Electrochemical Corrosion Measurement of Non-Inhibited and Inhibited Reinforcement Mechanical Properties Embedded in Concrete

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ABSTRACT

Environmental concerns globally are increasing and are likely to influence the choice of corrosion inhibitors in the future due to hazardous properties of some organic inhibitors. The research work evaluated the application of environmentally friendly inorganic extracts of natural origin of trees. Olibanum exudates / resins direct application on reinforcing steel of varying thicknesses, embedded in concrete slab, ponded in corrosive environment for 150 days accelerated stage with constant current for polarization potential test of -200 mV through 1200mV, with a scan rate of 1mV/s.Results of potential E_{corr} corroded values of percentile averaged value 319.7249% and percentile variation of 219.7249% against -68.7231% and -65.0698% of control and coated specimens. Concrete resistivity ρ, kΩcm percentile averaged value of 61.72032% and percentile difference -38.2797% against 62.02119% and 76.27475% of control and coated specimens. Mechanical properties "ultimate strength" specimens' percentile value of 109.577% and percentile difference of 9.577011% against -8.73998% and -8.35009% of control and coated specimens. High ultimate yield results recorded of corroded specimens to control and coated specimens due to attack on the mechanical properties of the steel reinforcement. Mechanical properties "weight loss of steel" of corroded specimens' percentile value of 183.3103% and percentile difference of 83.31034% against -45.4477% and -42.2923% of control and coated specimens. Results of weight loss of steel indicated higher percentile values against control and coated specimen, this resulted from corrosion attack on surface and reduction of fibre / ribbed properties of the reinforcing steel. Averaged mechanical properties "cross- section area reduction" of coated specimen percentile value of 84.00926% and percentile difference -15.9907% against 19.0345% and 19.0345%. Cross- section area reduction of corroded specimen 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.

1.0 Introduction

The havoc created by the effect of corrosion attack on reinforcing steel embedded in concrete has given researchers rapid development of various materials and methods which can be used for increasing the service life of concrete structure subjected to chloride attack. It is more likely very easy, attractive and easy application, economically attractive in the use of corrosion inhibitors.

Environmental concerns worldwide are increasing and are likely to influence the choice of corrosion inhibitors in the future. Environmental requirements are still being developed but some elements have been established (Uhlig [1]). Novokshcheov [2] studied and showed that calcium nitrite is in no way detrimental to concrete properties as seen in the issue of inhibitors based on sodium or potassium. Latter study by Skotinck [3] and Slater [4] showed that considering long-standing accelerated testing, calcium nitrite was of better quality in terms of strength.

Obot *et al*. [5] Studied the effect of Aningeria robusta extract as corrosion inhibitor on aluminium in 2M HCl solution and the contribution of potassium iodide additive on the inhibition efficiency using hydrogen evolution method at 300^0C and 60^oC. The level of inhibition efficiency with temperature was used to initiate the mechanism of inhibition. Aningeria robusta extract, acted as an inhibitive to acid induced corrosion aluminium from results obtained. Inhibition efficiency was found to increase with extract concentration and temperature.

Macdonald [6] carried out the investigation of inhibitors in solutions of alkaline and extracts from cement. The extracts from cement experiment revealed corrosion was inhibited using sodium nitrite in the presence of chlorides while sodium benzoate did not. Furthermore, the initiation of corrosion was delayed with sodium nitrite, with the delay increasing with inhibitor content.

Charles et al. [6] 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. Corrosion test was conducted on high tensile reinforcing steel bar of 12mm, specimens rough surface were treated with Symphonia globulifera linn resin extracts with layered thickness of 150µm, 250µm and 350µm polished and embedded into concrete slab. 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. Average percentile results of potential and concrete resistivity are 29.9% and 63.6% respectively. 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 betokening a high or moderate probability of corrosion

Charles et al. [7] Investigated the corrosion potential, concrete resistivity and tensile tests of Control, corroded and coated reinforcing steel of concrete slab member. Direct application of corrosion inhibitor of dacryodes edulis resins thicknesses 150µm, 250µm, 350µm were coated on 12mm diameter reinforcement, embedded into concrete slab and exposed to severe corrosive environment for 119 days for accelerated corrosion test, half-cell potential measurements, concrete resistivity measurement and tensile testsWhen 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.

Charles et al. [8] Investigated the effects of chloride attack on reinforcing steel embedded in reinforced concrete structures built in the marine environment. An experimental work simulated the quick process by acceleration process on non-inhibited and inhibited reinforcement of acardium occidentale l. resins extracts with polished thicknesses of 150µm, 250µm and 350µm, embedded in concrete slab and immersed in sodium chloride (NaCl) and accelerated for 119 days using Wenner four probes method. Average percentile results of potential Ecorr,mV, and concrete resistivity are 27.45% and 68.45% respectively. When compared to corroded samples, corroded has 75.4% increased values potential Ecorr,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. [9] investigated corrosion level probability assessment potential through half cell potential corrosion measurement, concrete resistivity test and tensile strength test mechanical properties of Control, corroded and inhibited reinforcement with Moringa Oleifera lam resin paste of trees extract. When compared to corroded samples, corroded has 70.1% increased values potential Ecorr,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. [10] 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 Ecorr,mV, and concrete resistivity are 26.57% and 61.25% respectively. When compared to corroded samples, corroded has 70.1% increased values potential Ecorr,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. [11] 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 Control, corroded and inhibited reinforcement coated thicknesses of 150µm, 250µm and 350µm specimens embedded in concrete, exposed to severe and corrosive environment medium for 119 days after 28 days initial cured, with required constant current for polarization potential test of -200 mV through 1200mV, with a scan rate of 1mV/s. When compared to corroded samples, corroded has 70.1% increased values potential Ecorr,mV and 35.5% decreased values of concrete resistivity. Average percentile results of potential Ecorr,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. [12] 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 of 150µm, 250µm and 350µm thicknesses were embedded in concrete slab with exposed sections, immersed sodium chloride solution and accelerated using Wenner four probe method. 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. 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.

2.0 Materials and Methods for Experinment

2.1 Aggregates

The fine aggregate and coarse aggregate were purchased. Both met the requirements of [13]

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 [14]

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, Rivers State. The water met the requirements of [15]

2.1.4 Structural Steel Reinforcement

The reinforcements are gotten directly from the market in Port Harcourt, [16]

2.1.5 Corrosion Inhibitors (Resins / Exudates) Olibanum

The study inhibitor is Olibanum 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. 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.

Table 2.1: Dependence between potential and corrosion probability

Potential E_{corr}	Probability of corrosion
Ecorr < −350mV	Greater than 90% probability that reinforcing steel corrosion is occurring in that area at the time of measurement
−350mV ≤ E_{corr} ≤ −200mV	Corrosion activity of the reinforcing steel in that area is uncertain
E_{corr} > −200mV	90% probability that no reinforcing steel corrosion is occurring in that area at the time of measurement (10% risk of corrosion

2.5 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 Control, 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 Control steel bars were subsequently used for mechanical properties of steel.

3.0 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 (-350mV $\leq E_{corr} \leq -200$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 (< -350mV) 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

Results obtained from table 3.1 of half-cell potential measurements for and concrete resistivity for 7days to 178 days respectively indicated a 10% or uncertain probability of corrosion which indicates no corrosion presence or likelihood and concrete resistivity which indicated a low probability of corrosion or no corrosion indication.

Table 3.1 into 3.1A, present results of control, corroded and exudates/resin coated plotted in figures 3.1 and 3.1A of concrete resistivity ρ, kΩcm versus potential $E_{corr,}{}^{mV}$. Obtained Potential E_{corr} control specimen averaged results are -101.49mV, -101.223mV, -101.357mV, summarized to -101.357mV, with percentile value of 31.27689% and percentile difference -68.7231%. Results of concrete resistivity ρ, kΩcm from table 3.2 into 3.2A and plotted in figures 3.2 and 3.2A are 13.752kΩcm, 13.50867kΩcm, 13.782kΩcm, summarized to 13.68089kΩcm with percentile averaged value 162.0212% and percentile difference 62.02119%. Mechanical properties "ultimate strength" of control specimens from table 3.3 into 3.3A and plotted in figures 3.3 and 3.3A are 546.7783N/mm^2, 546.4117N/mm^2, 545.9783N/mm^2, summed to 546.3894N/mm^2, with percentile averaged value 91.26002% and percentile difference -8.73998%. 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 6.618667grams, 6.622grams, 6.572grams, summarized to 6.604222grams with percentile averaged value 54.5523% and percentile difference -45.4477%. 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 summarized to 12mm with percentile averaged value 119.0345% and percentile difference 19.0345%. Control specimens result showed no corrosion potential.

3.2 Corroded Concrete Slab Members

Averaged Potential E_{corr} corroded values of -284.413mV, -363.713mV, -324.063mV summed to -324.063mV, with percentile averaged value 319.7249% and percentile variation of 219.7249% against -68.7231% and -65.0698% of control and coated specimens derived from table 3.1 into 3.1A and graphically presented in figures 3.1 and 3.1A. Potential E_{corr} results proved that values of corroded specimens are high with the range of ($-350\text{mV} \leq E_{corr} \leq -200\text{mV}$), which indicates a 10% or uncertain probability of corrosion. Concrete resistivity ρ, kΩcm averaged results from table 3.2 into 3.2A and plotted in figures 3.2 and 3.2A are **7.325**kΩcm, 8.443889kΩcm, 9.605kΩcm, summarized to 8.443889kΩcm with percentile averaged value 61.72032% and percentile difference -38.2797% against 62.02119% and 76.27475% of control and coated specimens. 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. Mechanical properties "ultimate strength" specimens from table 3.3 into 3.3A and plotted in figures 3.3 and 3.3A are 599.3617N/mm^2, 597.7283N/mm^2, 599.0617N/mm^2, summarized to 598.7172N/mm^2, with percentile averaged value 109.577% and percentile difference of 9.577011% against -8.73998% and -8.35009% of control and coated specimens. High ultimate yield results recorded of corroded specimens to control and coated specimens due to attack on the mechanical properties of the steel reinforcement. Mechanical properties "weight loss of steel" of corroded specimens from table 3.4 into 3.4A and plotted in figures 3.4 and 3.4A are 12.04933grams, 12.17567grams, 12.09367grams, summarized to 12.10622grams with percentile averaged value 183.3103% and percentile difference of 83.31034% against -45.4477% and -42.2923% of control and coated specimens. Results of weight loss of steel indicated higher percentile values against control and coated specimen, this resulted from corrosion attack on surface and reduction of fibre / ribbed properties of the reinforcing steel. Averaged mechanical properties "cross- section area reduction" of coated specimen from table 3.5 into 3.5A and plotted in figures 3.5 and 3.5A are 9.963333mm, 10.08333mm, 10.19667mm and summarized to 10.08111mm with percentile averaged value 84.00926% and percentile difference -15.9907% against 19.0345% and 19.0345%. Cross- section area reduction of corroded specimen results showed higher percentile reduction values due to effect of corrosion on the mechanical properties of steel.

3. Olibanum Exudate Steel Bar Coated Concrete Slab Members

Collated results from table 3.1 into 3.1A is the averaged values derived from samples of control, corroded and exudates/resin coated specimens and plotted in figures 3.1 and 3.1A of concrete resistivity ρ, kΩcm versus Potential $E_{corr,}{}^{mV}$ relationship showed averaged potential E_{corr} coated values of -113.281mV , -113.111mV, -113.196mV summarized to -113.196mV, with percentile averaged value 34.93018% and percentile difference -65.0698% over 219.7249% corroded specimen. Results of concrete resistivity ρ, kΩcm averaged values from table 3.2 into 3.2A and plotted in figures 3.2 and 3.2A are 14.66333kΩcm, 14.92kΩcm, 15.07kΩcm, summarized to 14.88444kΩcm with percentile averaged value 176.2748% and percentile difference 76.27475% over -38.2797% corroded specimen. Averaged mechanical properties "ultimate strength" of control specimens from table 3.3 into 3.3A and plotted in figures 3.3 and 3.3A are 547.496N/mm^2,

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547.496N/mm^2, 549.8793N/mm^2, summarized to 548.7238N/mm^2, with percentile averaged value 91.64991% and percentile difference -8.35009% over 9.577011% corroded specimen. Mechanical properties “weight loss of steel” of coated from table 3.4 into 3.4A and plotted in figures 3.4 and 3.4A are 6.974grams, 6.987333grams, 6.997333grams, summarized to 6.986222grams with percentile averaged value of 57.7077% and percentile difference -42.2923% over 83.31034% corroded. Averaged mechanical properties “cross- section area reduction” of coated from table 3.5 into 3.5A and plotted in figures 3.5 and 3.5A are 12mm, 12mm, 12mm and summarized to 12mm with percentile averaged value 119.0345% and percentile difference 19.0345% over -15.9907% corroded specimen. Control specimens result showed no corrosion potential, the presence of exudates / resins formed resistance coatings to the reinforcing steel embedded into concrete structures.

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	AD1	AD2	AD3	AD4	AD5	AD6	AD7	AD8	AD9
Durations	(7days)	(21days)	(28days)	(58days)	(88days)	(118days)	(148days)	(163days)	(178days)
	Control Concrete slab Specimens								
CSHA1	-101.99	-102.19	-100.29	-101.19	-101.69	-100.79	-100.29	-101.39	-100.39
CSHB1	**Corroded Concrete Slab Specimens**								
	-255.646	-281.846	-315.746	-354.846	-364.646	-371.646	-405.546	-412.746	-416.846
	Olibanum Exudate (steel bar coated specimen)								
	(150µm) coated			**(300µm) coated**			**(450µm) coated**		
CSHC1	-112.324	-109.994	-117.524	-112.694	-109.634	-117.004	-111.924	-115.694	-112.294

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

S/no	Samples	Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}			Summary Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}	Percentile Average Values Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}	Percentile Difference Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}
CSHA1	Control Specimens	-101.49	-101.223	-101.357	-101.357	31.27689	-68.7231
CSHB1	Corroded Specimens	-284.413	-363.713	-324.063	-324.063	319.7249	219.7249
CSHC1	Coated Specimens	-113.281	-113.111	-113.196	-113.196	34.93018	-65.0698

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	AD1	AD2	AD3	AD4	AD5	AD6	AD7	AD8	AD9
Durations	(7days)	(21days)	(28days)	(58days)	(88days)	(118days)	(148days)	(1days)	(178days)

	Control Concrete slab Specimens								
CSHA2	13.672	13.842	13.742	13.972	13.802	12.752	13.772	13.772	13.802
CSHB2	**Corroded Concrete Slab Specimens**								
	6.955	**7.095**	**7.925**	**8.235**	**8.405**	**8.565**	**9.305**	**9.735**	**9.775**
CSHC2	**Olibanum Exudate (steel bar coated specimen)**								
	(150µm) coated			**(300µm) coated**			**(450µm) coated**		
	14.47	14.62	14.9	15.03	14.72	15.01	14.96	15.11	15.14

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

S/no	Samples	Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}			Summary Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}	Percentile Average Values Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}	Percentile Difference Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}
	Concrete Resistivity ρ, kΩcm						
CSHA2	Control Specimens	13.752	13.50867	13.782	13.68089	162.0212	62.02119
CSHB2	Corroded Specimens	**7.325**	**8.401667**	9.605	8.443889	61.72032	-38.2797
CSHC2	Coated Specimens	14.66333	14.92	15.07	14.88444	176.2748	76.27475

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

	Time Intervals after 28 days curing								
Samples	AD1	AD2	AD3	AD4	AD5	AD6	AD7	AD8	AD9
Durations	(7days)	(21days)	(28days)	(58days)	(88days)	(118day)	(148day)	(163day)	(178days)
	Yield Stress (N/mm2) for Contro, Corroded and Coated Specimens								
CSHA3	410	410	410	410	410	410	410	410	410
	Ultimate strength (N/mm2)								
	Control Concrete slab Specimens								
CSHB3	547.245	548.145	544.945	545.145	549.345	544.745	547.745	545.245	544.945
CSHC3	**Corroded Concrete Slab Specimens**								
	598.295	599.395	600.395	596.395	600.395	596.395	598.995	596.195	601.995
CSHD3	**Olibanum Exudate (steel bar coated specimen)**								
	(150µm) coated			**(300µm) coated**			**(450µm) coated**		
	548.396	547.696	546.396	548.796	548.796	548.796	551.496	548.446	549.696

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

S/no	Samples	Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}	Summary Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}	Percentile Average Values Average A{D(1,2,3)}, (4,5,6)},	Percentile Difference Average A{D(1,2,3)}, (4,5,6)},

						A{D(7,8,9)}	A{D(7,8,9)}
	Ultimate strength (N/mm2)						
CSHB3	Control Specimens	546.7783	546.4117	545.9783	546.3894	91.26002	-8.73998
CSHC3	Corroded Specimens	599.3617	597.7283	599.0617	598.7172	109.577	9.577011
CSHD3	Coated Specimens	547.496	548.796	549.8793	548.7238	91.64991	-8.35009

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

	Weight Loss of Steel (in grams)								
	Control Concrete slab Specimens								
CSHA4	6.552	6.672	6.632	6.552	6.562	6.752	6.582	6.482	6.652
CSHB4	**Corroded Concrete Slab Specimens**								
	11.923	12.091	12.134	12.171	12.177	12.179	12.13	12.18	11.971
CSHC4	**Olibanum Exudate (steel bar coated specimen)**								
	(150µm) coated			**(300µm) coated**			**(450µm) coated**		
	6.964	6.974	6.984	6.974	7.014	6.974	7.014	6.974	7.004

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

S/no	Samples	Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}			Summary Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}	Percentile Average Values Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}	Percentile Difference Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}
	Weight Loss of Steel (in grams)						
CSHA4	Control Specimens	6.618667	6.622	6.572	6.604222	54.5523	-45.4477
CSHB4	Corroded Specimens	12.04933	12.17567	12.09367	12.10622	183.3103	83.31034
CSHC4	Coated Specimens	6.974	6.987333	6.997333	6.986222	57.7077	-42.2923

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

	Cross- section Area Reduction (Diameter, mm)								
	Control Concrete slab Specimens								
CSHA5	12	12	12	12	12	12	12	12	12
CSHB5	**Corroded Concrete Slab Specimens**								
	9.96	9.96	9.97	10.04	10.07	10.14	10.18	10.19	10.22
	Olibanum Exudate (steel bar coated specimen)								
	(150µm) coated			**(300µm) coated**			**(450µm) coated**		
CSHC5	12	12	12	12	12	12	12	12	12

Table 35 : Mechanical properties of Control, Corroded and Steel Coated Concrete Slab

S/no	Samples	Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}			Summary Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}	Percentile Average Values Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}	Percentile Difference Average A{D(1,2,3)}, (4,5,6)}, A{D(7,8,9)}
	Cross- section Area Reduction (Diameter, mm)						
CSHA5	Control Specimens	12	12	12	12	119.0345	19.0345
CSHB5	Corroded Specimens	9.963333	10.08333	10.19667	10.08111	84.00926	-15.9907
CSHC5	Coated Specimens	12	12	12	12	119.0345	19.0345

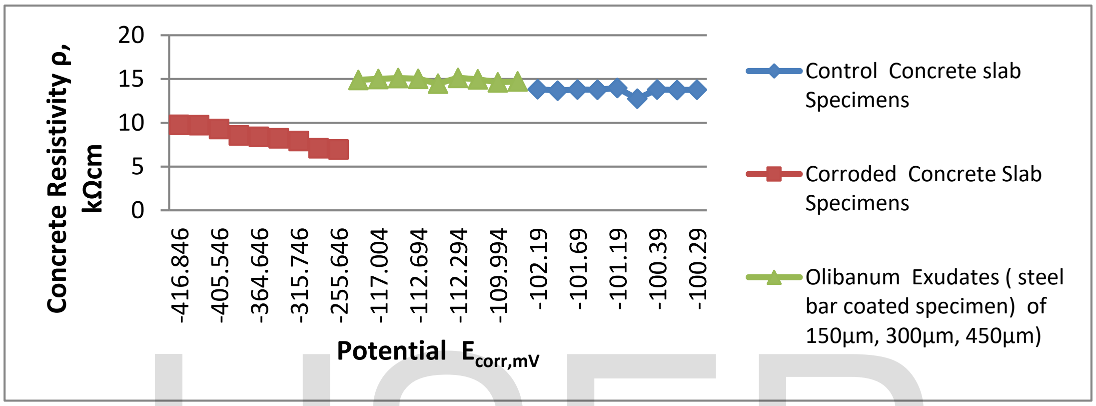

Figure 3.1: Concrete Resistivity ρ, kΩcm versus Potential $E_{corr,}$ ^{mV} Relationship

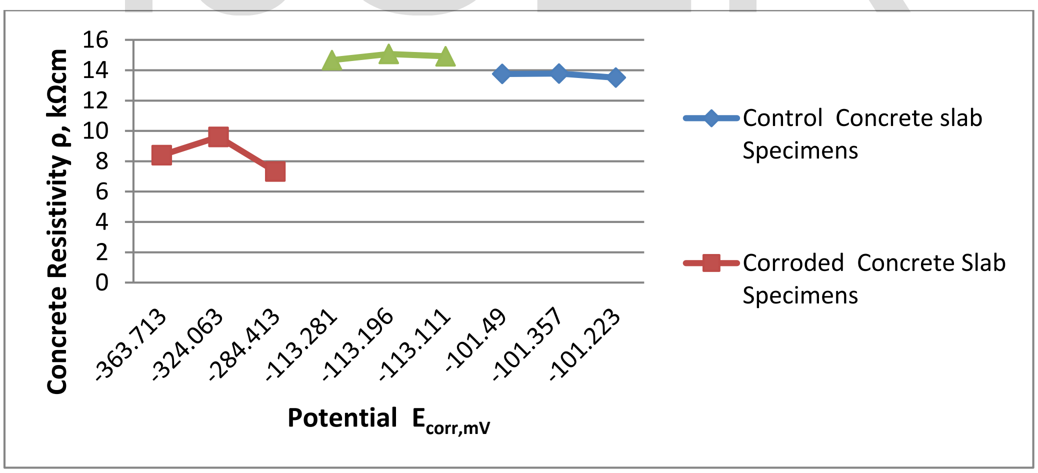

Figure 3.1A: Average Concrete Resistivity versus Potential Relationship

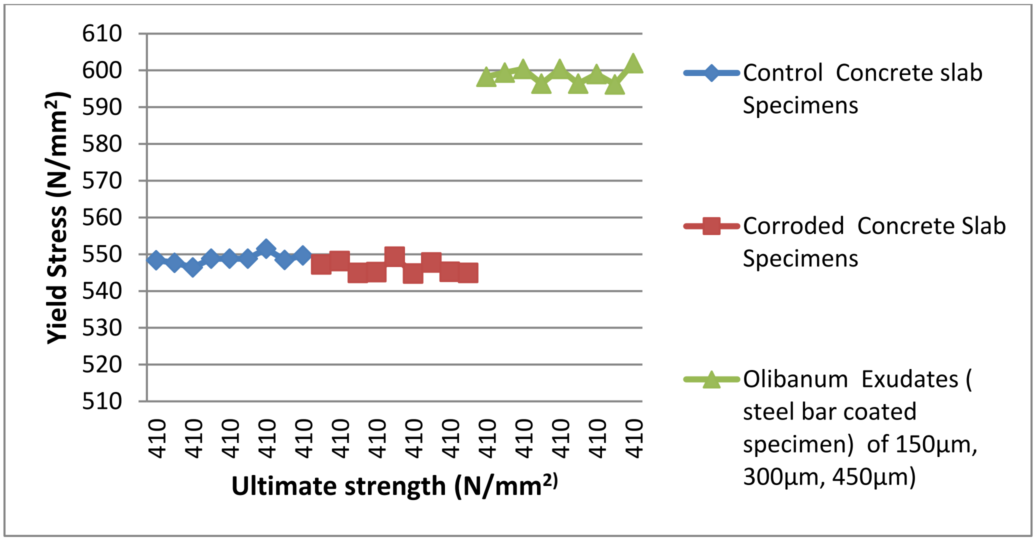

Figure 3.2: Yield Stress versus Ultimate strength

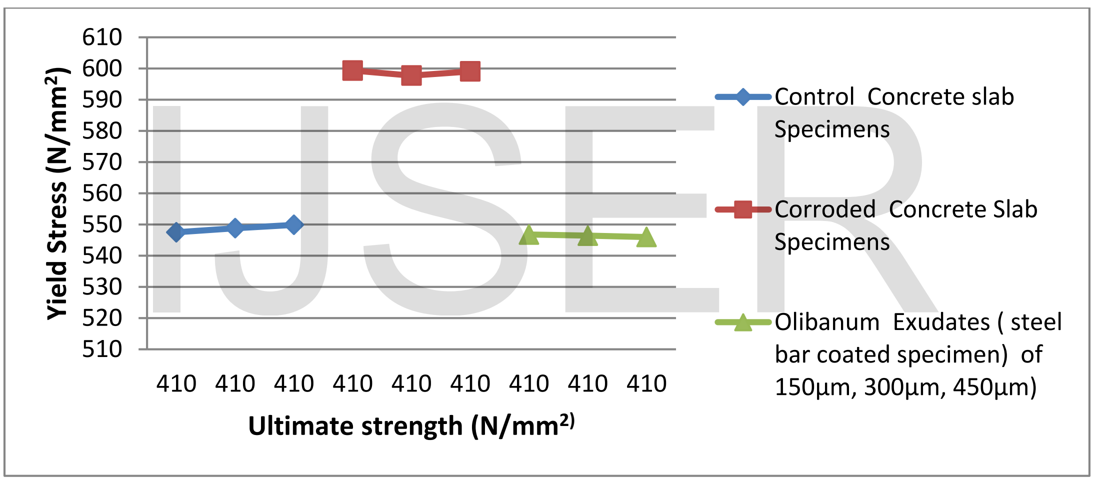

Figure 3.2A: Average Yield Stress versus Ultimate strength

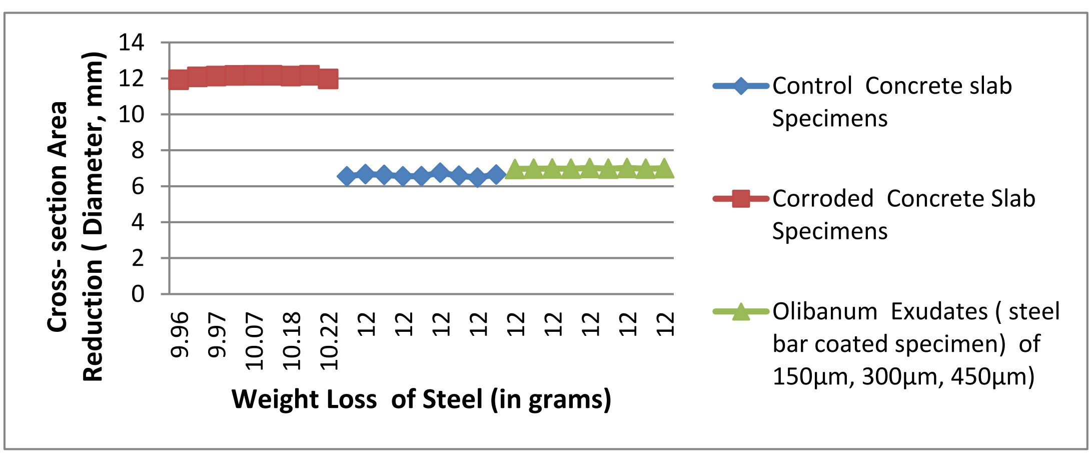

Figure 3.3: Weight Loss of Steel versus Cross- section Area Reduction

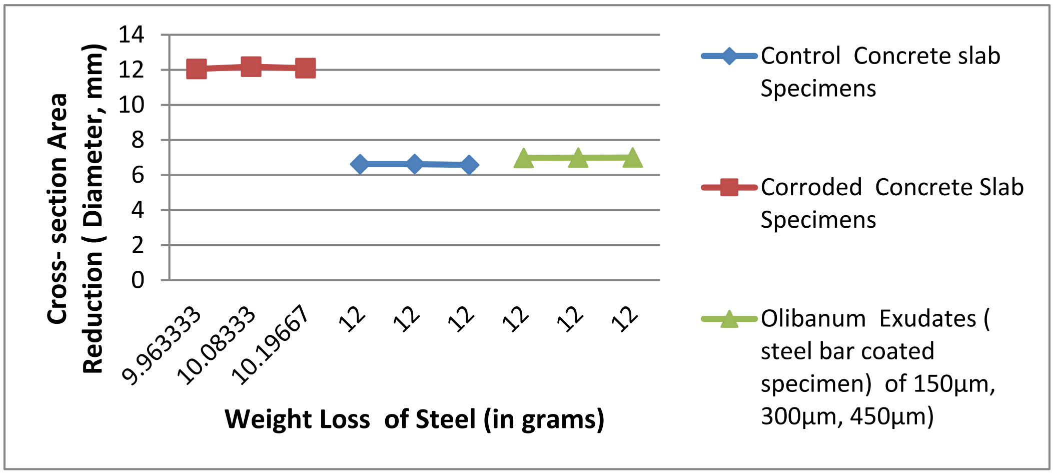

Figure 3.3A: Average Weight Loss of Steel versus Cross- section Area Reduction

4.0 Conclusion

Experimental results showed the following conclusions:

i. Control specimens result showed no corrosion potential, the presence of exudates / resins formed resistance coatings to the reinforcing steel embedded into concrete structures.

ii. Results of weight loss of steel indicated higher percentile values against control and coated specimen, this resulted from corrosion attack on surface and reduction of fibre / ribbed properties of the reinforcing steel.

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

iv. High ultimate yield results recorded of corroded specimens to control and coated specimens due to attack on the mechanical properties of the steel reinforcement

v. Corrosion potential manifested on corroded reinforcing steel.

vi. Results justified the effect of corrosion on the strength capacity of corroded and coated members.

vii. Inhibited specimens showed high level of protection against corroded

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