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Corrosion Potential Dependence Probability Assessment of Reinforcing Steel in Corrosive Media

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Abstract

The study investigated the application of Ficus sycomorus exudate/resin obtained from naturally occurring and extruded from the trunk of the tree and with eco-friendly and environmentally non-hazardous properties. Obtained exudate/resin was directly coated to reinforcing steel of varying coating thicknesses embedded in the concrete slabs and exposed to highly concentrate corrosive media for the assessment of the potentiality and effectiveness of inhibitive materials. The maximum Potential E_{corr}*,mV computed percentile controlled value is -66.43% against corroded and coated values of 260.36% and -69.312% and differential potential value of controlled 8.02%, corroded 93.63%, and coated 2.938%. The exudates/resins exhibited inhibitory characteristics against corrosion attacks on reinforcing steel embedded in the concrete slab, exposed to corrosive media by the formation of the resistive coating. The maximum computed concrete resistivity percentile value of the controlled sample is 143.14%, against corroded and coated values of -49.75% and 126.8%, and the maximum differential percentile value of controlled is 26.27% against corroded and coated values of 8.37% and 27.81%. The results of controlled and coated samples of concrete resistivity obtained at the maximum average are 17.65 kΩcm and 17.496 kΩcm with value indications of* $10 < \rho < 20$ *(low) against the corroded value of*

8.97kΩcm with an indication of $5 < \rho < 10$ (high) and with a reference range of dependence between concrete resistivity and corrosion probability of likelihood of significant corrosion ($\rho < 5$, $5 < \rho < 10$, $10 < \rho < 20$, $\rho > 20$) for very high, high, low to moderate and low, for the probability of corrosion. The maximum computed percentile values of yield strength of controlled are 7.93% against corrode and coated values -7.32% and 7.918% respectively and the potential differential values of 2% controlled, 0.04% corroded and 1.985% coated. The maximum computed percentile values of yield strength of controlled are 5.14% against corrode and coated values -4.64% and 4.886% respectively and the potential differential values of 0.16% controlled, 0.06% corroded, and 0.16% coated. The coated samples maintained values in both at average was attributed to the resistive potential to corrosion entrance into the reinforcing steel with the formation of protective membrane, these attributes showed the effectiveness and the efficiency of exudates/resin as an inhibitive material against corrosion effect of reinforced concrete structures exposed to the severe coastal marine regions with high salinity. The maximum computed percentile values are controlled 0.306% against corroded -0.49% and coated 0.796%, the percentile difference is corroded 0.38% against 0.026%.

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

INTRODUCTION

The reinforcement of steel embedded in reinforced concrete structures leads to the premature collapse and failure of many structures that are built and exposed to the harsh environment of the seabed. The entry of seawater into the concrete structure and the desiccation of groundwater and salts with high chloride ration is the entry of chloride from the environment. Transport of ions in the electrolyte due to the energy gradient (Mangat and Limbachiya, 1999, Erdogdu *et al*. 2004). Scully (1975) generally suggested that to 5mV to m 10mV should be used, while Trethwey and Chamberlain (1995) used ± 30mV.

Andrade and Alonso (2001) stated that the maximum error factor 2 is due to using B = 26mV when determining the corrosion rate.

Locke and Simon (1980) found that for steel in concrete with a total weight of 0 to 1% NaCl, the corrosion rate of embedded steel based on LRP was Wheat and Eleazer (1985) performed potention dynamic polarization measurements from -250mV to 1200mV (based on SCE) with a scan rate of 1mV / s with concrete samples (w / c = 0.52) immersed in 10% NaCl solution for 3050. Reported results indicated the corrosion variation rates are within 0.04mpy for 30 days to 3mpy for 150 days.

Charles et al (2018) Corrosion tests were carried out on 12 mm high strength reinforcing steel bars, rough sample surfaces were treated with Symphonia globulifera resin extract with layer of varying thicknesses, polished and embedded in the concrete slab. Control samples, uninhibited samples, and resin-inhibited samples were cured for the first 28 days and the corrosion acceleration process with sodium chloride lasted 119 days with a verified reading interval of 14 days. Compared with the corroded sample, the corroded has a 70.1% increase in the potential value of Ecorr, mV and 38.8% reduce the value of the concrete resistivity, the tensile stress relative to the maximum force compared to corrosion, because the nominal yield strength of 100% from 103.06% to 96%, a decrease of 12% and a decrease in weight of 67.5% versus 48.5% and a reduction of 47.80% to 94.82% in the cross-sectional diameter, both of which showed a reduced corrosion value compared to the sample with the cover.

Charles et al (2018) studied the rate of corrosion potentiality, concrete resistivity and tensile strength of controlled, corroded and coated reinforced concrete slab member. Results of potential E_{corr}, mV and concrete resistivity were recorded for non-corroded concrete samples in mapping areas for a fast period of 7 days to 119 days after initial curing of 28 days, indicating a 95% probability of corrosion and a high or moderate likelihood of corrosion. The average results on the comparison showed a 70.1% increase in the strength of the Potential E_{corr}, mV and 87.8% to 38.8% as opposed to the non-coated 27.2%. In summary the mean state of the slab decreased by 100% and the ultimate strength decreased from 100.68% to 96% with the stress and nominal values against the ultimate strength. Results of potential E_{corr}, M_V and concrete resistivity were recorded for non-blocked concrete samples in mapping areas for a fast period of 7 days to 119 days after initial curing of 28 days, indicating a 95% probability of corrosion and a high or moderate likelihood of corrosion. Compared to corroded specimens, coated have an increased efficiency of 70.1% and decreased values of concrete resistivity by 38.8%, yield stress against ultimate strength 100%, nominal yield stress 100.95%.

Charles et al (2018) evaluated potential of corrosion, concrete resistivity and tensile strength of on controlled, corroded and coated reinforced concrete slab member. Overall results showed that dacryodes edulis were effective in using as inhibitors, which sustained and protected against environmental attack.

Daso et al. (2019) evaluated the use of viable eco-friendly exudates/resins outside of cola acuminate. Half-cell potential, concrete resistivity, and tensile strength tests were used to analyze the mechanical properties of non-coated and exudates/resins coated samples, submerged in sodium chloride for 150 days, with a 1 mV / s scan rate, current by 1200 mV - 200 mV. The average value of the mechanical properties of the corroded sample is 107.65% and the percentage difference against the control and coated samples is 7.64%, -7.10% and -6.67339%. The average mechanical properties of corroded specimens are "steel weight loss" percentage mean value 180.43% and percentage difference for control and coated samples is 80.43747%, -44.5791% and -45.1857%. Cross-sectional reduction results due to corrosion effect on the mechanical properties of steel.

Charles et al (2018) investigated the effects of chloride attack on reinforcing steel embedded in reinforced concrete structures constructed in marine environment. Results of half-cell potential, concrete resistivity, and tensile strength properties were recorded for concrete samples that were not coated in the mapping areas for the 95% corrosion probability. The results of the potential E_{corr}, mv, concrete resistivity and tensile strength of the acardium occidental l were recorded. The mean percentage results of potential Ecorr, MV and concrete resistivity were 27.45% and 68.45%, respectively. Compared to corroded specimens, corroded has 75.4% increased values of potential Ecorr, mV, and 33.54% concrete resistivity decreased the yield stress against corrosion by 100% nominal yield stress against 101.38%. Weight loss was 43.98% and 51.45% to 89.25%, respectively, with a reduction in cross-sectional diameter, both decreasing values compared to coating specimens.

Charles et al (2018) investigated the potential for estimating possible corrosion rates by measuring half-cell potential tests, concrete resistance tests and tensile tests, mechanical properties of reinforcement that were not corroded, corroded and retarded with Moringa Oleifera laminated resin paste made from wood extract. The sample was immersed in concrete and accelerated in a corrosive environment for 119 days. The average percentage of Ecorr potential, mV and concrete resistance are 29.9% and 68.74%, respectively. Compared to the corroded sample, the corroded sample showed a 70.1% increase in the potential value of Ecorr, mV and a 35.5% decrease in the resistance value of concrete. The results of the calculation of the average percentage of stress at the melting point compared to corrosion because 100% nominal melting point decreased from 105.75% to 96.12% and weight loss was 67.5% compared to 48.5% and 48.34% to 94.82%, area reduction, both of which showed lower corrosion values compared to the coated samples.

Philip et al. (2019) examined the use of acacia senegal exudates / resins tree extract as corrosion inhibitors. Exudates/resins paste coated and non-coated reinforcing steel embedded in concrete members and immersed in corrosive media for 150 days in an accelerated process. The potential Ecorr results ($-350\text{mV} \leq E\text{corr} \leq -200\text{mV}$) showed that the values of the corroded specimens 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).

Charles et al (2018) Studies the utilizations of natural and eco-friendly inorganic corrosion inhibitor exudates / resins extracted from trees. Compared to corroded specimens, coated specimens increased by 70.1% with decreased values of potential Ecorr, MV, and concrete resistivity of 38.8% against cross-sectional diameter reductions, 43.98% and from 51.45% to 89.25%, 69.3%, both reduced the degraded values compared to the coated samples. Results of the potential Ecorr, MV, symphonia globulifera linn, ficus glumosa and acardium occidental l coated specimen, results indicated a 10% or less probability of corrosion, indicating the presence of corrosion, or lack of corrosion, or low incidence of corrosion. The normal and computational percentage values of the yield stress against the ultimate strength are 100.0% nominal yield stress versus 103.06% to 96.12%, 112.48% to 89.25%, and the ultimate strength in symphonia globulifera Linn from 108.38% to 90.25%. Ficus glumosa and acardium occidental L, 48.5% and 47.80% to 94.82%, ficus glumosa 69.5% to 47.29%, 48.95% to 77.89%, respectively, against the coated of symphonia globulifera linn samples. The mean percentage results of potential Ecorr, MV and concrete resistivity for symphonia globulifera linn, Ficus glumosa and Accardium occidental L.

Letam et al. (2019) investigated the corrosion rate of reinforcing steel embedded in concrete slab structures submerged in a corrosive environment, and applying Wenner accelerated four probe methods. The summarized results show that the range of values for the corroded samples indicates the probability of significant corrosion (ρ <5, 5 <, <10, 10 <, <20, ρ> 20) for most, high, low to moderate and low, for corrosion potential. 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 coating models due to the effect of corrosion on the mechanical properties of the steel.

Charles et al. (2019) Investigated comparatively of reinforced steel performance of mechanical properties of Celtic Zenkari exudates/resins paste coated and non-coated reinforcing steel embedded in concrete members exposed to corrosive media. Weight loss results of non-coated steel showed higher percentage values against control and coated members. The cross-sectional reduction results showed percentages loss due to the impact of corrosion on the mechanical properties of steel.

Nelson et al. (2019) investigated the investigation of eco-friendly inorganic exudates/resins extracted from the bark of Invincia gabonensis, coated to reinforce steel with different thicknesses, and immersed in sodium chloride for corrosion testing in a 150-day rapid process. The overall results of the exudates/resins coating models showed no signs of corrosion potential, results indicated that Invincia gabonensis exudates/resins were good corrosion inhibitors. Cross-sectional area reduction results showed higher percentage reduction values as fiber loss was negative on the mechanical properties of steel as a result of corrosion potential. The results of the weight loss of steel showed a high percentage of values against the control and coating models due to the effect of corrosion on the mechanical properties of the steel.

Kanee et al. (2019) investigated reinforcing steel by introducing milicia excelsa exudates/resins to reduce the surface reinforcement and mechanical properties of steel-reinforced concrete structures in saltwater environments. The corrosion acceleration process was 150 days and the corrosion efficiency was determined. The corrosion properties of scattering and fractures in non-coating members indicate that the overall test results indicate a low flexibility failure load; The effect of corrosion has not been observed on the mechanical properties of reinforcing steel on corroded (constrained) members

Gregory et al. (2019) evaluate the modifications and mechanical properties of steel-reinforced coated with exudates/resins and non-coated members, exposed to corrosive media embedded in concrete members. High yields of corrosion patterns in non-coated materials have been shown by the impact of corrosion on the mechanical properties of steel reinforcement. Due to the impact of corrosion on the mechanical properties of steel, steel weight loss results showed higher percentage values against control and coating models.

MATERIALS AND METHODS FOR EXPERINMENT

Aggregates

Fine and coarse aggregate were purchased from dumpsites. Both met the requirements of BS 8821

Cement

Limestone cement grade 42.5 is used for all concrete mixes for this research. Cement met BS EN 196-6requirements

Water

Water samples were obtained from Civil Engineering Department Laboratory, Kenule Beeson Polytechnic, Bori, Rivers State. Water met BS 12390 requirements

Structural Steel reinforcement

Reinforcement directly purchased from the market in Port Harcourt BS4449: 2005 + A3

Corrosion Inhibitors (Resins / Exudates) Ficus sycomorus

The crude gum exudates were gotten from Bassawa village in Sabon - Gari Local Government Area of Kaduna State Nigeria at coordinates (Latitude: 11° 06' 60.00" N, Longitude: 7° 43' 59.99" E). The gum was collected from the tree barks by tapping.

METHODS

Sample Preparation for Reinforcement with Coated Exudates /Resins

The study investigated the application of Ficus sycomorus exudate/resin obtained from naturally occurring and extruded from the trunk of the tree and with eco-friendly and environmentally non-hazardous properties. Obtained exudate/resin was directly coated to reinforcing steel of varying coating thicknesses embedded in the concrete slabs and exposed to coastal marine areas with high salinity concentration. Naturally, corrosion manifestation in reinforcement, metals and related materials is a long-term process that takes years. However, the artificial introduction of sodium chloride (NaCl) speeds up the corrosion rate and manifestation occur in a short time.

The rate of corrosion values is calculated by estimating the current density that is gotten or obtained from the polarization curve and the quantification rate of corrosion level. Concrete mixes were batched by material weight with the manual mixing method using a standard concrete ratio of 1.2.4, and a water-cement ratio of 0.65. The concrete standard was obtained with the gradual addition of cement, aggregates (fine and coarse), and water to consistency color achievement. The concrete slab of 100mm x 500 x 500mm (thickness, width, and length) with a concrete cover of 10mm was cast into a metal mold, compacted to removed air, and reinforced with 10 numbers of 12mm diameter reinforcing steel spaced at 100mm c/c (top and bottom) and de-molded after 72 hours, cured for 28 days at standard room temperature to a hardened state. The hardened concrete slab was wholly immersed and a solution of 5% sodium chloride (NaCl) to water and accelerated for rapid corrosion process for 360 days on interval checks and routine testing at 90 days, 180 days, 270 day, and 360 days with reading and records documentation for comparisons.

Accelerated Corrosion Test

The process of corrosion is a natural phenomenon that takes decades to manifest, that's a long-term process, but the rapid and accelerated corrosion process of using artificial substances of sodium chloride (NaCl) allows the corrosion of reinforcing bars embedded in concrete, and can simulate the increase in corrosion that will occur over decades with a short period. To test the corrosion resistance of concrete, an experimental process must be designed that will speed up the corrosion process and maximize the corrosion resistance of the concrete. The accelerated corrosion test is an embossed current technique, an effective technique for examining the corrosion processes of steel in concrete and for assessing damage to the concrete cover. The laboratory acceleration process helps distinguish the role of individual factors that can influence chloride-induced corrosion. Therefore, for the design of structural elements and corrosion resistance, as well as for the selection of suitable materials and a suitable protective system, it is necessary to carry out accelerated corrosion tests to obtain both quantitative and qualitative information about 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, the concrete resistance measurement can be used to assess the degree of corrosion. However, care must be taken when using these data, as the corrosion rate is assumed to be constant over time. This has also been established through practical experience (Figg and Marsden [24], Gower and Millard (25). Half-potential measurement is an indirect method of estimating the likelihood of corrosion occurrence. However, recently there has been much interest in developing a tool to perform disturbing electrochemical measurements on the steel itself to obtain a direct estimate of the corrosion rate (Stem and Geary [27]).

Corrosion rates are related to electrochemical measurements, the first to be based on data.

Table 1: Dependence between potential and corrosion probability (ASTMC876-91, 1999.)

Potential E_{corr}	**Probability of Corrosion**
Ecorr < −350mV	Greater than 90% probability that reinforcing steel corrosion is occurring in that area at the time of measurement
−350mV ≤ 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 of measurement (10% risk of corrosion

Test for Measuring the Resistance of Concrete

Different readings are made at different points on the concrete surface. After the water has been applied to the slab surface, the resistance of the concrete is measured daily at the reference point to determine its saturation state. This location was chosen on the side of the panel because special electrical resistance measurements can be made with water on top of the panel. The means of reading were recorded as the final reading of resistance in the study. The level of slab saturation is monitored by measuring the electrical resistance 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 from it while the other plate remains closed. The time limit is a major challenge for all experimental measurements as the saturation state of the concrete changes over time. This research used the Wenner method with four probes; for this purpose, the four probes are touched directly to the concrete on the reinforcing steel rail. 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 resistance becomes constant as soon as the concrete reaches saturation.

Table 2: Dependence between Concrete Resistivity and Corrosion Probability (ASTM Standard C876, 2012)

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

Tensile Strength of Reinforcement Bars

To determine the yield and tensile strength of the bar, the reinforced, non-coated, and reinforced steel strip with a diameter of 12 mm was tested under stress in the Universal Test Machine (UTM) and subjected to direct stress until failure load is recorded. To ensure stability, the remaining cut pieces were used in subsequent bonding testing.

RESULTS OF TESTING AND DISCUSSION

The results of the half-cell potential measurements in Table 2.1 are plotted against the resistivity in Table 2.2 for easier interpretation. 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 *E*corr is high (–350 mV ≤ E_{corr} ≤ –200 mV), which indicates a corrosion probability of 10% or uncertain. The results of concrete resistance measurements are shown in Table 2.1. It is evident that when the corrosion potential is low (<-350 mV) within a certain range, this represents a 95% chance of corrosion. Concrete resistance is usually measured using the four-electrode method. Data from resistance studies indicate whether specific circumstances are favorable for less ionic movement leading to greater corrosion.

Table 3: Potential Ecorr, after 28 days curing and 360 days Accelerated Periods of Control Concrete slab Specimens

Sample Numbers	FSS	FSS1	FSS2	FSS3	FSS4	FSS5	FSS6	FSS7	FSS8	FSS9	FSS10	FSS11
	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	-116.79	-109.96	-105.70	-104.29	-106.71	-103.68	-112.13	-107.81	-103.35	-105.67	-109.65	-110.82
Concrete Resistivity ρ, kΩcm	17.52	17.52	17.51	17.51	17.50	17.66	17.66	17.65	17.65	17.64	17.58	17.50
Yield Strength, fy (MPa)	456.13	453.13	456.13	456.43	455.13	454.36	457.36	457.66	456.36	457.75	454.26	458.10
Ultimate Tensile Strength, fu (MPa)	630.47	625.42	617.10	622.88	626.41	616.83	616.63	617.43	616.03	628.58	621.08	621.94
Strain Ratio	1.38	1.38	1.35	1.36	1.38	1.36	1.35	1.35	1.35	1.37	1.37	1.36
Rebar Diameter Before Test(mm)	11.95	11.93	11.94	11.96	11.93	11.95	11.95	11.93	11.93	11.93	11.93	11.94
Rebar Diameter at 28 days(mm)	11.95	11.93	11.94	11.96	11.93	11.95	11.95	11.93	11.93	11.93	11.93	11.92
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01
Rebar Weights- Before Test	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.80	0.79	0.79	0.79	0.79
Rebar Weights- After at 28 days (Kg)	0.79	0.79	0.80	0.79	0.80	0.80	0.80	0.80	0.80	0.79	0.79	0.79
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 4: Potential Ecorr, after 28 days curing and 360 days 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	-325.65	-338.85	-325.75	-364.85	-374.65	-381.65	-415.55	-422.75	-426.85	-408.55	-415.75	-422.01
Concrete Resistivity ρ, kΩcm	**6.96**	**7.09**	**7.93**	**8.23**	**8.41**	**7.57**	**7.39**	**9.74**	**9.78**	**7.38**	**6.75**	**7.56**
Yield Strength, fy (MPa)	422.69	419.69	422.69	422.99	421.69	420.92	423.92	424.22	422.92	424.31	420.82	424.65
Ultimate Tensile Strength, fu (MPa)	600.30	595.25	586.93	592.71	596.24	586.66	586.46	587.26	585.86	598.41	590.91	591.77
Strain Ratio	1.42	1.42	1.39	1.40	1.41	1.39	1.38	1.38	1.39	1.41	1.40	1.39
Rebar Diameter Before Test(mm)	11.94	11.94	11.94	11.95	11.95	11.95	11.95	11.94	11.94	11.94	11.93	11.94
Rebar Diameter- After Corrosion(mm)	11.89	11.89	11.89	11.90	11.91	11.90	11.90	11.89	11.89	11.89	11.89	11.89
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Rebar Weights- Before Test (Kg)	0.79	0.79	0.79	0.78	0.79	0.79	0.78	0.79	0.79	0.79	0.79	0.79
Rebar Weights- After Corrosion (Kg)	0.72	0.72	0.72	0.72	0.72	0.72	0.71	0.72	0.72	0.72	0.72	0.72
Weight Loss /Gain of Steel (Kg)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07

Table 5: Potential Ecorr, after 28 days curing and 360days Accelerated Periods of Ficus sycomorus 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	-128.32	-119.66	-123.26	-125.23	-115.63	-119.74	-117.92	-121.69	-118.29	-112.90	-113.37	-119.59
Concrete Resistivity ρ, kΩcm	17.24	17.39	17.67	17.80	17.49	17.78	17.73	17.88	17.91	17.38	17.27	17.12
Yield Strength, fy (MPa)	456.18	453.18	456.18	456.48	455.18	454.41	457.41	457.71	456.41	457.80	454.31	458.14
Ultimate Tensile Strength, fu (MPa)	629.23	624.18	615.86	621.64	625.17	615.59	615.39	616.19	614.79	627.34	619.84	620.70
Strain Ratio	1.38	1.38	1.35	1.36	1.37	1.35	1.35	1.35	1.35	1.37	1.36	1.35
Rebar Diameter Before Test(mm)	11.94	11.92	11.93	11.93	11.93	11.94	11.92	11.95	11.81	11.99	11.89	11.93
Rebar Diameter - After Corrosion(mm)	12.00	11.98	11.99	11.99	11.99	12.00	11.98	12.01	11.87	12.05	11.95	11.99
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Rebar Weights- Before Test (Kg)	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.80	0.79	0.79	0.79	0.79
Rebar Weights- After Corrosion (Kg)	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Weight Loss /Gain of Steel (Kg)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09

Table 6: Average Potential Ecorr, after 28 days curing and 360 days Accelerated Periods (Control, Corroded and Exudate/Resin Coated) (specimens)

Sampling and Durations	Control Concrete slab Specimens				Corroded Concrete slab Specimens				Ficus sycomorus 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 Ficus sycomorus Coated Specimens			
Potential Ecorr,mV	-110.82	-104.89	-107.76	-108.71	-330.08	-373.71	-421.71	-415.43	-123.75	-120.20	-119.30	-115.28
Concrete Resistivity ρ, kΩcm	17.52	17.56	17.65	17.57	7.33	8.07	8.97	7.23	17.43	17.69	17.84	17.26
Yield Strength, fy (MPa)	455.13	455.31	457.13	456.70	421.69	421.87	423.69	423.26	455.18	455.35	457.17	456.75
Ultimate Tensile Strength, fu (MPa)	624.33	622.04	616.69	623.86	594.16	591.87	586.52	593.69	623.09	620.80	615.46	622.63
Strain Ratio	1.37	1.37	1.35	1.37	1.41	1.40	1.38	1.40	1.37	1.36	1.35	1.36
Rebar Diameter Before Test(mm)	11.94	11.94	11.93	11.93	11.94	11.95	11.94	11.94	11.93	11.93	11.89	11.93
Rebar Diameter- After Corrosion(mm)	11.94	11.95	11.94	11.93	11.89	11.90	11.90	11.89	11.99	11.99	11.95	12.00
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.07	0.06	0.06	0.06	0.06
Rebar Weights- Before Test(Kg)	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Rebar Weights- After Corrosion(Kg)	0.80	0.80	0.80	0.79	0.72	0.72	0.72	0.72	0.88	0.88	0.88	0.88
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	0.07	0.07	0.07	0.07	0.09	0.09	0.09	0.09

Table 7: 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				Ficus sycomorus 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 Ficus sycomorus Coated Specimens			
Potential Ecorr,mV	-66.43	-71.93	-74.45	-73.83	166.73	210.91	253.48	260.36	-62.51	-67.84	-71.71	-72.25
Concrete Resistivity ρ, kΩcm	139.12	117.57	116.87	143.14	-57.98	-54.39	-49.75	-58.12	137.97	119.25	118.99	138.80
Yield Strength, fy (MPa)	7.93	7.93	7.89	7.90	-7.36	-7.35	-7.32	-7.33	7.94	7.94	7.90	7.91
Ultimate strength (N/mm2)	5.08	5.10	5.14	5.08	-4.64	-4.66	-4.70	-4.65	4.87	4.89	4.93	4.87
Strain Ratio	-2.63	-2.64	-2.53	-2.64	2.92	2.94	2.82	2.94	-2.84	-2.85	-2.75	-2.85
Rebar Diameter Before Test(mm)	0.443	0.438	0.441	0.441	0.444	0.440	0.443	0.439	0.441	0.439	0.443	0.439
Rebar Diameter- After Corrosion(mm)	0.443	0.438	0.441	0.441	-0.845	-0.765	-0.849	-0.876	0.812	0.776	0.798	0.844
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-28.57	-28.57	-28.57	-28.57	40.00	40.00	40.00	40.00
Rebar Weights- Before Test(Kg)	6.555	6.433	6.517	6.259	6.435	6.438	6.436	6.435	6.453	6.756	6.454	6.553
Rebar Weights- After Corrosion(Kg)	10.42	10.88	11.17	10.45	-18.28	-18.62	-18.82	-18.41	22.36	22.87	23.18	22.56
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	-20.69	-20.69	-20.69	-20.69	26.09	26.09	26.09	26.09

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

The results of Potential E_{corr},mV and Concrete Resistivity ρ, kΩcm as obtained from tables 3.1 – 3.3 and summarized to average and percentile values in table 3.4 and 3.5, graphically plotted in figures 3.1-3.8b are the results of controlled, non-coated (corroded) and coated samples for 36 concrete slabs, subdivided into 3 sets of 12 controlled samples which is the reference range of determinants', 12 non-coated (corroded) samples and 12 exudates/resin coated samples.

The minimum, maximum and differential average and percentile values of computed half-cell potential measurements of controlled samples are -110.82 mV and -104.89 mV (-74.45% and -66.43%) with potential difference of (5.93mV and 8.02%), the corroded samples are -421.71mV and -330.08mV (166.73% and 260.36%) and differential values of 91.63 mV and 93.63% and coated samples are -123.75mV and -120.456mV (-72.25% and -69.312%) and potential difference are 3.294mV and 2.938%. The maximum computed percentile controlled value is -66.43% against corroded and coated values of 260.36% and -69.312% and differential potential value of controlled 8.02%, corroded 93.63%, and coated 2.938%. The obtained maximum results of controlled and coated samples are -104.89 mV and -120.456 mV which showed dependence between potential and corrosion probability as $E_{corr} > -200$mV as the reference range. These results of potential E_{corr} results showed indication that the values of controlled and exudates/ resin coated specimens are low with the range of 90% probability that no reinforcing steel corrosion is occurring in that area at the time of measurement (10% risk of corrosion which indicates a 10% or uncertain probability of corrosion. For the non-coated sample, the maximum obtained computed value is -330.08 mV, the results are within the range reference of dependence between potential and corrosion probability of the value $-350\text{mV} \leq E_{\text{corr}} \leq -200\text{mV}$ indicating a high range of values, notifying a 10% or uncertain probability corrosion. The comparative results from the referencing range (controlled), showed that corroded samples exhibited corrosion presence resulting from the induced corrosion acceleration against coated samples that exhibited absence of corrosion. The exudates/resins exhibited inhibitory characteristics against corrosion attacks on reinforcing steel embedded in the concrete slab, exposed to corrosive media by the formation of the resistive coating.

The concrete resistivity minimum and maximum average and percentile values with potential differences of controlled samples are 17.52kΩcm and 17.65 kΩcm (116.87% and 143.14%) and differential values of 0.13 kΩcm and 26.27%. The corroded samples are 7.23kΩcm and 8.97kΩcm (-58.12% and -49.75%) and differential values of 1.74 kΩcm and 8.37%. the coated sample vales are 17.26 kΩcm and 17.496 kΩcm (118.99% and 126.8%) and differential values of 0.236mV and 7.81%. The maximum computed concrete resistivity percentile value of the controlled sample is 143.14%, against corroded and coated values of -49.75% and 126.8%, and the maximum differential percentile value of controlled is 26.27% against corroded and coated values of 8.37% and 27.81%. The results of controlled and coated samples of concrete resistivity obtained at the maximum average are 17.65 kΩcm and 17.496 kΩcm with value indications of $10 < \rho < 20$ (low) against the corroded value of 8.97kΩcm with an indication of $5 < \rho < 10$ (high) and with a reference range of dependence between concrete resistivity and corrosion probability of likelihood of significant corrosion ($\rho < 5$, $5 < \rho < 10$, $10 < \rho < 20$, $\rho > 20$) for very high, high, low to moderate and low, for the probability of corrosion. From the comparative results obtained of coated and corroded samples, the maximum obtained values of both samples clearly showed the coated sample value is with the ranges of exhibited $10 < \rho$

< 20 which classified the value range as Low to moderate, with the indication as the likelihood of significant corrosion. The corroded sample maximum value is within the range of $5 < \rho < 10$ indicating high, the signs showed the presence of corrosion probability 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 evaluated from the obtained results in comparison that the effect of corrosion attack was noticed in non-coated samples while exudates/resin coated samples exhibited anti-corrosive properties with high resistive and waterproofing membrane that prevented the entrance of corrosion on the reinforcing steel embedded in the concrete slab and exposed to induced accelerated corrosion media.

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

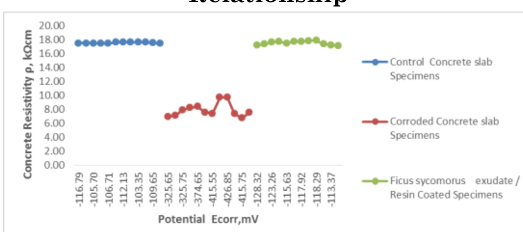


Figure 3.1A: Average Concrete Resistivity versus Potential Relationship

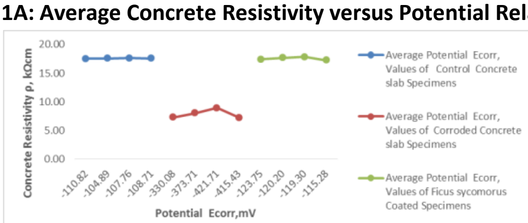
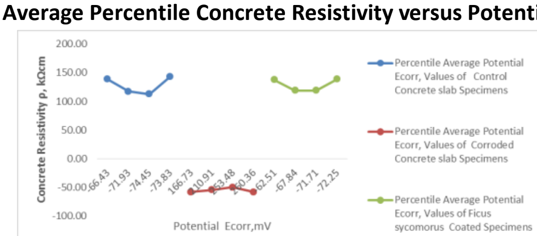


Figure 3.1B : Average Percentile Concrete Resistivity versus Potential Relationship



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

The results of the average, percentile, and differential values of minimum and maximum yield strength, fy (MPa) of controlled samples are 455.13MPa and 457.13MPa (7.89% and 7.93%) and the differential values are 2MPa and 2%, the corroded samples are 421.69Mpa and 423.69Mpa (-7.36% and -7.32%) and differential values of 2MPa and 0.04%, the coated sample values are 455.18MPa and 455.926MPa (7.9% and 7.918%) and differential values of 2MPa and 1.985%. The maximum computed percentile values of yield strength of controlled are 7.93% against corrode and coated values -7.32% and 7.918% respectively and the potential differential values of 2% controlled, 0.04% corroded and 1.985% coated. The average, percentile and differential values of minimum and maximum ultimate tensile strength, fu (MPa) of controlled samples are 616.69MPa and 624.33MPa (5.08% and 5.14%) and differential values of 7.64MPa and 0.06%, the corroded are 586.52MPa and 594.16MPa (-4.7MPa and -4.64%) 7.64MPa and 0.06%, the coated are 615.46MPa and 619.488MPa (4.87% and 4.886%) and differential values are 4.028MPa and 0.16%. The maximum computed percentile values of ultimate tensile strength of controlled are 5.14% against corrode and coated values -4.64% and 4.886% respectively and the potential differential values of 0.16% controlled, 0.06% corroded, and 0.16% coated.

The strain ratio minimum and maximum average, percentile and differential values of controlled samples are 1.35 and 1.37 (-2.64% and -2.53%) with differential values of 0.02 and 0.011%, the corroded sample values are 1.38 and 1.41(2.82% and 2.94%) and differential values of 0.03 and 0.12%, the coated samples are 1.35 and 1.36 (-2.85% and -2.83%) and differential values of 0.008 and 0.012%. The maximum computed percentile values for comparison are controlled -2.53% against corroded 2.94% and coated -2.83%n and the differential peak values are controlled 0.011%, corroded 0.12%, and coated 0.012% 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).

From the computed obtained results summarized in tables 3.4 and 3.5 and presented graphically in figures 3.1 – 3.8, of yield strength, ultimate tensile strength, and strain ratio of the average, percentile, and differential potential values of the controlled, non-coated(corroded), and coated concrete slab samples, the coated samples recorded higher failure load over corroded samples with decreased failure load and low load carrying capacity and having average and percentile values to the reference range while the non-coated (corroded) recorded low carry capacity and decreased values as compared to the reference ranges. The comparative results showed that the low load-carrying capacity was attributed to the effect of corrosion attacks on the non-coated (corroded) members that affected the reinforcing steel fibre, ribs, and formation of passivity and surface modification. The coated samples maintained values in both at average was attributed to the resistive potential to corrosion entrance into the reinforcing steel with the formation of protective membrane, these attributes showed the effectiveness and the efficiency of exudates/resin as an inhibitive material against corrosion effect of reinforced concrete structures exposed to the severe coastal marine regions with high salinity.

Figure 3.2 : Yield Strength versus Ultimate strength

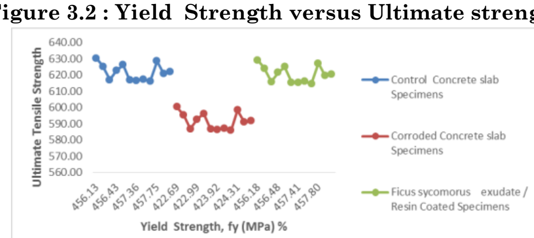


Figure 3.2A: Average Yield Strength versus Ultimate Tensile Strength

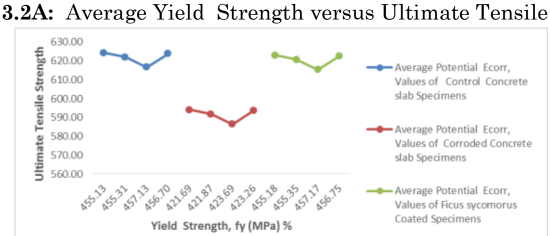


Figure 3.2B: Average Percentile Yield Strength versus Ultimate Tensile Strength

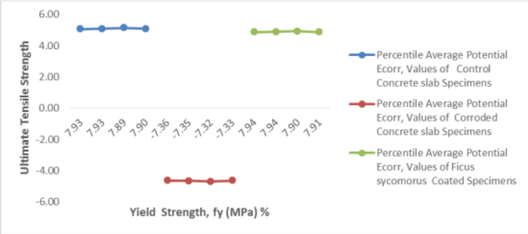


Figure 3.3: Ultimate Tensile Strength versus Strain Ratio

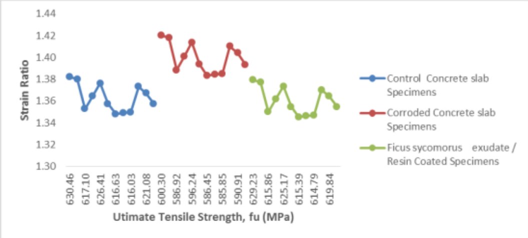


Figure 3.3A: Average Ultimate Tensile Strength versus Strain Ratio

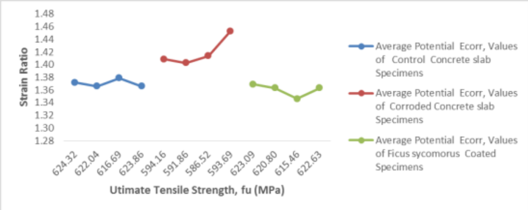
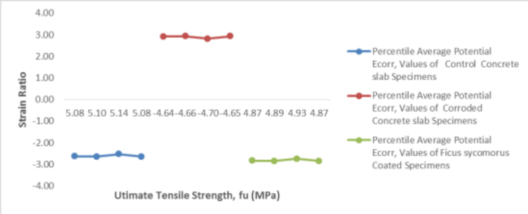


Figure 3.3B: Average percentile Ultimate Tensile Strength versus Strain Ratio



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 11.93mm and 11.94mm (0.297% and 0.306%) with differential values of 0.01mm and 0.009%, the corroded sample values are 11.94mm and 11.95mm (0.296% and 0.304%) and differential values of 0.01mm and 0.008% and the coated sample values are 11.89mm and 11.914mm (0.296% and 0.2966mm and differentially computed values of 0.024mm and 0.006%. 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 11.93mm and 11.94mm (0.297% and 0.306%), having 100% maintained reference value, the corroded sample values are 11.89mm and 11.90mm (-0.87% and -0.49%) and differentials of 0.01mm and 0.38%, the coated samples d values are 11.95mm and 11.976mm (0.77% and 0.796%) and differentials of 0.026mm and 0.026%. The maximum computed percentile values are controlled 0.306% against corroded -0.49% and coated 0.796%, the percentile difference is corroded 0.38% against 0.026%. 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 0.796% to -0.49% and average ranges values from 11.94mm to 11.89mm. 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 0.05mm and 0.05mm(-28.57% and -28.57%) and differentials of % at corroded, the coated sample values are 0.06mm and 0.06mm (40% and 40%) and differentials of 0%. The comparatively average and percentile value differences between coated and corroded samples are with the ranges of 40% to -28.57%. 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 0.79kg and 0.79kg (6.259% and 6.555%) and differentials are 0% and 0.296%, the corroded sample are 0.79kg and 0.79kg (6.435% and 6.438%) and differentials of 0% and 0.0301%, the coated samples are 0.79kg and 0.79kg (6.453% and 6.5338%) with differentials of 0% and 0.289%. 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 0.79kg and 0.79kg (10.42% and 11.17%) and differential values of 0.01% and 0.75, the corroded samples are 0.72Kg and 0.72Kg (-18.82% and -18.28%) and differentials of 0% and 0.54%, the coated sample values are 0.88kg and 0.88kg (22.36% and 22.666%) and differentials of 0% and 0.306%. 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 0.07kg and 0.07kg (-20.69% and -20.69%) and the coated are 0.09kg and 0.09kg (26.09% and 26.09%). The computed results obtained from tables 3.1-3.3 and summarized in 3.4 - 3.5, and graphically plotted in figures 3.7-3.8B 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 0.88kg to

0.72Kg and 22.666% to -18.28% corroded, 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). 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.

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

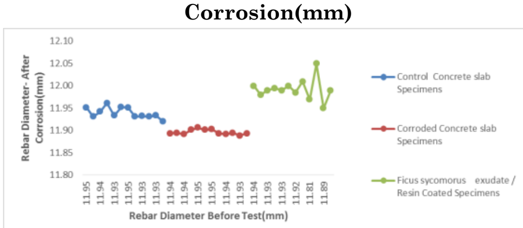


Figure 3.4A: Average Rebar Diameter Before Test(mm) versus Rebar Diameter-After Corrosion(mm)

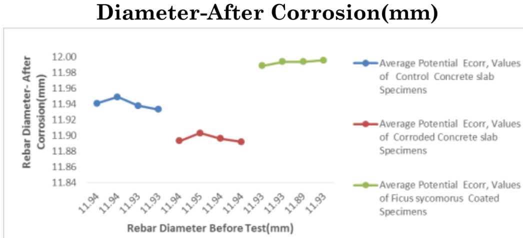


Figure 3.4B: Average Percentile Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

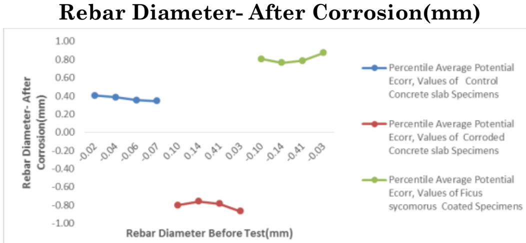


Figure 3.5: Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

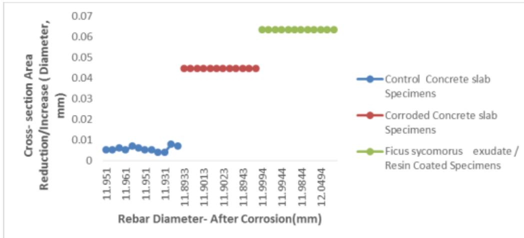


Figure 3.5A: Average Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

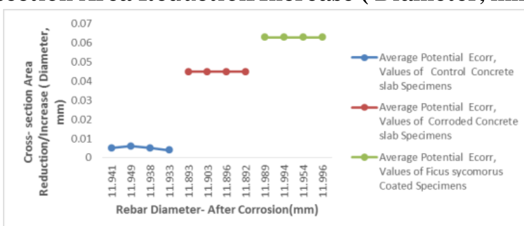


Figure 3.5B: Average Percentile Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

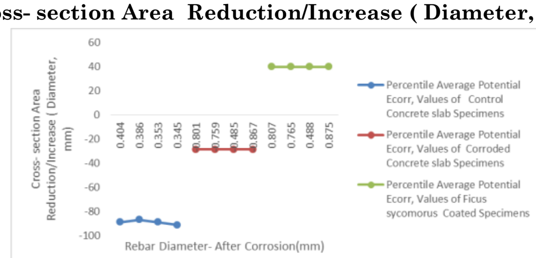


Figure 3.6: Rebar Weights- Before Test(Kg) versus Rebar Weights- After Corrosion(Kg)

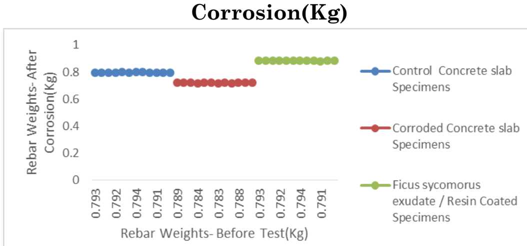


Figure 3.6A: Average Rebar Weights- Before Test(Kg) versus Rebar Weights- After Corrosion(Kg)

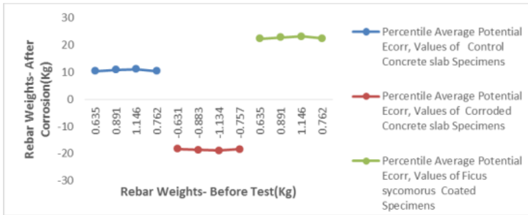


Figure 3.6B: Average Percentile Rebar Weights- Before Test(Kg) versus Rebar Weights- After Corrosion(Kg)

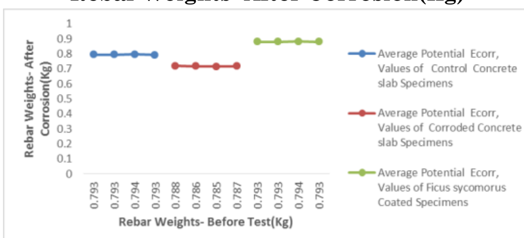


Figure 3.7: Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

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

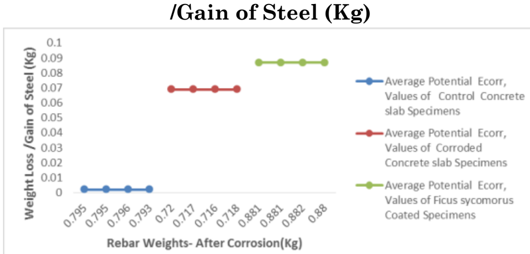
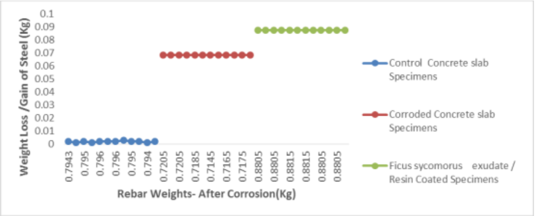


Figure 3.7B: Average Percentile Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)



4.0 CONCLUSION

Experimental results showed the following conclusions:

i. Coated reinforcing steel showed no indications of corrosion presence
ii. Ficus sycomorus 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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