicates the significant corrosion probability potential. The results showed high yields of the corrosive samples over coated due to the impact on the mechanical properties of the steel reinforcement. Steel weight loss results showed higher percentage values against control and coating samples.

[14] 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.

[15] Experimental work evaluated the use of environmental inorganic exudates/resins from Invincias gabonensis layered to reinforced steel with different thickness and non-layered members, submerged in sodium chloride for corrosion tests of 150 days. The overall results of the exudates/resins coated samples showed no sign of corrosion potential, and the results showed that Invincias gabonensis exudates/resins were good corrosion inhibitors while non-layered corrosion showed possible signs. The cross-sectional area reduction results show high percentage reduction values because the loss of fiber was negative on the mechanical properties of the steel as a result of corrosion potential.

[16] Investigated the strength of steel reinforcement with the introduction of milicia excelsa exudates/resins to reduce the surface modifications and mechanical properties of reinforcing steel in concrete structures constructed in saltwater with accelerated corrosion determination for 150 days. The overall experimental results showed that the corrosion properties of the spalling and fractures in the coated members indicate a lower flexibility failure load. The effect of corrosion on the mechanical properties of reinforcing steel over the degraded (controlled) members has not been observed.

[17] experimental study introduced exudates/resins extracts from garcina cola as corrosion inhibitors coated to reinforcing steel and with comparison to non-coated members embedded in a concrete slab, immersed in a corrosive media for 150 days accelerated period to assessed surface changes, modifications and mechanical properties. 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 percentage of values against the control and coated specimens due to the effect of corrosion on the mechanical properties of the steel.

II. MATERIALS AND METHODS FOR EXPERINMENT

Aggregates

Fine and coarse aggregates are purchased at the sand dumpsite. Both meet the requirements of [18]

Cement

Cement limestone 42.5 was used for all concrete mixtures. The cement meets the requirements of [19]

Water

Water samples were taken from the Department of Civil Engineering Laboratory at Kenule Beeson Polytechnic, Bori, Rivers State. Water meets [20] requirements

2.1.4 Structural steel reinforcement

Reinforcement purchased directly from the market at Port Harcourt. It conformed to [21] requirements

Corrosion Inhibitors (Resins / Exudates) Anogeissus latifolia (Combretaceae)

The ghatty gummy sticky exudates were obtained from the tree trunk of Anogeissus leiocarpus from Benue State, in Achaba, Ebukodo, and Ologba villages of Apa Local Government Area.

Prepare samples for Reinforcement with Coated Exudate/resin

Investigative work examined the use of Anogeissus latifolia (Combretaceae) exudate/resin extracted from extruded tree trunks and has possessed environmentally stable properties of non-hazardous and harmless. The extracted exudate/resin is coated directly to reinforcing steels of different thicknesses, embedded in concrete slabs, and exposed to coastal marine areas with high salt content. Indeed, 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 plate mold measuring 100 mm × 500 mm × 500 mm (thickness, width, and length) with a concrete cover of 10 mm is poured into a metal mold, covered with air removed, and reinforced by 10 pieces of reinforcing steel with a diameter of 12 mm, at 100 mm c / c (top and bottom) are placed and molded after 72 hours, compacted for 28 days at standard room temperature to harden. The hardened concrete slabs are completely immersed in 5% sodium chloride (NaCl) solution in water and accelerated for a rapid corrosion process for 360 days with interval checks and routine tests of 90 days, 180 days, 270 days, and 360 days for examination and record documentations for comparison of tested sample performances.

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

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 [22], Gower and Millard [23]. Measurement of half potential is an indirect method of estimating the probability of corrosion. Recently, there has been much interest in developing tools for carrying out electrochemical measurements of disturbances on the steel itself to obtain a direct estimate of the corrosion rate (Stem and Geary [24]). Corrosion rate refers to electrochemical measurements, the first based on data.

Table 2.1: Dependence between potential and corrosion probability[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

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 coated. 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[25]

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

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.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The results of the half-cell potential measurements in Table 1 are plotted against the Resistivity in Table 3 for ease of interpretation. 2. It is used as an indication of the probability of significant corrosion (ρ <5, 5 <ρ <10, 10 <ρ <20, ρ> 20) for very high, high, low to a moderate and low probability of corrosion. At another measurement point, the potential for correction was high (–350 mV ≤ Ecorr ≤ –200 mV), indicating a corrosion probability of 10% or uncertain. The results of concrete resistivity measurements are shown in Table 2.1. It is proven that if the potential for corrosion is low (<-350 mV) within a certain range, there is a 95% chance of corrosion. Concrete resistivity is usually measured using the four-electrode method. Resistivity study data show whether certain states are conducive to lower ion movement, leading to greater corrosion.

Results and Discussion

The results of a half cell potential measurement in Table 1 are plotted against the resistivity in Table 3 for ease of interpretation. 2. This is used as an indication of significant corrosion probability (ρ <5, 5 <ρ <10, 10 <ρ <20, ρ> 20) with very high, high, low to moderate and low corrosion probability. , At other measurement points, high correction potential (-350 mV ≤ ECorr ≤ -200 MV), shows a corrosion probability of 10% or uncertain. The results of the measurement of concrete resistivity are shown in Table 2. Proven that if low corrosion potential (<-350 mV) in a certain range, there is a possibility of 95% corrosion. Concrete resistivity is usually measured using a four-electrode method. Resistivity study data shows whether certain conditions are conducive to reduce ion movements, which lead 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	ALS	ALS 1	ALS 2	ALS 3	ALS 4	ALS 5	ALS 6	ALS 7	ALS 8	ALS 9	ALS 10	ALS 11
	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	-106.95	-102.63	-104.36	-101.96	-106.37	-105.34	-104.79	-100.47	-104.02	-103.33	-102.32	-101.48
Concrete Resistivity ρ, kΩcm	17.88	17.87	17.87	17.86	17.86	18.02	18.01	18.01	18.00	18.00	17.94	17.86
Yield Strength, fy (MPa)	453.31	456.31	452.31	452.61	453.31	452.54	455.54	455.84	454.54	455.93	452.43	456.27
Ultimate Tensile Strength, fu (MPa)	632.23	630.18	631.86	627.64	631.17	631.59	631.39	632.19	630.79	632.34	631.84	631.70
Strain Ratio	1.40	1.38	1.40	1.39	1.39	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	11.89	11.89	11.90
Rebar Diameter at 28 days(mm)	11.89	11.89	11.90	11.89	11.89	11.90	11.90	11.88	11.89	11.89	11.89	11.90
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	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.86	0.85	0.85	0.85	0.85
Rebar Weights- After at 28 days (Kg)	0.86	0.85	0.86	0.85	0.85	0.86	0.86	0.86	0.85	0.85	0.86	0.86
Weight Loss /Gain of Steel (Kg) at 28 days	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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)	430.43	433.43	429.43	429.73	430.43	429.66	432.66	432.96	431.66	433.05	429.56	433.39
Ultimate Tensile Strength, fu (MPa)	617.34	615.29	616.97	612.75	616.28	616.70	616.50	617.30	615.90	617.45	616.95	616.81
Strain Ratio	1.43	1.42	1.44	1.43	1.43	1.44	1.43	1.43	1.43	1.43	1.44	1.42
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)	0.87	0.87	0.87	0.87	0.87	0.87	0.88	0.88	0.87	0.87	0.87	0.88
Rebar Weights- After Corrosion (Kg)	0.82	0.81	0.81	0.81	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
Weight Loss /Gain of Steel (Kg)	0.05	0.06	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 Anogeissus latifolia 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)	455.00	458.00	454.00	454.30	455.00	454.23	457.23	457.53	456.23	457.62	454.13	457.96
Ultimate Tensile Strength, fu (MPa)	636.61	634.56	636.24	632.02	635.55	635.97	635.77	636.57	635.17	636.72	636.22	636.08
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)	11.99	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)	12.06	12.05	12.06	12.06	12.05	12.07	12.06	12.05	12.06	12.06	12.05	12.06
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Rebar Weights- Before Test (Kg)	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
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	0.08	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.07	0.08

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				Anogeissus latifolia 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 Anogeissus latifolia Coated Specimens			
Potential Ecorr, mV	-104.65	-102.98	-104.23	-104.56	-345.43	-349.90	-349.59	-352.66	-116.26	-115.60	-114.51	-113.84
Concrete Resistivity ρ, kΩcm	17.87	17.87	17.86	17.91	8.74	8.74	8.95	8.73	14.89	15.08	15.11	15.15
Yield Strength, fy (MPa)	453.97	453.74	452.74	452.82	431.10	430.86	429.86	429.94	455.66	455.43	454.43	454.51

Ultimate Tensile Strength, fu (MPa)	631.43	629.90	630.23	630.14	616.53	615.00	615.33	615.24	635.80	634.27	634.60	634.51
Strain Ratio	1.39	1.39	1.39	1.39	1.43	1.43	1.43	1.43	1.40	1.39	1.40	1.40
Rebar Diameter Before Test (mm)	11.89	11.89	11.89	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	11.90	11.93	11.93	11.94	11.94	12.06	12.06	12.06	12.06
Cross- Sectional Area Reduction/ Increase (Diameter, mm)	0.00	0.00	0.00	0.00	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
Rebar Weights- Before Test (Kg)	0.85	0.85	0.85	0.85	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
Rebar Weights- After Corrosion (Kg)	0.86	0.86	0.85	0.85	0.82	0.81	0.82	0.82	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	0.08	0.08	0.08	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				Anogeissus latifolia 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 Anogeissus latifolia Exudate / Resin Coated Specimens			
Potential Ecorr, mV	-69.71	-70.57	-70.19	-70.35	197.12	202.69	205.30	209.80	-66.34	-66.96	-67.25	-67.72
Concrete Resistivity ρ, kΩcm	104.63	104.41	99.65	105.25	-41.35	-42.03	-40.81	-42.39	70.50	72.51	68.94	73.59
Yield Strength, fy (MPa)	5.31	5.31	5.32	5.32	-5.39	-5.39	-5.41	-5.41	5.70	5.70	5.72	5.71
Ultimate strength (N/mm2)	2.42	2.42	2.42	2.42	-3.03	-3.04	-3.04	-3.04	3.13	3.13	3.13	3.13
Strain Ratio	-2.73	-2.73	-2.73	-2.73	2.51	2.44	2.51	2.51	-2.45	-2.38	-2.45	-2.45
Rebar Diameter Before Test (mm)	0.335	0.333	0.330	0.333	0.340	0.337	0.330	0.337	0.335	0.327	0.332	0.335
Rebar Diameter- After Corrosion(mm)	0.328	0.345	0.372	0.394	-1.068	-1.049	-1.013	-0.999	1.07	1.05	1.02	1.00
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-19.44	-16.67	-16.67	-18.06	24.14	20.85	21.59	22.03
Rebar Weights- Before Test (Kg)	6.527	6.405	6.489	6.231	6.407	6.41	6.408	6.407	6.425	6.728	6.426	6.525
Rebar Weights- After Corrosion (Kg)	14.91	15.04	14.66	14.53	-13.85	-13.95	-13.74	-13.55	16.07	16.22	15.93	15.67
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	-22.67	-21.33	-22.67	-22.97	29.31	27.12	29.31	29.83

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

Reinforcement corrosion is only seen when the damage to the outer surface of the reinforced concrete is visible in the presence of corrosion stains, cracks, delamination, and pouring of the concrete cover (Liu, 1996). Electrochemical techniques have been successfully used to measure the corrosion rate of reinforcement in concrete for both laboratory and field concrete. Techniques include half-cell potential, electrical resistance, and linear polarization methods. They are considered to be the most reliable non-destructive technique in field and laboratory corrosion measurement [27]. The Potential Ecorr,mV and Concrete Resistivity ρ, kΩcm are obtained from Tables 3.1 - 3.3 and summarized into mean and percentile values in Tables 3.4 and 3.5, plotted graphically in Figures 3.1-3.8b, are the results of controlled samples, not coated (corroded) and coated for 36 concrete slabs, divided into 3 sets of 12 controlled samples, which is the determinant reference range, 12 uncoated (corroded) samples, and 12 exudate/resin coated samples.

The mean and the minimum, maximum, and differential percentages of the calculated measurements of the half-cell controlled corrosion potentials were -105 mV and -103mV (-70.6% and -69.7%) with a potential difference of 1.67mV and 0.86%), the corroded samples were -353 mV and -345mV (-197% and -210%) and the difference values were 7.23mV and 12.7%, and the coated samples were -116mV and -114mV (-67.7% and -66.3%)) and the potential differences are 2.47mV and 1.38%, respectively.

The corrosion potentials 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 -103mV and -114mV, indicating the relationship between corrosion potential and probability as $E\text{corr} > -200\text{mV}$ as a reference range. The results from this potential Ecorr result show that the controlled and exudate/resin-coated sample values are low with a 90% probability that no corrosion of reinforcing steel was observed at the time of measurement (10% corrosion risk, which means a 10% for uncoated samples the maximum value obtained is -345 mV, the results are within the reference value of the relationship between corrosion potential. The value $-350\text{mV} \leq E\text{corr} \leq -200\text{mV}$ indicates a high-value range, 10% or indicates an uncertain corrosion probability. The comparison of the reference range (controlled) shows that the corrosive sample shows corrosion due to accelerated induced corrosion compared with coated samples showing no corrosion attack on reinforcing steel reinforcement embedded in concrete, exposed to the corrosive environment by forming a resistant layer.

The average value and the minimum and maximum percentage of concrete resistance with a controlled sample potential difference were 17.9kΩcm and 17.9kΩcm (99.7% and 105%) and the difference values were 0.05kΩcm and 5.6%, corroded samples were 8.73kΩcm and 8.95kΩcm (-42.4% and -40.8%) and the difference values were 0.22kΩcm and 1.58%, the coated samples were 14.9kΩcm and 15.2kΩcm (68.9% and 73.6%) and the difference values were 0.28kΩcm and 4.78%, respectively. The calculated maximum value of the controlled sample concrete resistivity was 105% compared to the corroded and coated values of -40.8% and 73.6% and the maximum controlled difference percentage were 5.6% compared to the corroded and coated value of 1.58% and 4.78%. The test results of controlled and coated samples with concrete resistance obtained a maximum average value of 17.9kΩcm and 15.2kΩcm with a description of the value 10 <20 <20 (low) compared to the corrosion value of 8.95kΩcm with specification $5 < \rho < 10$ (high) and with a reference range of dependence between concrete resistance and corrosion probability at significant corrosion probability ($\rho < 5$, $5 < \rho < 10$, $10 < \rho < 20$, $\rho > 20$) for very high, high, low to moderate and low, for possible corrosion. From the comparison results of coated and corroded samples, the maximum values obtained for both samples indicate 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 significant corrosion probability. The maximum value of the corroded sample was in the range of $5 < \rho < 10$ indicating high, signs indicating the presence of possible corrosion, confirmed in the works of [[9]; [11]; [12]; [14]]. From the results obtained it can be compared that the effect of corrosion attack was observed in the uncoated samples, while the samples with exudate/resin coating had corrosion protection properties with a highly resistant and water-resistant membrane that prevented corrosion of the reinforcing steel constructed into the concrete preventing slabs and induced accelerations from being exposed to corrosive media.

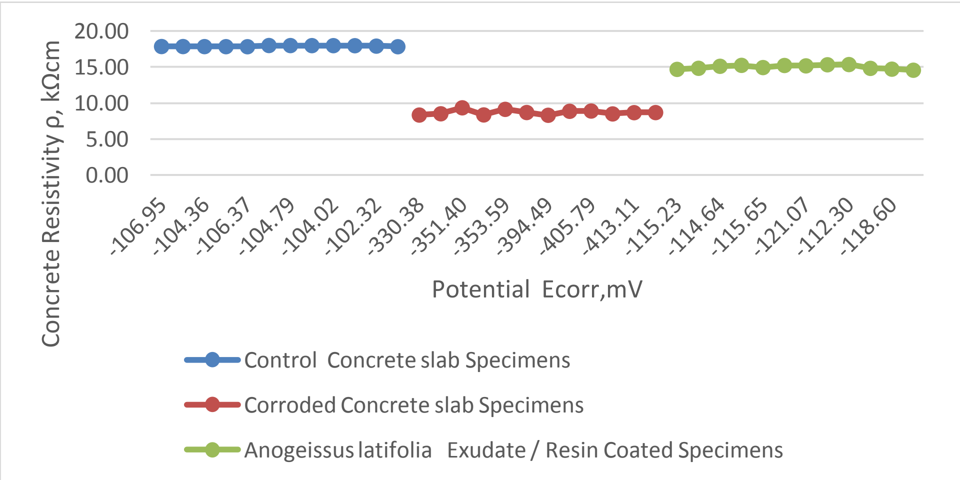

Figure 3.1 : Concrete Resistivity ρ, kΩcm versus Potential Ecorr,mV Relationship

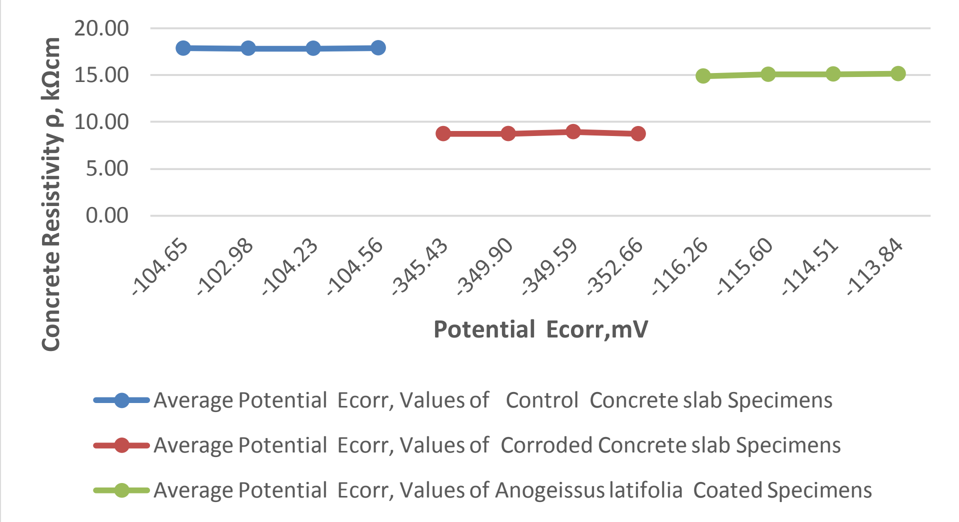

Figure 3.1A: Average Concrete Resistivity versus Potential Relationship

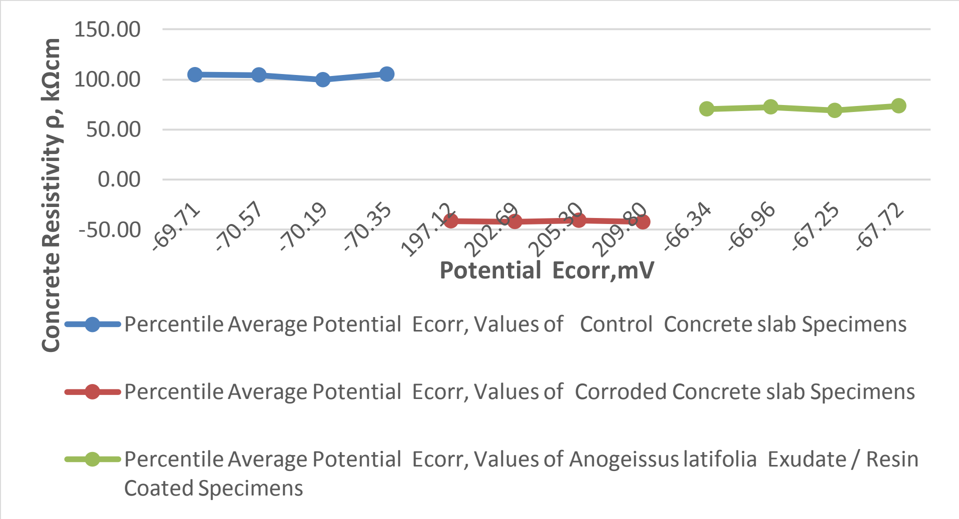

Figure 3.1B : Average Percentile Concrete Resistivity versus Potential Relationship

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

The corrosion of steel in concrete is an electrochemical process; The two most common conditions that cause corrosion of reinforcement and destruction of the passive film in reinforced concrete are carbonization and chloride erosion [28]. Corrosion due to chloride attack is the main cause of corrosion of concrete steel reinforcement. The results of the mean, percentile, and the difference between the minimum and maximum yield strength (limits), fy (MPa) of the controlled sample were 453 MPa and 454 MPa (5.31% and 5.32%) and the difference value was 1.23MPa and 0.01%, corroded samples were 43 MPa and 431 MPa (-5.41% and -5.39%) and the difference values were 1.24MPa and 0.02%, the coated sample values were 454 MPa and 456MPa (5.7% and 5.72%), and the difference between 1.23 MPa and 0.02%. The calculated maximum percentage value of the controlled yield strength is 5.32% compared to the corrosion and coating values of -5.39% and 5.72% respectively and the controlled potential difference value is 0.01%, corroded is 0.02%, and 0.02% coated.

The mean values, percentiles, and the difference between the minimum and maximum ultimate tensile strength values, fu (MPa) of the controlled samples were 630MPa and 631MPa (2.42% and 2.42%) and the difference values were 1.53MPa and 0.03%, corroded are 615MPa and 617MPa (-3.04MPa and -3.03%) and the difference is 1.53MPa and 0.01%, coated of 634MPa and 636MPa (3.13% and 3.13% and the difference value is 1.53MPa and 0.12%. The maximum ultimate tensile strength calculated percentage at the limit is 5.32% based on the corroded and coated values are -5.39% and 5.72% and the possible diffrence value is controlled by 0.01%, corroded 0.02%, and coated 0.02%.

The strain ratio minimum and maximum average, percentile and different values of the controlled samples were 1.39 and 1.39 (-2.73% and -2.73%) with a different value of 0.00 and 0.00%, the values of the corroded samples were 1.43 and 1.43 (2.44% and 2.51%) and the difference values were 0.00 and 0.069%, the coated samples were 1.39 and 1.4 (-2.45% and – 2.38%) and the difference values of 0.00% and 0.008%. The maximum strain ratio percentage calculated for comparison is controlled -2.73% against corroded 2.51% and coated -2.38%, and the different peaks controlled for 0.08%, corroded 0.069% and coated 0.008%, as in confirmed works of [[12]; [14]; [10]; [17]].

From the calculation results obtained, summarized in Tables 3.4 and 3.5 and displayed graphically in Figures 3.1 - 3.8, the yield strength, tensile strength, and strain ratio of the mean, percentile, and controlled differential potential values, uncoated (corroded) and coated concrete slab samples were determined, coated samples had higher failure loads compared to corroded samples with reduced failure load and low load-bearing capacity and with mean and percentile values with the reference range, whereas uncoated (corroded) samples, had a load-bearing capacity which is low and a reduced value compared to the reference range. The comparison results show that the low load carrying capacity is caused by the effect of corrosion attack on the uncoated (corroded) elements, which damage the reinforcing steel fibers, ribs, and passive formation and surface modification. The observed mean values for the coated samples were associated with the corrosion resistance potential to penetrate the reinforcing steel with the formation of a protective membrane;. This attribute indicates the efficiency and effectiveness of the exudate/resin as an inhibitor against corrosive effects. of reinforced concrete structures exposed to the edges of strong, high salinity marine areas.

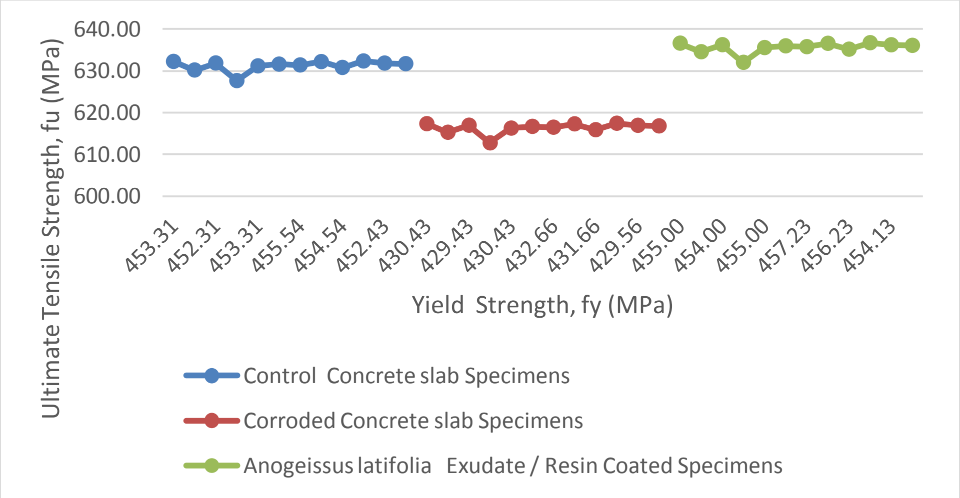

Figure 3.2 : Yield Strength versus Ultimate strength

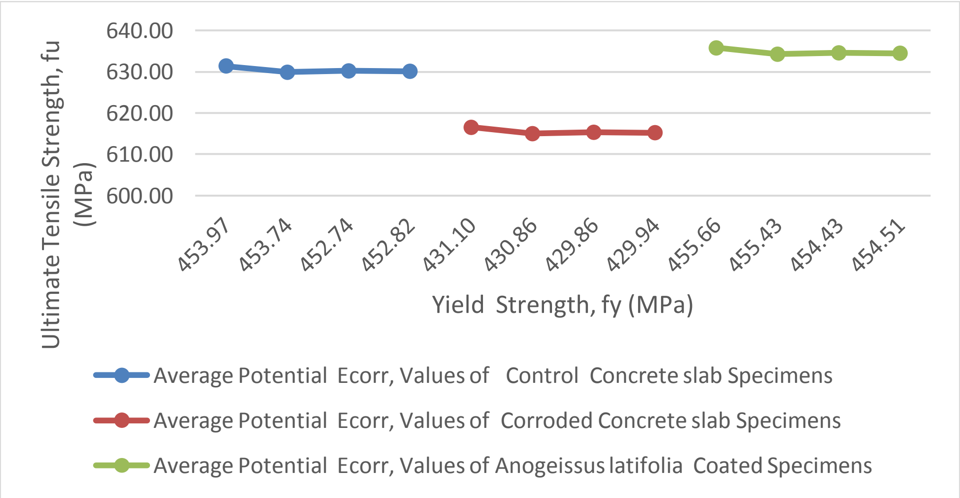

Figure 3.2A: Average Yield Strength versus Ultimate Tensile Strength

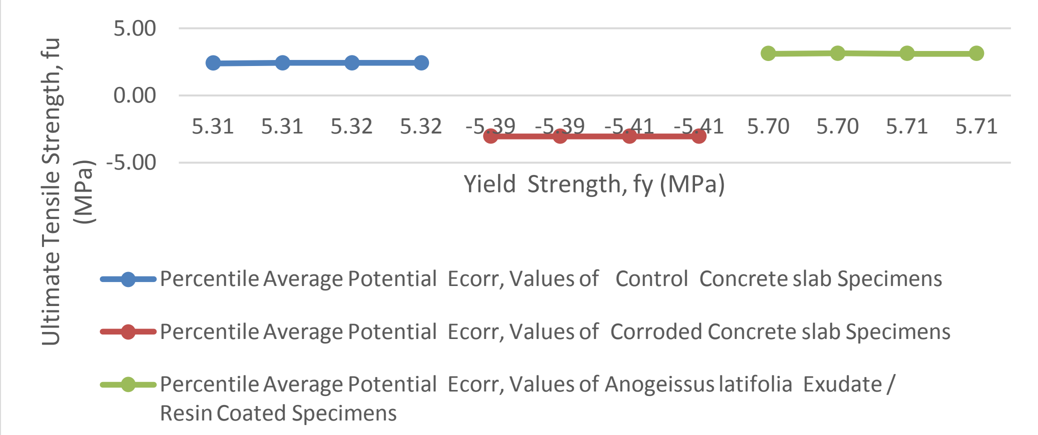

Figure 3.2B: Average Percentile Yield Strength versus Ultimate Tensile Strength

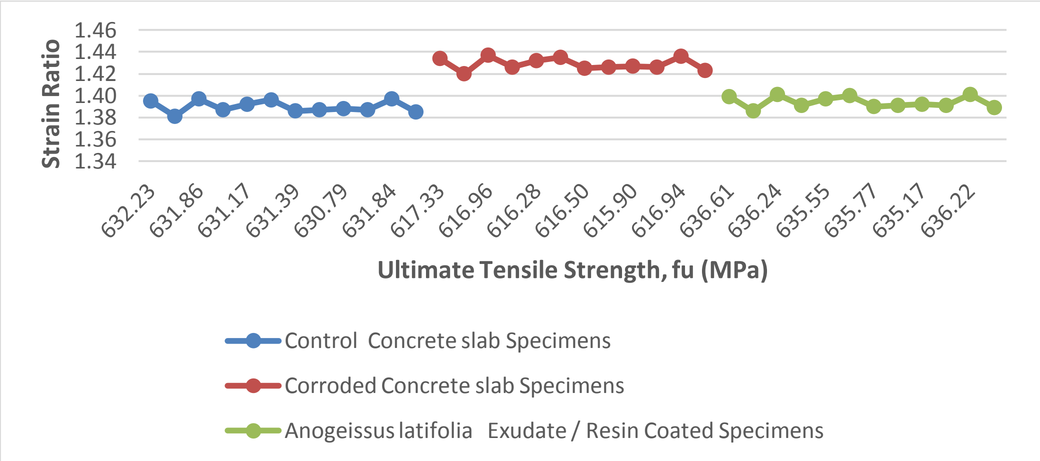

Figure 3.3: Ultimate Tensile Strength versus Strain Ratio

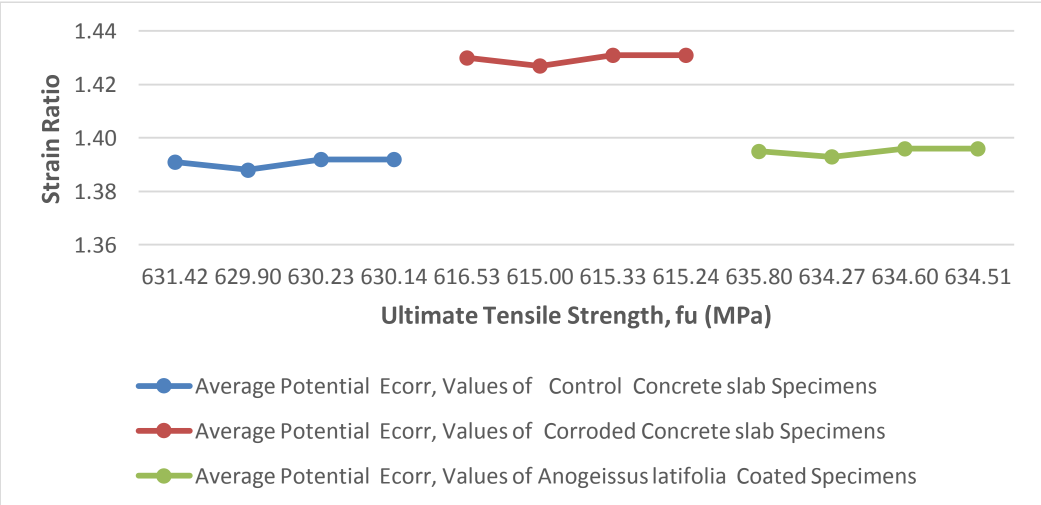

Figure 3.3A: Average Ultimate Tensile Strength versus Strain Ratio

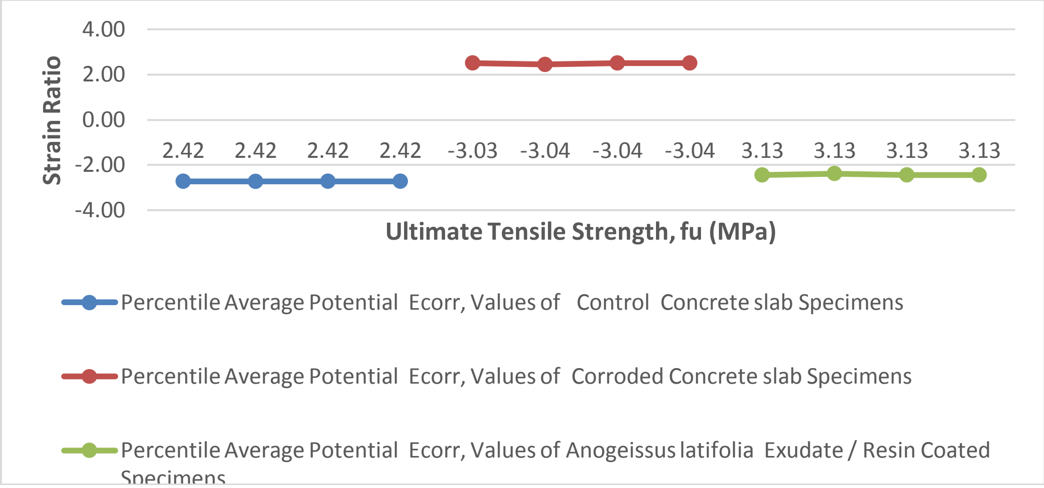

Figure 3.3B: Average percentile Ultimate Tensile Strength versus Strain Ratio

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

The development of corrosion in RC structures features a number of effects. There are four majo rproblems caused by corrosion [29]; are - Loss of cross-sectional area of the reinforcing bars, - Changes within the mechanical properties of the reinforcing steel, - Reduction of bond between steel and concrete and - Cracking, spalling and delamination of the concrete. The last two effects are commonest for generalized corrosion. The oxide of iron produced in localized corrosion is different from that produced generally corrosion with lower volume per unit mass. Thus, localized corrosion, doesn't often affect, a minimum of at moderate corrosion levels, the concrete cover and produces little rust staining within the external concrete surfaces, as a result being difficult to detect through usual visual inspections [29].

.The rebar diameter before test (mm) minimum and maximum average and percentile values are controlled 11.9mm and 11.9mm (0.33% and 0.34%) with differential values of 0.01mm and 0.01%, the corroded sample values are 12mm and 12mm (0.33% and 0.34%) and differential values of 0.01mm and 0.01% and therefore the coated sample values are 12mm and 12mm (0.33% and 0.34mm and differentially computed values of 0.00mm and 0.01%. The unit weight of rebar before the corrosion test exhibited infinitesimal differences supported product and company molds also because the byproducts utilized 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 (0.33% and 0.34%), having 100% maintained reference value, the corroded sample values are 11.93mm and 11.94mm (-1.06% and -0.99%) and differentials of 0.01mm and 0.07%, the coated samples d values are 12.1mm and 12.1mm (1.0% and 1.07%) and differentials of 0.00mm and 0.07%. the utmost computed percentile values are controlled 0.344% against corroded -0.99% and coated 1.07%, the percentile difference is corroded 0.07% 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 consequences of corrosion attacks on the reinforcing steel embedded within the concrete slab and exposed to induced corrosion acceleration activities. Comparatively, the results of corroded samples showed reduction and decreased values as compared of rebar diameter before and after induced accelerated corrosion test with values reduction percentile range from 0.344% to -0.99% and average ranges values from 11.99mm to 11.93mm.

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(-19.4% and -16.7%) and differentials of twenty-two at corroded, the coated sample values are 0.07mm and 0.07mm (20.9% and 24.1%) and differentials of 0.00mm and 3.29%. The cross-sectional area reduction/increase comparatively average and percentile value differences between coated and corroded samples are with the ranges of 24.1% to -16.7%. 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 within the works of [[19]; [12]; [10]; [15]].

It are often summarized that exudates/resin exhibited inhibitive characteristics against corrosion influences on reinforcing steel embedded in concrete slab samples that were induced during 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 (6.23% and 6.53%) and differentials are 0% and 0.296%, the corroded sample are 0.87kg and 0.87kg (6.41% and 6.41%) and differentials of 0.00% and 0.00%, the coated samples are 0.87kg and 0.87kg (6.43% and 6.73%) with differentials of 0.00% and 0.3%.

The rebar weights-after corrosion(Kg) average and percentile results and therefore the summarized differential values of the minimum and maximum values of controlled samples are 0.85kg and 0.86kg (14.5% and 15%) and differential values of 0.01% and 0.51%, the corroded samples are 0.81Kg and 0.82Kg (-14% and -13.6%) and differentials of 0.01% and 0.4%, the coated sample values are 0.95kg and 0.95kg (15.7% and 16.2%) and differentials of 0.00% and 0.55%.

The typical and percentile minimum and maximum unit weight loss /gain of steel (Kg) and therefore the percentile differences as compared are controlled 100% maintained values resulting from pooling during a freshwater tank with no traces of corrosion potentials against the corroded sample values of 0.06kg and 0.06kg (-22.97% and -21.33%) and therefore the coated are 0.07kg and 0.08kg (27.12% and 29.83%). 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 therefore the examination of unit weight of rebar before and after corrosion test and also because the weight loss/gain. Comparatively, obtained results unit weight loss/gain of steel showed average and percentile values reduction / decreased and increased with coated with 0.08kg to 0.06Kg and 29.83% to -22.97% corroded, as validated within the works of [[10]; [11]; [14]; [16]].

. 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 leading to 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.

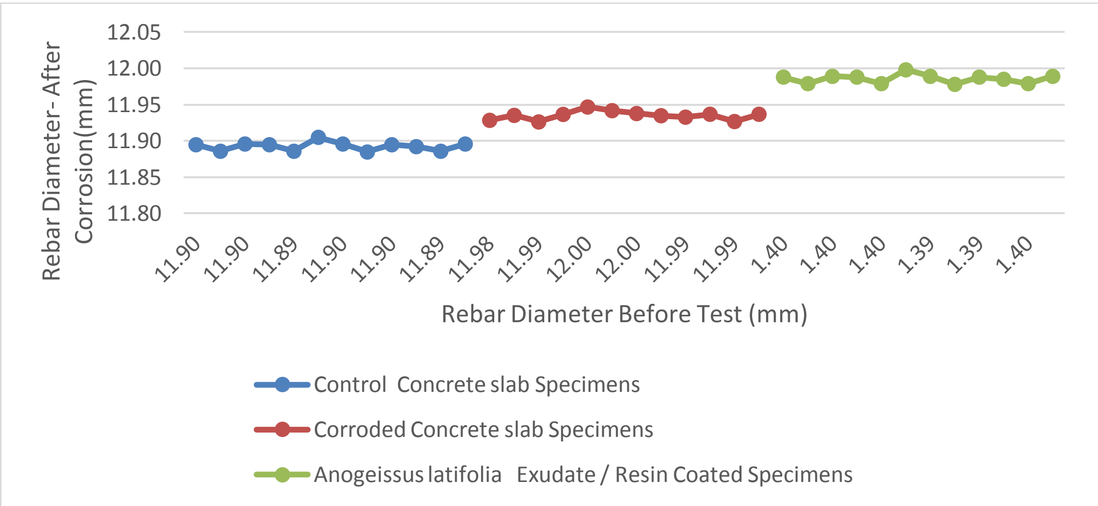

Figure 3.4: Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

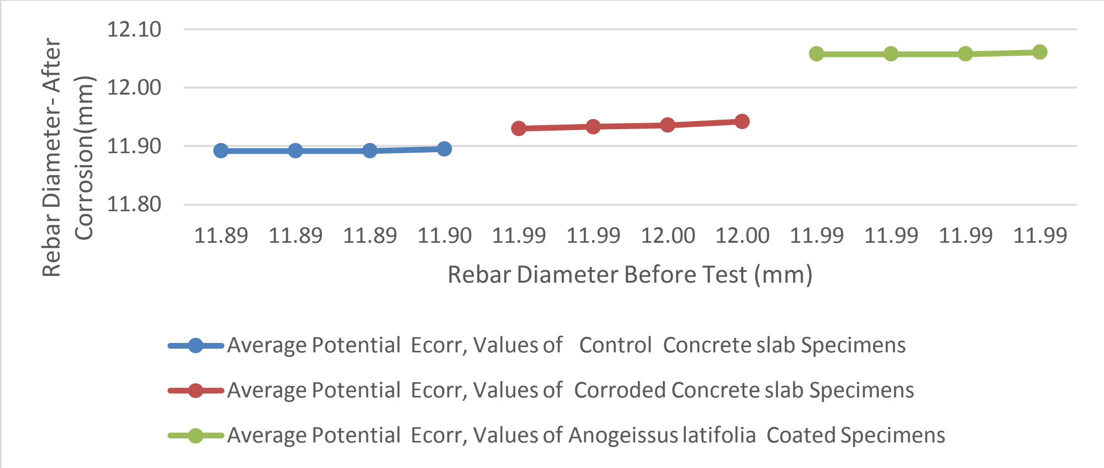

Figure 3.4A: Average Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

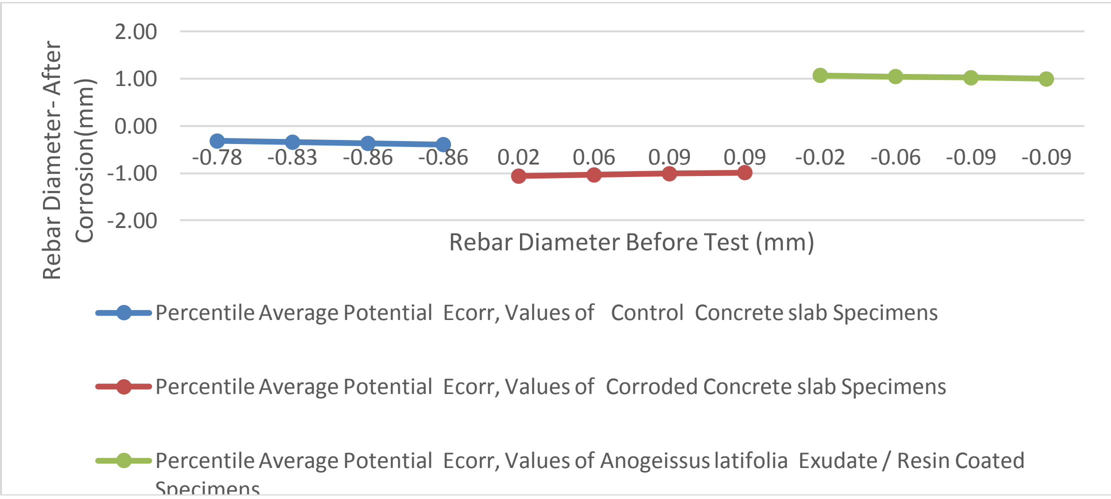

Figure 3.4B: Average Percentile Rebar Diameter Before Test(mm) versus Rebar Diameter-After Corrosion(mm)

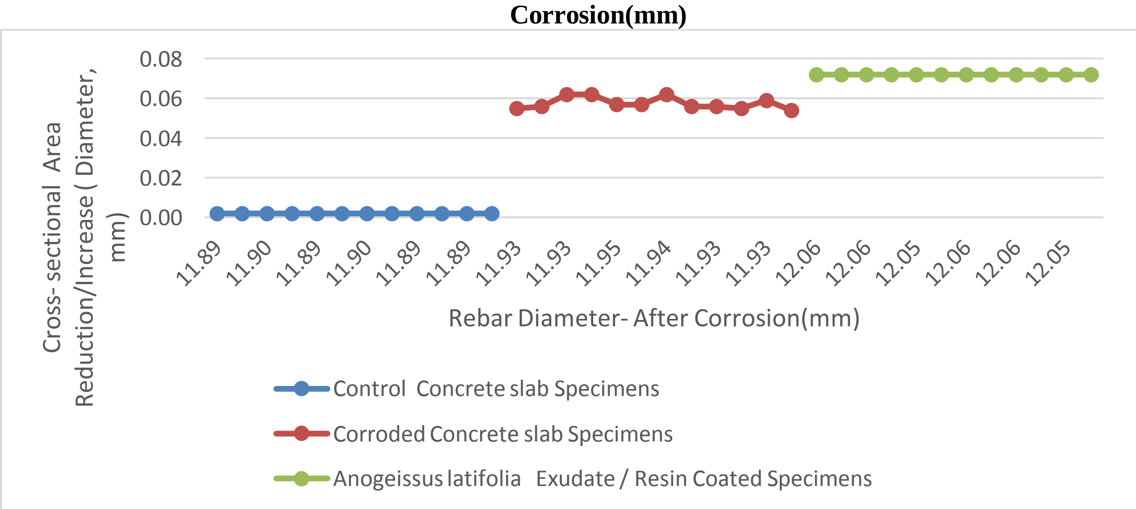

Figure 3.5: Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

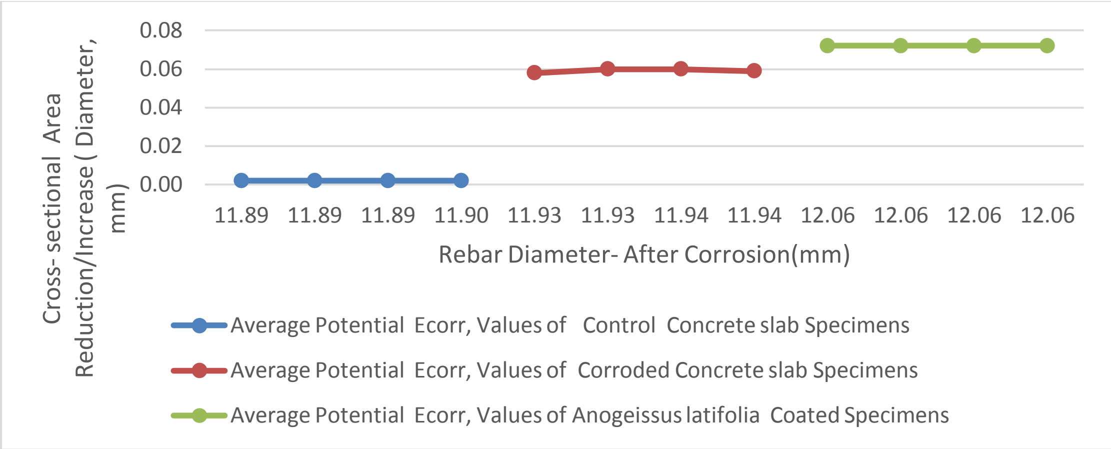

Figure 3.5A: Average Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

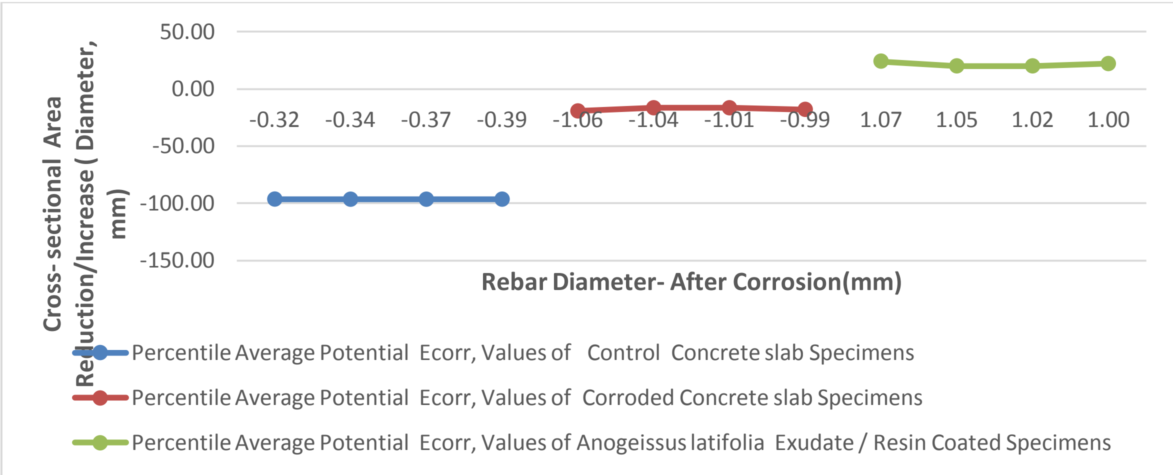

Figure 3.5B: Average Percentile Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

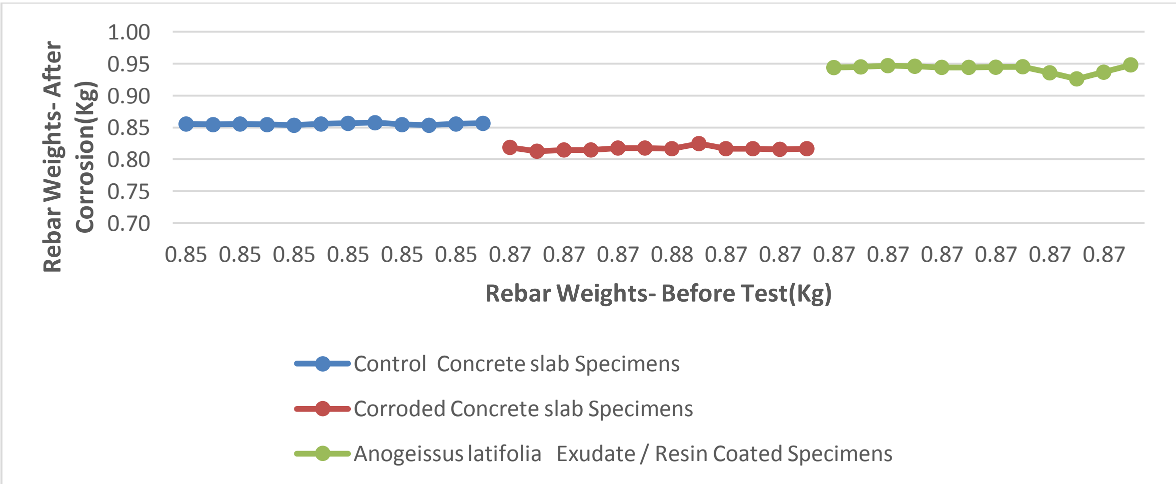

Figure 3.6: Rebar Diameter - After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

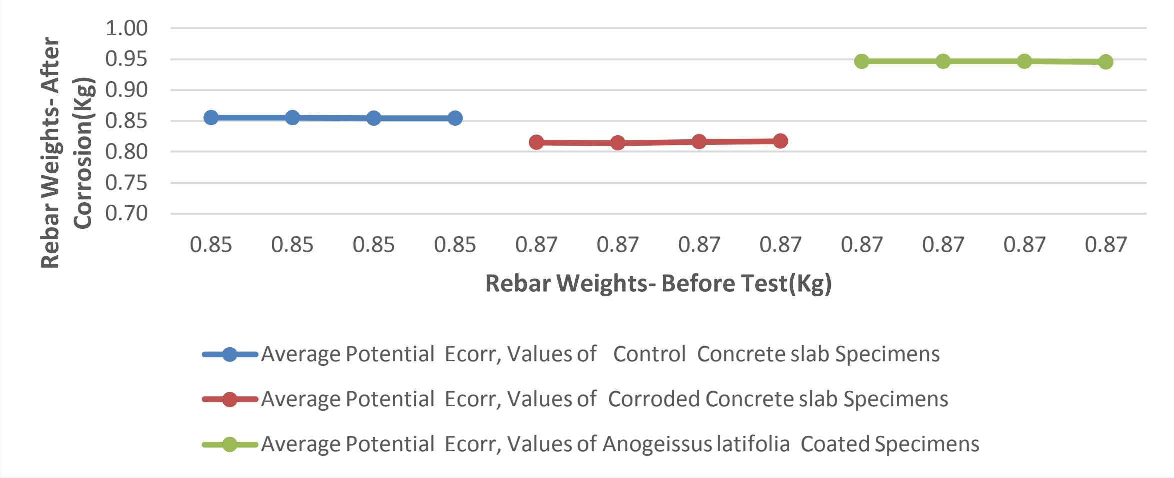

Figure 3.6A: Average Rebar Diameter - After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm

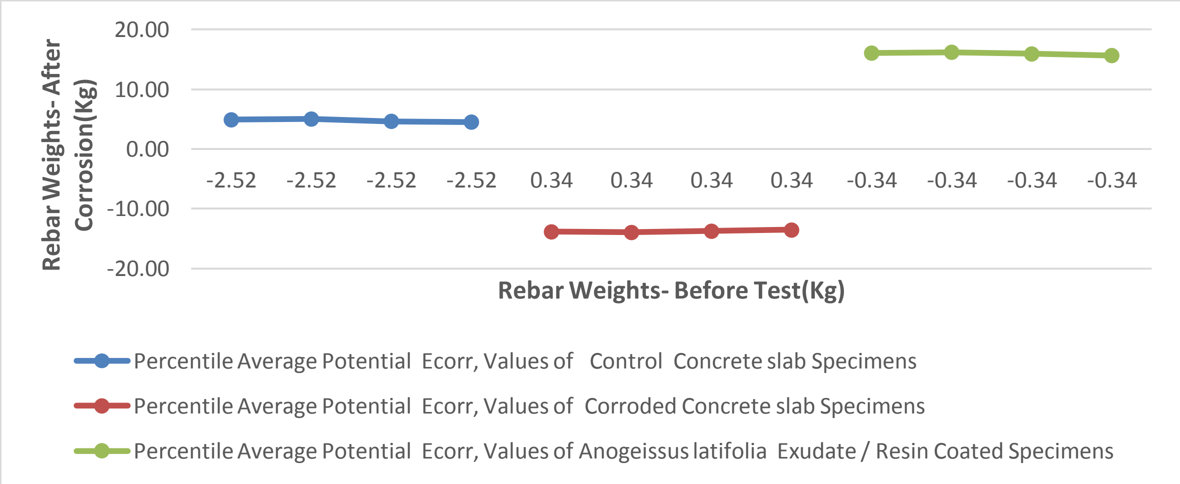

Figure 3.6B: Average Percentile Rebar Diameter - After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

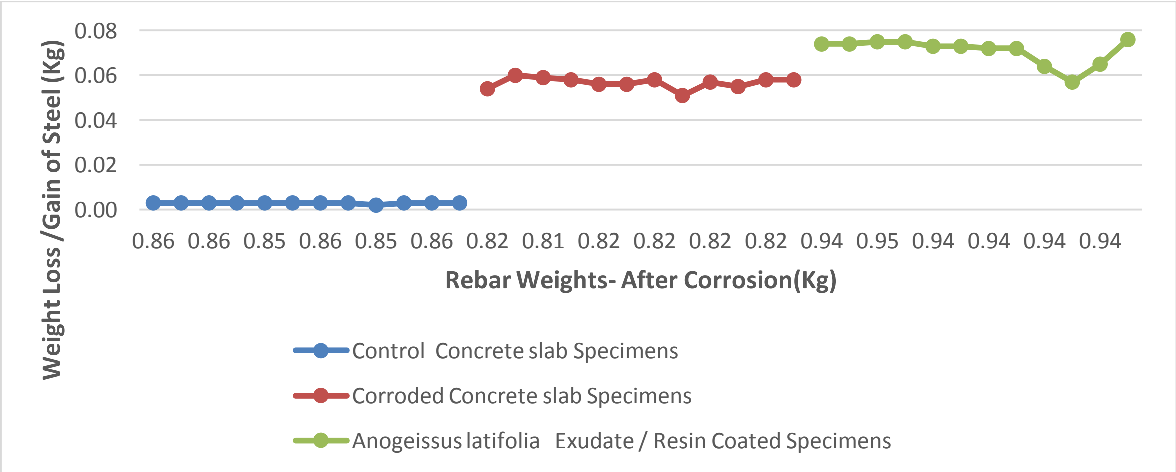

Figure 3.7: Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

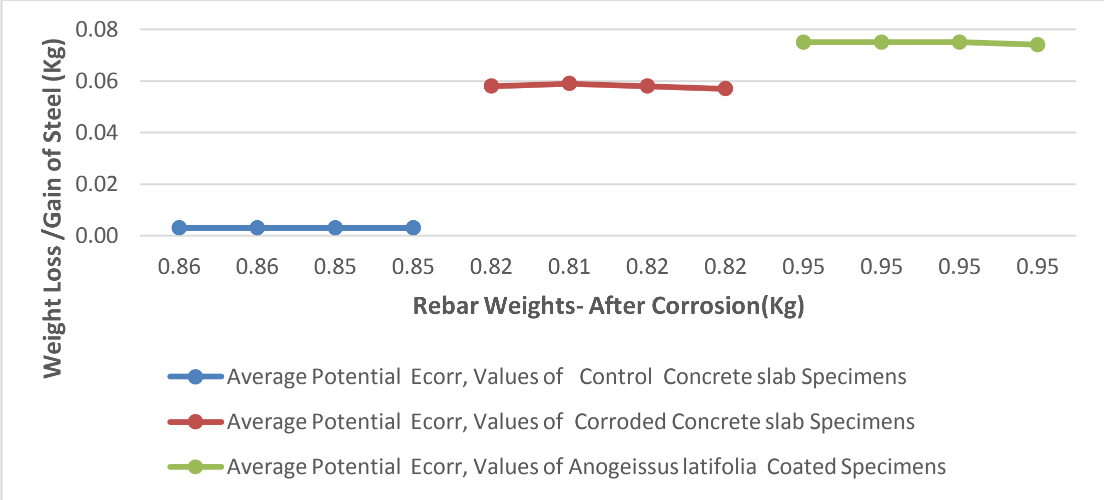

Figure 3.7A: Average Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

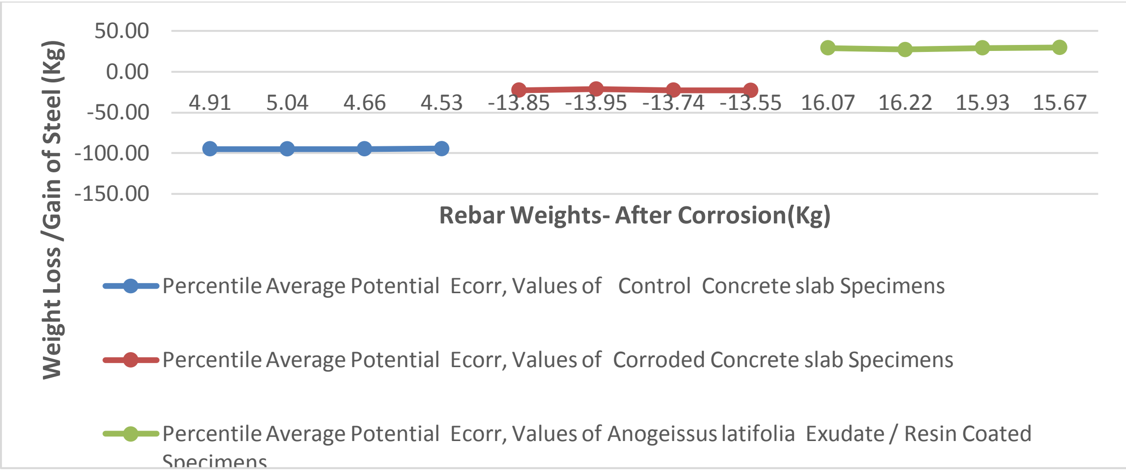

Figure 3.7B: Average Percentile Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

VI. CONCLUSION

Experimental results showed the following conclusions:

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

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