Non-coated and Coated Reinforcement in Concrete Corrosion Probability Measurement in Accelerated Environment by Wenner Method

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ABSTRACT

The researched work investigated the corrosion rate of embedded reinforcing steel in concrete slab structures immersed in an unfriendly environment and accelerated using Wenner four probe methods. Half cell potential, concrete resistivity measurement, tensile strength tests were performed to assessed corrosion potential levels and the mechanical properties of weight loss and cross- section area reduction of embedded steel. Slab with control, corroded and exudates/resin coated specimens of 150μm, 300μm, 450μm were examined. Results of Potential E_{corr},mV summed up to -349.239mV, with percentile value of 334.4169% and percentile difference 234.4169% against -70.0972% and -69.4102% of control and coated specimens. Concrete resistivity ρ, kΩcm summed up value is 7.449056kΩcm with percentile averaged value 55.79362% and percentile difference -44.2064% against 79.23197% and 103.2465% of control and coated specimens. Mechanical properties "ultimate strength" of corroded specimens are summed up to 591.2439N/mm^2, with percentile average value 108.2885% and percentile difference 8.28852% against -7.65411% and -3.01205% of control and coated specimens. Weight loss of steel corroded specimens summed up to 12.77411grams with percentile average value 177.5881% and percentile difference 77.58812% against -43.6899% and -44.4871% of control and coated specimens. Cross- section area reduction" of corroded summed up to 10.60111mm with percentile average value 88.34259% and percentile difference -11.6574% against 13.19568 % and 13.19568%. Summarized results showed that the range of values of corroded specimens showed indication 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 Probability of corrosion. Results showed high ultimate yielding of corroded specimens to control and coated specimens due to the effect of corrosion on the mechanical properties of the steel reinforcement. Results of weight loss of steel showed higher percentile values against control and coated specimens due to the effect of corrosion on the mechanical properties of steel. Cross- section area reduction results showed higher percentile reduction values due to effect of corrosion on the mechanical properties of steel.

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

I. INTRODUCTION

Embedded steel reinforcement in reinforced concrete structures can lead to untimely collapse and failure of many structures built and exposed to unfriendly severe harsh environment of the marine coastal regions. Chloride ingress from the environment can be due to seawater entering the concrete structure, ground water with high chloride concentration and deicing salts. These include diffusion which is movement of substance due to a concentration gradient, permeation which is the flow of liquid in concrete due to pressure, capillary absorption which is the transport of liquid into porous non-saturated concrete due to surface tension forces, and migration which is the transport of ions in an electrolyte due to an electrical potential gradient (Mangat and Limbachiya, 1999, Erdogdu *et al*. 2004). Scully (1975) suggested a range of ±5mV to ±10mV to be normally used, but Trethwey and Chamberlain (1995) used ±30mV. Andrade and Alonso (2001) have claimed that using B =26mV had a maximum error factor of 2 when determining the corrosion rate. Song (2000) suggested that B value for steel in concrete might range from as low as 8mV to approaching infinity under different conditions.

Gouda *et al*. (1970)investigated the corrosion in reinforced slag cement concrete containing 0-5% $CaCl_2$ using a LRP technique. They reported that the calculated corrosion rate was in the range of 0.05 to 0.34mpy. Locke and Simon (1980) was found for steel in concrete mixed with 0 to 1% NaCl by total weight of concrete, the estimated corrosion rate of embedded steel based on LRP was in the range of 0.03 to 0.52mpy. Wheat and Eliezer (1985) carried out potentiodynamic polarization measurements in potential ranging from -250mV to 1200mV (based on SCE) at a scan rate of 1mV/s with concrete specimens (w/c = 0.52) immersed in 10% NaCl solution for 30 and 150 days. They reported that the corrosion rate varied from 0.04mpy for 30 day to 3mpy for 150 days.

Charles et al (2018) 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 incremental values of 70.1% against 27.2% non-corroded of potential and 87.8% to 38.8% decremented values in concrete resistivity, yield stress against ultimate strength at summary and average state of corroded slab with nominal values of 100% and decremented in ultimate strength from 100.68% to 96.12%, weight loss versus cross-section diameter reduction decremented due to assail from sodium chloride from 67.1% to 48.5% and 98.2% to 94.82% respectively. Average percentile results of potential and concrete resistivity are 29.9% and 63.6% respectively. When compared to corroded samples, corroded has 70.1% incremented values potential Ecorr,mV and 38.8% decremented values of concrete resistivity, yield stress against ultimate vigor at in comparison to corrode as 100% nominal yield stress decremented from 103.06% to 96.12% and weight loss at 67.5% against 48.5% and 47.80% to 94.82% cross-sectional diameter reduction, both showed decremented values of corroded compared to coated specimens.

Charles et al (2018) investigated the corrosion potential, concrete resistivity and tensile tests of non-corroded, corroded and coated reinforcing steel of concrete slab member. Results recorded of potential Ecorr,mV, and concrete resistivity for non- inhibited concrete specimens on the mapping areas for the accelerated periods of 7days to 119 days after 28 days initial curing, indicated 95% probability of corrosion and indicating a high or moderate probability of corrosion. Average results on comparison showed an increase of 70.1% against 27.2% non-corroded of Potential Ecorr, mV and 87.8% to 38.8%, 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 from 100.68% to 96.12%, weight loss versus cross-section diameter reduction decreased due to attack from sodium chloride from 67.1% to 48.5% and 98.2% to 94.82% respectively. When compared to

corroded samples, corroded has 70.1% increased values potential and 38.8% decreased values of concrete resistivity, yield stress against ultimate strength at in comparison to corrode as 100% nominal yield stress decreased from 100.95% to 96.12% and figures 3.5 and 3.6 respectively presented weight loss at 67.5% against 48.5% and 98.7% to 94.82%, cross-sectional diameter reduction, both showed decreased values of corroded compared to coated specimens. The entire results showed effectiveness in the use of dacroyodes edulis as inhitors, it sustained and preserved the reinforcement against environmental attack.

Charles et al (2018) investigated the effects of chloride attack on reinforcing steel embedded in reinforced concrete structures built in the marine environment. Results recorded of half cell potential, concrete resistivity and tensile strength properties for non- inhibited concrete specimens on the mapping areas for the expedited periods designated 95% probability of corrosion and indicating a high or moderate probability of corrosion. Results recorded of potential E_{corr},mV, concrete resistivity and tensile strength of Acardium occidentale l. inhibited specimen, indicated a 10% or uncertain probability of corrosion which indicates no corrosion presence or likelihood and concrete resistivity indicated a low probability of corrosion or no corrosion indication. Average percentile results of potential E_{corr},mV, and concrete resistivity are 27.45% and 68.45% respectively. When compared to corroded samples, corroded has 75.4% increased values potential E_{corr},mV and 33.54% decreased values of concrete resistivity, yield stress against ultimate strength at in comparison to corrode as 100% nominal yield stress decremented from 108.38% to 90.25% respectively, weight loss at 69.3% against 43.98% and 51.45% to 89.25%, cross-sectional diameter reduction, both showed decreased values of corroded compared to coated specimens.

Charles et al (2018) investigated corrosion level probability assessment potential through half cell potential corrosion measurement, concrete resistivity test and tensile strength test mechanical properties of non-corroded, corroded and inhibited reinforcement with Oleifera lam resin paste of trees extract. Average percentile results of potential E_{corr},mV, and concrete resistivity are 29.9% and 68.74% respectively. When compared to corroded samples, corroded has 70.1% increased values potential E_{corr},mV and 35.5% decreased values of concrete resistivity. Results of computed percentile average values of yield stress against ultimate strength, when compared to corrode as 100% nominal yield stress decremented from 105.75 % to 96.12% and weight loss at 67.5% against 48.5% and 48.34% to 94.82%, cross-sectional diameter reduction, both showed decreased values of corroded compared to coated specimens.

Charles et al (2018) investigated the use of inorganic inhibitors and Greener approach inhibitors to evaluate the assessment of corrosion potential using Mangifera indica resins paste extracts layered to reinforcing steel with coated thicknesses of 150μm, 250μm and 350μm. Average percentile results of potential E_{corr},mV, and concrete resistivity are 26.57% and 61.25% respectively. When compared to corroded samples, corroded has 70.1% increased values potential E_{corr},mV and 38.8% decreased values of concrete resistivity, yield stress against ultimate strength at summary and average state of corroded slab with nominal values of 100% and decremented in ultimate strength from 105.36% to 96.12%, weight loss versus cross-section diameter reduction decreased due to attack from sodium chloride from 64.8% to 44.45% and 46.76% to 86.43% respectively.

Charles et al (2018) investigated corrosion probability level assessments of three different resins extracts of trees from dacryodes edulis, mangifera indica and moringa oleifera lam using half cell potential corrosion measurement, concrete resistivity measurement and tensile strength test to ascertain the surface condition of the mechanical properties of non-corroded, corroded and inhibited reinforcement. Average percentile results of potential E_{corr},mV, and concrete resistivity are dacryodes edulis 29.9% and 63.6% , mangifera indica

26.57% and 61.25% and moringa oeifera lam 29.9% and 68.74% respectively. Arbitrarily and computed percentile average values of yield stress against ultimate strength, when compared to corrode as 100% nominal yield stress decreased from100.95% to 96.12% dacryodes edulis inhibited, 105.36% to 96.12% mangifera indica inhibited, and 105.75 % to 96.12% moringa oleifera lam inhibited and weight loss of dacryodes edulis inhibited are 67.5% against 48.5% and 98.7% to 94.82%, cross-sectional diameter reduction, mangifera indica inhibited specimen 64.8% to 44.45% and 46.76% to 86.43% cross-sectional diameter reduction and moringa oleifera lam inhibited specimen 67.5% against 48.5% and 48.34% to 94.82%, cross-sectional diameter reduction, all showed decreased values of corroded compared to coated specimens.

Charles et al (2018) examined the effectiveness in the utilization of three eco-friendly inorganic inhibitors tree extract exudates / resins of Symphonia globulifera linn, Ficus glumosa and Acardium occidentale l. Non-inhibited and inhibited reinforcements with exudates / resins. When compared to corroded samples, corroded has 70.1% incremented values potential Ecorr,mV and 38.8% decremented values of concrete resistivity. 69.3% against 43.98% and 51.45% to 89.25%, cross-sectional diameter reductions, both showed decremented values of corroded compared to coated specimens. Results recorded of potential Ecorr,mV, .concrete resistivity and tensile strength of symphonia globulifera linn, ficus glumosa and acardium occidentale l inhibited specimen, the results indicated a 10% or dubious probability of corrosion which denotes no corrosion presence or likelihood and concrete resistivity designated a low probability of corrosion or no corrosion denotement. General and compute percentile average values of yield stress against ultimate strength at in comparison to corrode as 100% nominal yield stress decremented ultimate strength from 103.06% to 96.12% , 112.48% to 89.25%, and 108.38% to 90.25% of Symphonia globulifera linn, Ficus glumosa and Acardium occidentale l respectively, weight loss at of corroded against inhibited Symphonia globulifera linn specimens at 67.5% against 48.5% and 47.80% to 94.82%, inhibited Ficus glumosa 69.5% to 47.29%, 48.95% to 77.89% and inhibited acardium occidentale l. Average percentile results of potential Ecorr,mV, and concrete resistivity for Symphonia globulifera linn, Ficus glumosa and acardium occidentale l are 29.9% and 63.6% , 23.75% and 66.48% and 27.45% and 68.45% respectively.

II. MATERIALS AND METHODS FOR EXPERIMENT

2.1.1 Aggregates
The fine aggregate and coarse aggregate were purchased. Both met the requirements of BS 882

2.1.2 Cement
Portland limestone cement grade 42.5 is the most and commonly type of cement in Nigerian Market. It was used for all concrete mixes in this investigation. The cement met the requirements of BS EN 196-6

2.1.3 Water
The water samples were clean and free from impurities. The fresh water used was gotten from the tap at the Civil Engineering Department Laboratory, Kenule Beeson Polytechnic, Bori, and Rivers State. The water met the requirements of BS 3148

2.1.4 Structural Steel Reinforcement
The reinforcements are gotten directly from the market in Port Harcourt. BS 4449:2005+A3

2.1.5 Corrosion Inhibitors (Resins / Exudates) Artocarpus altilis exudates
The study inhibitor is Artocarpus altilis exudate of natural tree resins /exudates substance extracts.

2.2 Experimental Procedures
2.2.1 Experimental method
2.2.2 Sample preparation for reinforcement with coated resin/exudates

The corrosion rates were quantified predicated on current density obtained from the polarization curve and the corrosion rate quantification set-up. Fresh concrete mix batch were fully compacted to remove trapped air, with concrete cover of 15mm and projection of 150mm for half cell potential measurement and concrete resistivity tests. The polarization curve was obtained as the relationship between corrosion potential and current density. The samples were designed with sets of reinforced concrete slab of 150mm thick x 350mm width x 900mm long, uncoated and coated specimens of above thicknesses were embedded into the concrete, spaced at 150mm apart. The corrosion cell consisted of a saturated calomel reference electrode (SCE), counter electrode (graphite rod) and the reinforcing steel embedded in concrete specimen acted as the working electrode. Slabs were demoulded after 72 hours and cured for 28 days with room temperature and corrosion acceleration ponding process with Sodium Chloride lasted for 150days with 14 days checked intervals for readings. Mix ratio of 1:2:3 by weight of concrete, water cement ratio of 0.65, and manual mixing was adopted

2.3 Accelerated Corrosion Test

The accelerated corrosion test allows the acceleration of corrosion to reinforcing steel embedded in concrete and can simulate corrosion growth that would occur over decades. In order to test concrete resistivity and durability against corrosion, it was necessary to design an experiment that would accelerate the corrosion process and maximize the concrete's resistance against corrosion until failure. An accelerated corrosion test is the impressed current technique which is an effective technique to investigate the corrosion process of steel in concrete and to assess the damage on the concrete cover. A laboratory acceleration process helps to distinguish the roles of individual factors that could affect chloride induced corrosion. Therefore, for design of structural members and durability against corrosion as well as selection of suitable material and appropriate protective systems, it is useful to perform accelerated corrosion tests for obtaining quantitative and qualitative information on corrosion.

2.4 Corrosion Current Measurements (Half-cell potential measurements)

Classifications of the severity of rebar corrosion rates are presented in Table 2.1. If the potential measurements indicate that there is a high probability of active corrosion, concrete resistivity measurement can be subsequently used to estimate the rate of corrosion. However, caution needs to be exercised in using data of this nature, since constant corrosion rates with time are assumed.

Table 2.1: Dependence between potential and corrosion probability

Potential E_{corr}	Probability of corrosion
$E_{corr} < -350mV$	Greater than 90% probability that reinforcing steel corrosion is occurring in that area at the time of measurement
$-350mV \leq E_{corr} \leq -200mV$	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

This was also stated from practical experience (Figg and Marsden, 1985 and Langford and Broomfield ,1987). Half-cell potential measurements are indirect method of assessing potential bar corrosion, but there has been much recent interest in developing a means of performing perturbative electrochemical measurements on the steel itself to obtain a direct evaluation of the corrosion rate (Gowers and Millard, 1999a). Corrosion rates have been related to electrochemical measurements based on data first reported by Stern and Geary (1957).

2.5 Concrete Resistivity Measurement Test

Different readings were taken at different locations at the surface of the concrete. After applying water on the surface of the slabs, the concrete resistivity was measured daily at the reference locations, looking for the saturation condition. These locations were chosen at the side of the slabs, since concrete electrical resistivity measurements could be taken when water was on the top surface of the slab. The mean values of the readings were recorded as the final readings of the resistivity in the study. The saturation level of the slabs was monitored through concrete electrical resistivity measurements, which are directly related to the moisture content of concrete. Once one slab would reach the saturated condition, the water could be drained from that slab, while the other slabs remained ponded. Time limitation was the main challenge to perform all the experimental measurements, as the concrete saturation condition changes with time. In the study, the Wenner four probes method was used; it was done by placing the four probes in contact with the concrete directly above the reinforcing steel bar. Henceforth, these measurements will be referred to as the measurements in «dry» conditions. Since each of the slabs had a different w/c, the time needed to saturate each of the slabs was not the same. Before applying water on the slabs, the concrete electrical resistivity was measured in the dry condition at the specified locations. The electrical resistivity becomes constant once the concrete has reached saturation.

Table 2.2: Dependence between concrete resistivity and corrosion probability

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

2.6 Tensile Strength of Reinforcing Bars

To ascertain the yield and tensile strength of tension bars, bar specimens of 12 mm diameter of non-corroded, corroded and coated were tested in tension in a Universal Testing Machine and were subjected to direct tension until failure; the yield, maximum and failure loads being recorded. To ensure consistency, the remaining cut pieces from the standard length of corroded and non-corroded steel bars were subsequently used for mechanical properties of steel.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The results of the half-cell potential measurements in table 3.1 were plotted against concrete resistivity of table 3.2 for easy interpretation. It used as indication 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 Probability of corrosion. In the other measuring points, potential

Ecorr is high $(-350\text{mV} \leq E_{corr} \leq -200\text{mV}),$ which indicates a 10% or uncertain probability of corrosion. Results of the concrete resistivity measurements are shown in Table 3.2. It is evident that potential E_{corr} if low $(< -350\text{mV})$ in an area measuring indicates a 95% probability of corrosion. Concrete resistivity is commonly measured by four-electrode method. Resistivity survey data gives an indication of whether the concrete condition is favorable for the easy movements of ions leading to more corrosion..

3.1 Control Concrete Slab Members

Tables 3.1 into 3.1A, are the results of preliminary and average results gotten from control, corroded and exudates/resin coated specimens of 150µm, 300µm, 450µm thicknesses and plotted in figures 3.1 and 3.1A of Concrete Resistivity ρ, kΩcm versus Potential $E_{corr,}^{mV}$. Average potential Ecorr control specimen results are -102.875mV, -104.907mV, -105.515mV, fused into -104.432mV, with percentile average value 29.90279% and percentile difference -70.0972%. Average Results of Concrete Resistivity ρ, kΩcm from table 3.2 into 3.2A and plotted in figures 3.2 and 3.2A are 13.4222kΩcm, 13.17887kΩcm, 13.4522kΩcm, fused into 13.35109kΩcm with percentile average value 179.232% and percentile difference 79.23197%. Average Mechanical properties "Ultimate strength" of Control specimens from table 3.3 into 3.3A and plotted in figures 3.3 and 3.3A are 546.3783N/mm², 546.0117N/mm², 545.5783N/mm², fused into 545.9894N/mm², with percentile average value 92.34589% and percentile difference -7.65411%. Average Mechanical properties "Weight Loss of Steel" of Control from table 3.4 into 3.4A and plotted in figures 3.4 and 3.4A are 7.208667grams, 7.208667grams, 7.162grams, fused into 7.193111grams with percentile average value 56.31007% and percentile difference -43.6899%. Average mechanical properties "Cross-section Area Reduction" of Control from table 3.5 into 3.5A and plotted in figures 3.5 and 3.5A are 12mm, 12mm, 12mm and fused into 12mm with percentile average value 113.1957% and percentile difference 13.19568%. Control specimens result showed no corrosion potential.

3.2 Corroded Concrete Slab Members

Averaged values obtained from table 3.1 into 3.1A from 27 specimens of slab for control, corroded and exudates/resin coated specimens of 150µm, 300µm, 450µm as presented in figures 3.1 and 3.1A of Potential $E_{corr,}^{mV}$. Potential E_{corr} averaged corroded values are -280.373mV , -359.673mV, -407.673mV summed up to -349.239mV, with percentile value of 334.4169% and percentile difference 234.4169% against -70.0972% and -69.4102% of control and coated specimens. Potential E_{corr} results showed that the values of corroded specimens are high with the range of $(-350\text{mV} \leq \square_{corr} \leq -200\text{mV})$, which indicates a 10% or uncertain probability of corrosion. From table 3.2 into 3.2A and plotted in figures 3.2 and 3.2A, average results of concrete resistivity ρ, kΩcm are **6.996833**kΩcm, 7.406833kΩcm, 7.9435kΩcm, summed up to 7.449056kΩcm with percentile average value 55.79362% and percentile difference -44.2064% against 79.23197% and 103.2465% of control and coated specimens. From table 3.3 into 3.3A and plotted in figures 3.3 and 3.3A, average Mechanical properties "ultimate strength" of control specimens are 587.6217N/mm², 592.3883N/mm², 593.7217N/mm², summed up to 591.2439N/mm², with percentile average value 108.2885% and percentile difference 8.28852% against -7.65411% and -3.01205% of control and coated specimens. From table 3.4 into 3.4A and plotted in figures 3.4 and 3.4A, average mechanical properties "weight loss of steel" of corroded specimens are 12.75933grams, 12.75933grams, 12.80367grams, summed up to 12.77411grams with percentile average value 177.5881% and percentile difference 77.58812% against -43.6899% and -44.4871% of control and coated specimens. From table 3.5 into 3.5A and plotted in figures 3.5 and 3.5A, average mechanical properties "cross- section area reduction" of

corroded are 10.52333mm, 10.52333mm, 10.75667mm and fused into 10.60111mm with percentile average value 88.34259% and percentile difference -11.6574% against 13.19568 % and 13.19568%. Summarized results showed that the range of values of corroded specimens showed indication of likelihood of significant corrosion ($\square < 5$, $5 < \square < 10$, $10 < \square < 20$, $\square > 20$) for Very high, high, low to moderate and low, for Probability of corrosion. Results showed high ultimate yielding of corroded specimens to control and coated specimens due to the effect of corrosion on the mechanical properties of the steel reinforcement. Results of weight Loss of steel showed higher percentile values against control and coated specimens due to the effect of corrosion on the mechanical properties of steel. Cross- section area reduction results showed higher percentile reduction values due to effect of corrosion on the mechanical properties of steel.

3.3 Artocarpus altilis Exudates   Steel Bar Coated Concrete Slab Members

Presented average results from tables 3.1 into 3.1A is the average values gotten from 27 samples of control, corroded and exudates/resin coated specimens of 150µm, 300µm, 450µm and represented in figures 3.1 and 3.1A of concrete resistivity ρ, kΩcm against potential $E_{corr,}^{mV}$. Relationship indicated averaged potential Ecorr control values of -106.881mV , -106.711mV, -106.904mV summed up to -106.832mV, with average percentile value 30.58985% and percentile difference -69.4102% over 234.4169% corroded specimen. Results of concrete resistivity ρ, kΩcm average values from table 3.2 into 3.2A and plotted in figures 3.2 and 3.2A are 14.91883kΩcm, 15.1755kΩcm, 15.3255kΩcm, summed up to 15.13994kΩcm with percentile average value 203.2465% and percentile difference 103.2465% over -44.2064% corroded specimen. Average Mechanical properties "ultimate strength" of control specimens from table 3.3 into 3.3A and plotted in figures 3.3 and 3.3A are 546.996N/mm^2, 585.9883N/mm^2, 587.3217N/mm^2, fused into 573.4353N/mm^2, with percentile average value 96.98795% and percentile difference -3.01205% over 8.183891% corroded specimen. Average Mechanical properties "weight Loss of steel" of control from table 3.4 into 3.4A and plotted in figures 3.4 and 3.4A are 7.0835grams, 7.0835grams, 7.106833grams, fused into 7.091278grams with percentile average value 55.51289% and percentile difference -44.4871% over 77.58812% corroded . Average mechanical properties "cross- section area reduction" of control from table 3.5 into 3.5A and plotted in figures 3.5 and 3.5A are 12mm, 12mm, 12mm and fused into 12mm with percentile average value 113.1957% and percentile difference 13.19568% over -11.6574% corroded specimen. Control specimens result showed no corrosion potential.

Table 3.1 : Potential Ecorr, after 28 days curing and 150 days Accelerated Periods

Potential E$_{corr,mV}$									
Time Intervals after 28 days curing									
Samples	AH1	AH2	AH3	AH4	AH5	AH6	AH7	AH8	AH9
Durations	(7days)	(21days)	(28days)	(58days)	(88days)	(118days)	(148days)	(163days)	(178days)
	Control Concrete slab Specimens								
CSNA1	-103.38	-103.853	-101.39	-107.093	-103.79	-103.837	-106.373	-104.229	-105.942
CSNB1	**Corroded Concrete Slab Specimens**								
	-251.606	-277.806	-311.706	-350.806	-360.606	-367.606	-401.506	-408.706	-412.806
	Artocarpus altilis exudates (steel bar coated specimen)								
	(150µm) coated			**(300µm) coated**			**(450µm) coated**		
CSNC1	-105.924	-103.594	-111.124	-106.294	-103.234	-110.604	-105.524	-109.294	-105.894

Table 3.1A :Average Potential Ecorr, after 28b days curing and 150 days Accelerated Periods

S/no	Samples	Average A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}			Summary Average A{H(1,2,3)}, (4,5,6)}, A{H(7,8,9)}	Percentile Average Values A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}	Percentile Difference Average A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}
CSNA1	Control Specimens	-102.875	-104.907	-105.515	-104.432	29.90279	-70.0972
CSNB1	Corroded Specimens	-280.373	-359.673	-407.673	-349.239	334.4169	234.4169
CSNC1	Coated Specimens	-106.881	-106.711	-106.904	-106.832	30.58985	-69.4102

Table 3.2 : Results of Concrete Resistivity ρ, kΩcm Time Intervals after 28 days curing and 150 days Accelerated Periods

	Concrete Resistivity ρ, kΩcm								
	Time Intervals after 28 days curing								
Samples	AH1	AH2	AH3	AH4	AH5	AH6	AH7	AH8	AH9
Durations	(7days)	(21days)	(28days)	(58days)	(88days)	(118days)	(148days)	(163days)	(178days)
	Control Concrete slab Specimens								
CSNA2	13.3422	13.5122	13.4122	13.6422	13.4722	12.4222	13.4422	13.4422	13.4722
CSNB2	Corroded Concrete Slab Specimens								
	6.2935	**6.4335**	**8.2635**	**6.5735**	**7.7435**	**7.9035**	**7.6435**	**8.0735**	**8.1135**
CSNC2	Artocarpus altilis exudates (steel bar coated specimen)								
	(150μm) coated			**(300μm) coated**			**(450μm) coated**		
	14.7255	14.8755	15.1555	15.2855	14.9755	15.2655	15.2155	15.3655	15.3955

Table 3.2B : Average Results of Concrete Resistivity ρ, kΩcm Time Intervals after 28 days curing and 150 days Accelerated Periods

S/no	Samples	Average A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}			Summary Average A{H(1,2,3)}, (4,5,6)}, A{H(7,8,9)}	Percentile Average Values A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}	Percentile Difference Average A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}
		Concrete Resistivity ρ, kΩcm					
CSNA2	Control Specimens	13.4222	13.17887	13.4522	13.35109	179.232	79.23197
CSNB2	Corroded Specimens	**6.996833**	7.406833	7.9435	7.449056	55.79362	-44.2064
CSNC2	Coated Specimens	14.91883	15.1755	15.3255	15.13994	203.2465	103.2465

Table 3.3 : Mechanical properties of Control, Corroded and Steel Coated Concrete Slab

Samples	AH1	AH2	AH3	AH4	AH5	AH6	AH7	AH8	AH9
	Time Intervals after 28 days curing								
Durations	(7days)	(21days)	(28days)	(58days)	(88days)	(118days)	(148days)	(163days)	(178days)
	Yield Stress (N/mm2) for Contro, Corroded and Coated Specimens								
CSNA3	410	410	410	410	410	410	410	410	410
	Ultimate strength (N/mm2)								
	Control Concrete slab Specimens								
CSNB3	546.845	547.745	544.545	544.745	548.945	544.345	547.345	544.845	544.545
CSNC3	**Corroded Concrete Slab Specimens**								
	586.555	587.655	588.655	584.655	588.655	584.655	587.255	584.455	590.255
CSND3	**Artocarpus altilis exudates (steel bar coated specimen)**								
	(150μm) coated			**(300μm) coated**			**(450μm) coated**		
	549.896	549.196	547.896	550.296	550.296	550.296	552.996	549.946	551.196

Table 3.3A : Average Mechanical properties of Non-Corroded, Corroded and Steel Coated Concrete Slab

S/no	Samples	Average A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}			Summary Average A{H(1,2,3)}, (4,5,6)}, A{H(7,8,9)}	Percentile Average Values A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}	Percentile Difference Average A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}
		Ultimate strength (N/mm2)					
CSNB3	Control Specimens	546.3783	546.0117	545.5783	545.9894	92.34589	-7.65411
CSNC3	Corroded Specimens	587.6217	592.3883	593.7217	591.2439	108.2885	8.28852
CSND3	Coated Specimens	546.996	585.9883	587.3217	573.4353	96.98795	-3.01205

Table 3.4 : Mechanical properties of Control, Corroded and Steel Coated Concrete Slab

		Weight Loss of Steel (in grams)							
		Control Concrete slab Specimens							
CSNA4	7.142	7.262	7.222	7.142	7.152	7.342	7.172	7.072	7.242
CSNB4	**Corroded Concrete Slab Specimens**								
	12.633	12.801	12.844	12.881	12.887	12.889	12.84	12.89	12.681
CSNC4	**Artocarpus altilis exudates (steel bar coated specimen)**								
	(150μm) coated			**(300μm) coated**			**(450μm) coated**		
	7.0735	7.0835	7.0935	7.0835	7.1235	7.0835	7.1235	7.0835	7.1135

Table 3.4A : Average Mechanical properties of Non-Corroded, Corroded and Steel Coated Concrete Slab

S/no	Samples	Average A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}			Summary Average A{H(1,2,3)}, (4,5,6)}, A{H(7,8,9)}	Percentile Average Values A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}	Percentile Difference Average A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}
		Weight Loss of Steel (in grams)					
CSNA4	Control Specimens	7.208667	7.208667	7.162	7.193111	56.31007	-43.6899
CSNB4	Corroded Specimens	12.75933	12.75933	12.80367	12.77411	177.5881	77.58812
CSNC4	Coated Specimens	7.0835	7.0835	7.106833	7.091278	55.51289	-44.4871

Table 3.5 : Mechanical properties of Control, Corroded and Steel Coated Concrete Slab

	Cross- section Area Reduction (Diameter, mm)								
	Control Concrete slab Specimens								
CSNA5	12	12	12	12	12	12	12	12	12
CSNB5	**Corroded Concrete Slab Specimens**								
	10.52	10.52	10.53	10.6	10.63	10.7	10.74	10.75	10.78
	Artocarpus altilis exudates (steel bar coated specimen)								
	(150μm) coated			**(300μm) coated**			**(450μm) coated**		
CSNC5	12	12	12	12	12	12	12	12	12

Table 35 : Average Mechanical properties of Non-Corroded, Corroded and Steel Coated Concrete Slab

| S/no	Samples	Average A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}			Summary Average A{H(1,2,3)}, (4,5,6)}, A{H(7,8,9)}	Percentile Average Values A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}	Percentile Difference Average A{H(1,2,3)},(4,5,6)}, A{H(7,8,9)}
		Cross- section Area Reduction (Diameter, mm)					
CSNA5	Control Specimens	12	12	12	12	113.1957	13.19568
CSNB5	Corroded Specimens	10.52333	10.52333	10.75667	10.60111	88.34259	-11.6574
CSNC5	Coated Specimens	12	12	12	12	113.1957	13.19568
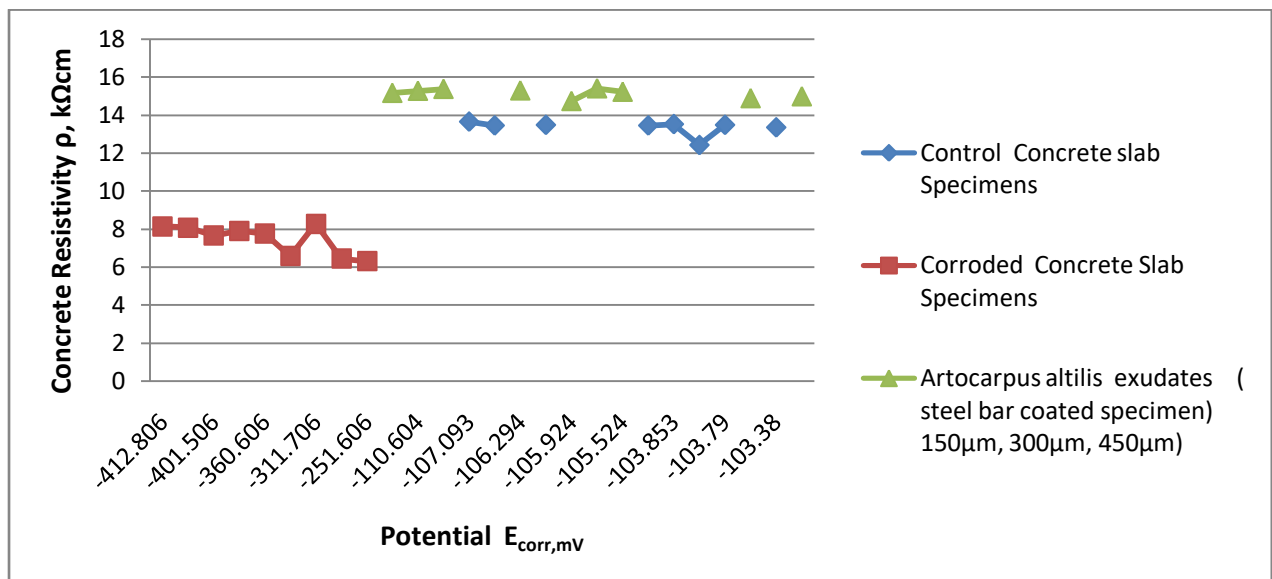
Figure 3.1: Concrete Resistivity ρ, kΩcm Versus Potential $E_{corr,}^{mV}$ Relationship
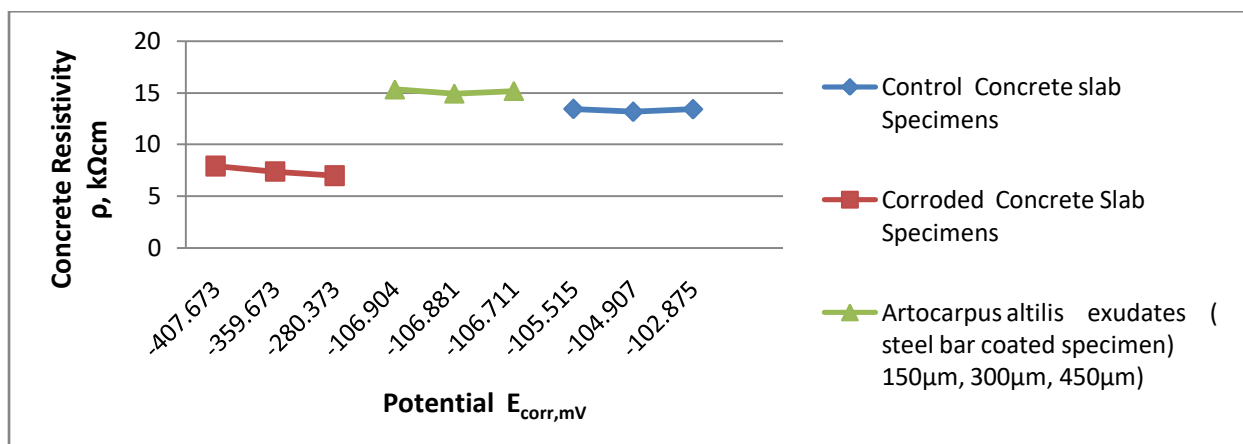

Figure 3.1A: Average Concrete Resistivity versus Potential Relationship
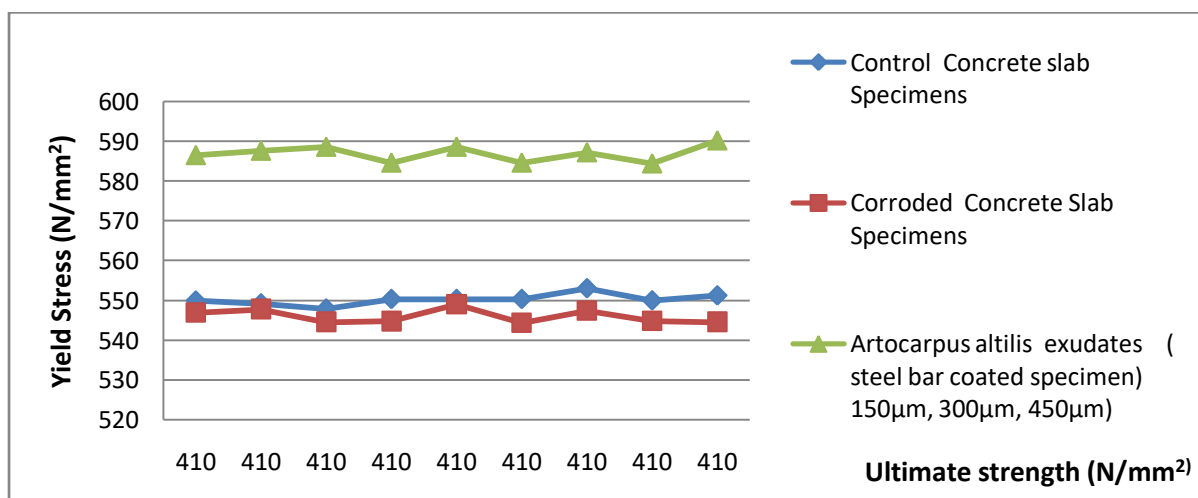

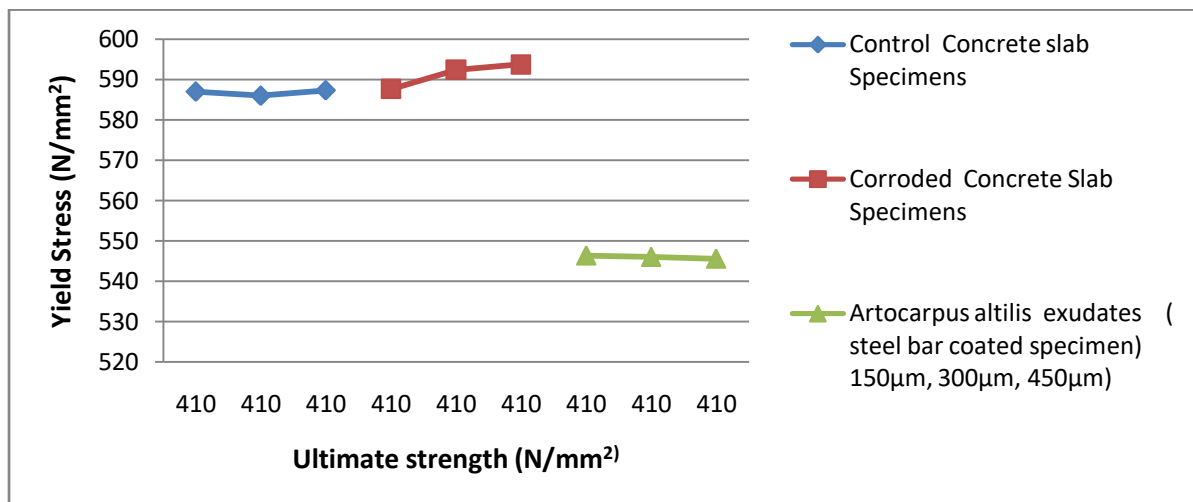**Figure 3.2: Yield Stress versus Ultimate strength**

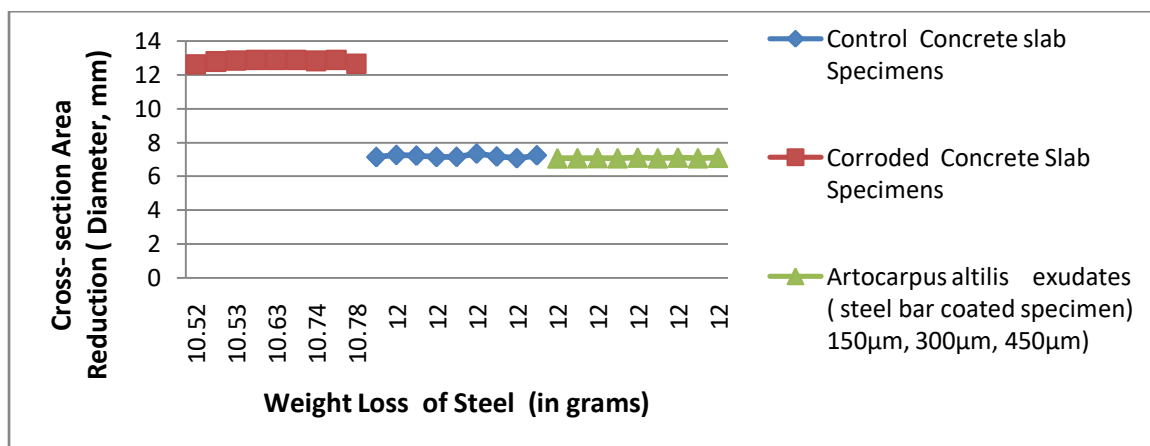**Figure 3.2A: Average Yield Stress versus Ultimate strength.**

Figure 3.3: Weight Loss of Steel versus Cross- section Area Reduction
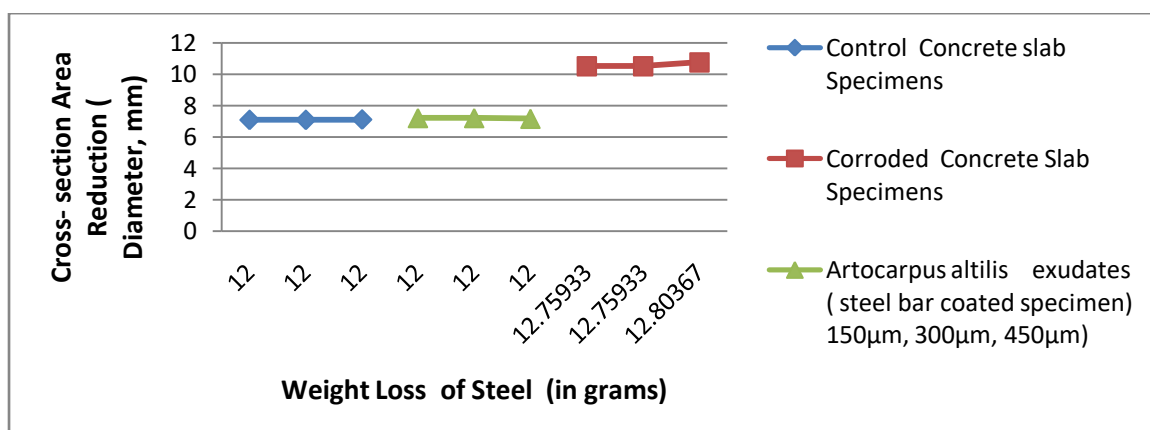

Figure 3.3A: Average Weight Loss of Steel versus Cross- section Area Reduction

IV.   CONCLUSION

Experimental results showed the following conclusions:

i. Summarized results showed that the range of values of corroded specimens showed indication of likelihood of significant corrosion ($\square < 5$, $5 < \square < 10$, $10 < \square < 20$, $\square > 20$) for Very high, high, low to moderate and low, for Probability of corrosion.

ii. Results showed high ultimate yielding of corroded specimens to control and coated specimens due to the effect of corrosion on the mechanical properties of the steel reinforcement.

iii. Results of weight Loss of steel showed higher percentile values against control and coated specimens due to the effect of corrosion on the mechanical properties of steel.

iv. Cross- section area reduction results showed higher percentile reduction values due to effect of corrosion on the mechanical properties of steel.

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