International Journal of Civil and Structural Engineering Research ISSN 2348-7607 (Online)
Vol. 7, Issue 2, pp: (1-12), Month: October 2019 - March 2020, Available at: www.researchpublish.com

Half-cell potential Measurement of Concrete Resistivity of Exudates Layered Reinforcement in Chloride threshold Corrosive Environment

Terence Temilade Tam Wokoma[1], Daso Dokibo[2], Charles Kennedy[3]

[1]School of Engineering, Department of Civil Engineering, Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria

[1]School of Engineering, Department of Mechanical Engineering, Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria

[1]Faculty of Engineering, Department of Civil Engineering, Rivers State University, Nkpolu, Port Harcourt, Nigeria.

Authors E-mail:, terencett.wokoma@gmail.com [2]mori7real@yahoo.com, [3]ken_charl@yahoo.co.uk

Abstract: **The fundamental concept of corrosion inhibition is the development of a stable compound with the metal surface and the formation of an adsorption complex with the metal oxide. This study evaluated the effect of salt water on reinforced concrete structures located in the costal marine environment. Corrosion accelerated simulated process was performed on non-coated and khaya senegalensis exudates / resins coated specimens for 150 days period and evaluate the actions of half cell potential, concrete resistivity and tensile strength of reinforcing steel embedded in concrete and exposed to corrosion. Results of concrete resistivity ρ, kΩcm against potential $E_{corr,}^{mV}$ relationship showed averaged potential E_{corr} control percentile average value of 30.33509% and percentile difference -69.6649% over 235.1921% corroded specimen. Results of concrete resistivity ρ, kΩcm percentile average value of 183.4935% and percentile difference 83.49351% over -30.1921% corroded specimen. Mechanical properties "ultimate strength" of control specimen value of 93.71429% and percentile difference -6.28571% over 7.138101% corroded specimen. Mechanical properties "weight loss of steel" of control percentile average value of 53.50441% and percentile difference -46.4956% over 91.49347% corroded. Mechanical properties "cross- section area reduction" of control specimen with percentile average value of 118.5055% and percentile difference 18.50551% over -15.6157% corroded specimen. Control specimens result showed no corrosion potential due to the presence of inhibitory exudates / resins that acted as an insulator to reinforcing steel embedded in corrosive environment**

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

1. INTRODUCTION

When steel corrodes the initial corrosion product formed can slightly improve the bond, but increasing the level of corrosion will often result in cracking and decrease in bond at the steel/concrete interface (Cabrera [1], Chung et al. [2]). The formation of rust involves a substantial volume increase (a factor of about 4) which causes cracking, spalling and staining of concrete, and reduces the effective cross-sectional area of reinforcing bars and weakens the bond between reinforcement and concrete, seriously affecting thedurability, and the service-life of structures (Almusallam et atl [3], Rashid et al.[4]). The fundamental concept of corrosion inhibition is the development of a stable compound with the metal surface and the formation of an adsorption complex with the metal oxide. Inhibitors are of three basic types: anodic, cathodic, and mixed. Anodic inhibitors function by arresting the reaction at the anode. In ideal situations, they react with existing corrosion products to form a highly insoluble film that adheres tightly to the metal surface. This film can act as a barrier to metal dissolution by preventing the metal surface from contacting the corrosive electrolyte.

Charles et al. [5] 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. Specimens of control, non-inhibited and resin inhibited specimens were cured for initial 28 days and corrosion acceleration process with Sodium Chloride lasted for 119days with 14 days checked intervals for readings. 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. [6] investigated the corrosion potential, concrete resistivity and tensile tests of non-corroded, 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 tests. 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.

Macdonald [7] 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. [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, 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.

Novokshcheov [9] 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[9]. Latter study by Skotinck [10] and Slater [11] showed that considering long-standing accelerated testing, calcium nitrite was of better quality in terms of strength.

Charles et al. [12] 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 Moringa Oleifera lam resin paste of trees extract. Specimens were embedded in concrete and accelerated in corrosive environment medium for 119 days. Average percentile results of potential Ecorr,mV, and concrete resistivity are 29.9% and 68.74% respectively. 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. [13] 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 [14] 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 coated thicknesses of 150µm, 250µm and 350µm specimens embedded in concrete, exposed to severe and corrosive environment medium for 119 days after 28 days. 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. [15] 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. 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. MATERIALS AND METHODS

2.1 Aggregates

The fine aggregate and coarse aggregate were purchased. Both met the requirements of BS 882 [16].

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 [17].

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 BS 12390-5; 2005 [18].

2.1.4 Structural Steel Reinforcement

The reinforcements are gotten directly from the market in Port Harcourt BS 4449:2005+A3 [19].

2.1.5 Corrosion Inhibitor (Resin / Exudate) Khaya senegalensis

The study inhibitor is Khaya senegalensis of natural tree resins /exudates substance extracts.

2.2 Methods

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
$E\text{corr} < -350\text{mV}$	Greater than 90% probability that reinforcing steel corrosion is occurring in that area at the time of measurement
$-350\text{mV} \le E\text{c}_{orr} \le -200\text{mV}$	Corrosion activity of the reinforcing steel in that area is uncertain
$E_{corr} > -200\text{mV}$	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 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.

3. RESULTS AND DISCUSSIONS

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 ($-350\text{mV} \leq E_{\text{corr}} \leq -200\text{mV}$), 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

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. The results of averaged potential E_{corr} control specimens are -101.681mV, -104.43mV, -105.038mV, summarized into -103.716mV, with percentile average value 29.83364% and percentile difference -70.1664% derived from tables 3.1 into 3.1A and plotted in figure3.1 and 3.1A of sampled slab concrete structures. Concrete resistivity ρ, kΩcm averaged results are 11.4222kΩcm, 11.17887kΩcm, 11.4522kΩcm, fused into 11.35109kΩcm with percentile average value 143.2503% and percentile difference 43.25028% from table 3.2 into 3.2A and plotted in figures 3.2 and 3.2A. Mechanical properties “ultimate strength” of control specimens are 547.8983N/mm^2, 547.5317N/mm^2, 547.0983N/mm^2, fused into 547.5094N/mm^2, with percentile average value 93.33748% and percentile difference -6.66252% from table 3.3 into 3.3A and plotted in figures 3.3 and 3.3A. Mechanical properties “weight loss of steel” of control specimens are 6.858667grams, 6.858667grams, 6.812grams, fused into 6.843111grams with percentile average value 52.2211% and percentile difference -47.7789% from table 3.4 into 3.4A and plotted in figures 3.4 and 3.4A. Mechanical properties “cross- section area reduction” of control are 12mm, 12mm, 12mm and fused into 12mm with percentile average value 118.5055% and percentile difference 18.50551% from table 3.5 into 3.5A and plotted in figures 3.5 and 3.5A. Control specimens result showed no corrosion potentials, it was tested with clean tap water for controlled results.

3.2 Corroded Concrete Slab Members

Average potential E_{corr} corroded specimens values derived from tables 3.1 into 3.1A are of -278.782mV-358.082mV, -406.082mV fused into -347.648mV, with percentile average value 335.1921% and percentile difference 235.1921% against -70.1664% and -69.6649% of control and coated specimens as presented in figures 3.1 and 3.1A. Obtained results of potential E_{corr} results of corroded specimens showed indications of high values with ranges of ($-350\text{mV} \leq E_{\text{corr}} \leq -200\text{mV}$), which indicates a 10% or uncertain probability of corrosion . Results of concrete resistivity ρ, kΩcm are 7.471733kΩcm, 7.881733

kΩcm, 8.4184kΩcm, derived into 7.923956kΩcm with percentile value of 69.80789% and percentile difference of -30.1921% against 43.25028% and 83.49351% of control and coated specimens from table 3.2 into 3.2A and plotted in figures 3.2 and 3.2A. 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" of control specimens are 587.2357N/mm^2, 585.6023N/mm^2, 586.9357N/mm^2, fused into 586.5912N/mm^2, with percentile value of 107.1381% and percentile difference 7.138101% against -6.66252% and -6.28571% of control and coated specimens from table 3.3 into 3.3A and plotted in figures 3.3 and 3.3A. Results elucidated and indications of low load application with potential of high ultimate yield of corroded specimens to control and coated specimens resulting from corrosion on the mechanical properties of the steel reinforcement with high surface change. 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 13.08933grams, 13.08933grams, 13.13367grams, fused into 13.10411grams with percentile average value 191.4935% and percentile difference 91.49347% against -47.7789% and -46.4956% of control and coated specimens. Results of weight loss of steel showed higher percentile values against control and coated specimens resulting from mechanical properties degradation of reinforcing steel from corrosion attack. Mechanical properties "cross- section area reduction" of control specimens are 10.04833mm, 10.04833mm, 10.28167mm and summarized into 10.12611mm with percentile average value 84.38426% and percentile difference -15.6157% against 18.50551% and 18.50551% from table 3.5 into 3.5A and plotted in figures 3.5 and 3.5A. Cross- section area reduction results showed higher percentile reduction values resulting from corrosion attack on mechanical properties of reinforcing steel due to effect of corrosion on the mechanical properties of steel.

3.3 Khaya senegalensis Exudate Steel Bar Coated Concrete Slab Members

Average values derived from tables 3.1, 3.1A and figures 3.1, 3.1A of control, corroded and exudates/resin coated specimens of concrete resistivity ρ, kΩcm against potential $E_{corr,}{}^{mV}$ relationship showed averaged potential E_{corr} control values of -106.175mV , -105.338mV, -104.865mV derived into -105.459mV, with percentile average value 30.33509% and percentile difference -69.6649% over 235.1921% corroded specimen. Results of concrete resistivity ρ, kΩcm are 14.31883kΩcm, 14.5755kΩcm, 14.7255kΩcm, fused into 14.53994kΩcm with percentile average value 183.4935% and percentile difference 83.49351% over -30.1921% corroded specimen from table 3.2 into 3.2A and plotted in figures 3.2 and 3.2A. Mechanical properties "ultimate strength" of control specimens are 548.492N/mm^2, 549.792N/mm^2, 550.8753N/mm^2, derived into 549.7198N/mm^2, with percentile average value 93.71429% and percentile difference -6.28571% over 7.138101% corroded specimen from table 3.3 into 3.3A and plotted in figures 3.3 and 3.3A. 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 7.0035grams, 7.0035grams, 7.026833grams, fused into 7.011278grams with percentile average value 53.50441% and percentile difference -46.4956% over 91.49347% 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 derived into 12mm with percentile average value 118.5055% and percentile difference 18.50551% over -15.6157% corroded specimen. Control specimens result showed no corrosion potential due to the presence of inhibitory exudates / resins that acted as an insulator to reinforcing steel embedded in corrosive environment.

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

	Potential Ecorr,mV								
	Time Intervals after 28 days curing								
Samples	AK1	AK2	AK3	AK4	AK5	AK6	AK7	AK8	AK9
Durations	(7days)	(21days)	(28days)	(58days)	(88days)	(118days)	(148days)	(163days)	(178days)
	Control Concrete slab Specimens								
CSQA1	-100.753	-103.376	-100.913	-106.616	-103.313	-103.36	-105.896	-103.752	-105.465
CSQB1	**Corroded Concrete Slab Specimens**								
	-250.015	-276.215	-310.115	-349.215	-359.015	-366.015	-399.915	-407.115	-411.215
	Khaya senegalensis exudates (steel bar coated specimen)								
	(150μm) coated			**(300μm) coated**			**(450μm) coated**		
CSQC1	-105.885	-105.555	-107.085	-104.255	-103.195	-108.565	-103.485	-107.255	-103.855

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

S/no	Samples	Average A{K(1,2,3)},(4,5,6)}, A{K(7,8,9)}			Summary Average A{K(1,2,3)},(4,5, 6)}, A{K(7,8,9)}	Percentile Average Values Average A{K(1,2,3)},(4,5, 6)}, A{K(7,8,9)}	Percentile Difference Average A{K(1,2,3)},(4,5,6)}, A{K(7,8,9)}
					Potential Ecorr,mV		
CSQA1	Control Specimens	-101.681	-104.43	-105.038	-103.716	29.83364	-70.1664
CSQB1	Corroded Specimens	-278.782	358.082	-406.082	-347.648	335.1921	235.1921
CSQC1	Coated Specimens	-106.175	-105.338	-104.865	-105.459	30.33509	-69.6649

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 Durations	AK1 (7days)	AK2 (21days)	AK3 (28days)	AK4 (58days)	AK5 (88days)	AK6 (118days)	AK7 (148days)	AK8 (163days)	AK9 (178days)
					Control Concrete slab Specimens				
CSQA2	11.3422	11.5122	11.4122	11.6422	11.4722	10.4222	11.4422	11.4422	11.4722
CSQB2					**Corroded Concrete Slab Specimens**				
	6.7684	6.9084	8.7384	7.0484	8.2184	8.3784	8.1184	8.5484	8.5884
CSQC2					**Khaya senegalensis exudates (steel bar coated specimen)**				
	(150μm) coated				**(300μm) coated**			**(450μm) coated**	
	14.1255	14.2755	14.5555	14.6855	14.3755	14.6655	14.6155	14.7655	14.7955

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{K(1,2,3)},(4,5,6)}, A{K(7,8,9)}			Summary Average A{K(1,2,3)},(4,5,6)}, A{K(7,8,9)}	Percentile Average Values Average A{K(1,2,3)}, (4,5,6)}, A{K(7,8,9)}	Percentile Difference Average A{K(1,2,3)}, (4,5,6)}, A{K(7,8,9)}
					Concrete Resistivity ρ, kΩcm		
CSQA2	Control Specimens	11.4222	11.17887	11.4522	11.35109	143.2503	43.25028
CSQB2	Corroded Specimens	**7.471733**	7.881733	8.4184	7.923956	69.80789	-30.1921
CSQC2	Coated Specimens	14.31883	14.5755	14.7255	14.53994	183.4935	83.49351

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

					Time Intervals after 28 days curing				
Samples Durations	AK1 (7days)	AK2 (21days)	AK3 (28days)	AK4 (58days)	AK5 (88days)	AK6 (118days)	AK7 (148days)	AK8 (163days)	AK9 (178days)
					Yield Stress (N/mm2) for Contro, Corroded and Coated Specimens				
CSQA3	410	410	410	410	410	410	410	410	410
					Ultimate strength (N/mm2)				
					Control Concrete slab Specimens				
CSQB3	548.365	549.265	546.065	546.265	550.465	545.865	548.865	546.365	546.065

CSQC3	**Corroded Concrete Slab Specimens**								
	586.169	587.269	588.269	584.269	588.269	584.269	586.869	584.069	589.869
CSQD3	**Khaya senegalensis exudates (steel bar coated specimen)**								
	(150µm) coated			**(300µm) coated**			**(450µm) coated**		
	549.392	548.692	547.392	549.792	549.792	549.792	552.492	549.442	550.692

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

S/no	Samples	Average A{K(1,2,3)},(4,5,6)}, A{K(7,8,9)}			Summary Average A{K(1,2,3)},(4,5,6)}, A{K(7,8,9)}	Percentile Average Values Average A{K(1,2,3)}, (4,5,6)}, A{K(7,8,9)}	Percentile Difference Average A{K(1,2,3)}, (4,5,6)}, A{K(7,8,9)}
				Ultimate strength (N/mm2)			
CSQB3	Control Specimens	547.8983	547.5317	547.0983	547.5094	93.33748	-6.66252
CSQC3	Corroded Specimens	587.2357	585.6023	586.9357	586.5912	107.1381	7.138101
CSQD3	Coated Specimens	548.492	549.792	550.8753	549.7198	93.71429	-6.28571

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

	Weight Loss of Steel (in grams)								
	Control Concrete slab Specimens								
CSQA4	6.792	6.912	6.872	6.792	6.802	6.992	6.822	6.722	6.892
CSQB4	**Corroded Concrete Slab Specimens**								
	12.963	13.131	13.174	13.211	13.217	13.219	13.17	13.22	13.011
CSQC4	**Khaya senegalensis exudates (steel bar coated specimen)**								
	(150µm) coated			**(300µm) coated**			**(450µm) coated**		
	6.9935	7.0035	7.0135	7.0035	7.0435	7.0035	7.0435	7.0035	7.0335

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

S/no	Samples	Average A{K(1,2,3)},(4,5,6)}, A{K(7,8,9)}			Summary Average A{K(1,2,3)},(4,5,6)}, A{K(7,8,9)}	Percentile Average Values Average A{K(1,2,3)}, (4,5,6)}, A{K(7,8,9)}	Percentile Difference Average A{K(1,2,3)}, (4,5,6)}, A{K(7,8,9)}
				Weight Loss of Steel (in grams)			
CSQA4	Control Specimens	6.858667	6.858667	6.812	6.843111	52.2211	-47.7789
CSQB4	Corroded Specimens	13.08933	13.08933	13.13367	13.10411	191.4935	91.49347
CSQC4	Coated Specimens	7.0035	7.0035	7.026833	7.011278	53.50441	-46.4956

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

	Cross- section Area Reduction (Diameter, mm)								
	Control Concrete slab Specimens								
CSQA5	12	12	12	12	12	12	12	12	12
CSQB5	**Corroded Concrete Slab Specimens**								
	10.045	10.045	10.055	10.125	10.155	10.225	10.265	10.275	10.305
	Khaya senegalensis exudates (steel bar coated specimen)								
	(150µm) coated			**(300µm) coated**			**(450µm) coated**		
CSQC5	12	12	12	12	12	12	12	12	12

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

S/no	Samples	Average A{K(1,2,3)}, (4,5,6)}, A{K(7,8,9)}			Summary Average A{K(1,2,3)},(4,5,6)}, A{K(7,8,9)}	Percentile Average Values Average A{K(1,2,3)}, (4,5,6)}, A{K(7,8,9)}	Percentile Difference Average A{K(1,2,3)}, (4,5,6)}, A{K(7,8,9)}
CSQA5	Control Specimens	12	12	12	12	118.5055	18.50551
CSQB5	Corroded Specimens	10.04833	10.04833	10.28167	10.12611	84.38426	-15.6157
CSQC5	Coated Specimens	12	12	12	12	118.5055	18.50551

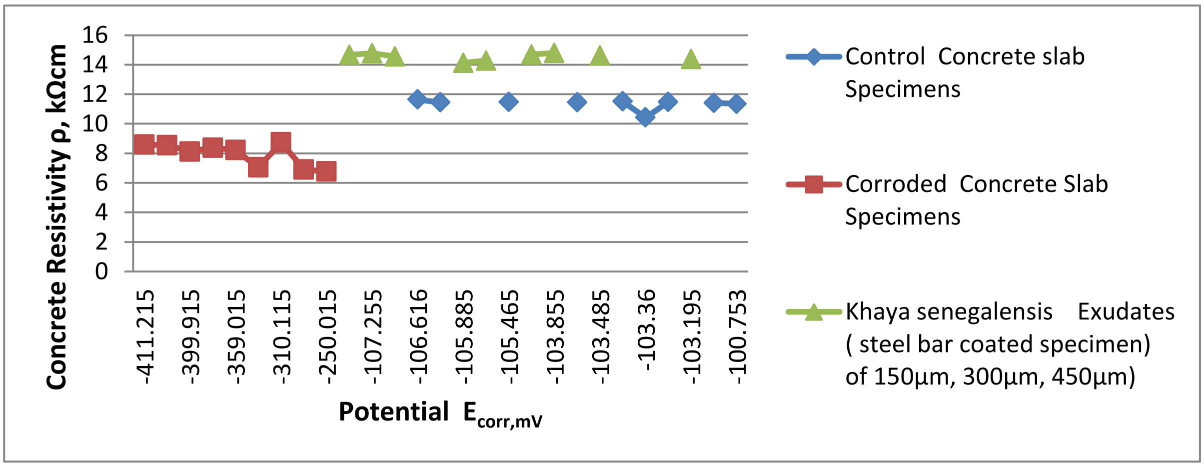


Figure 3.1: Concrete Resistivity versus Potential Relationship

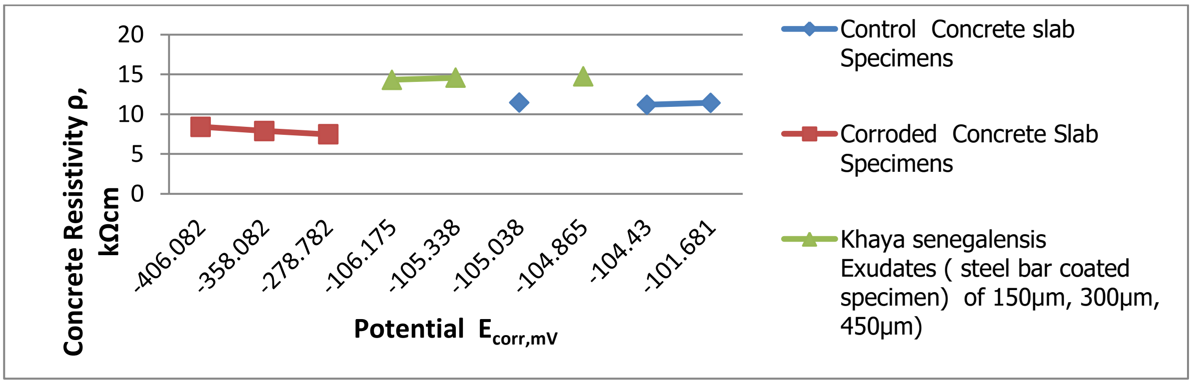
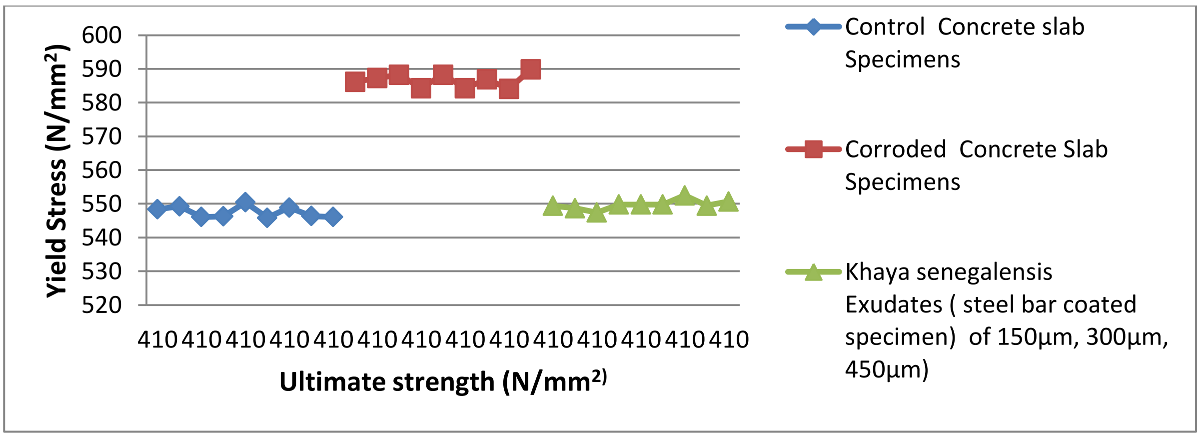


Figure 3.1A: Average Concrete Resistivity versus Potential Relationship



International Journal of Civil and Structural Engineering Research ISSN 2348-7607 (Online)
Vol. 7, Issue 2, pp: (1-12), Month: October 2019 - March 2020, Available at: www.researchpublish.com

Figure 3.2: Yield Stress versus Ultimate strength

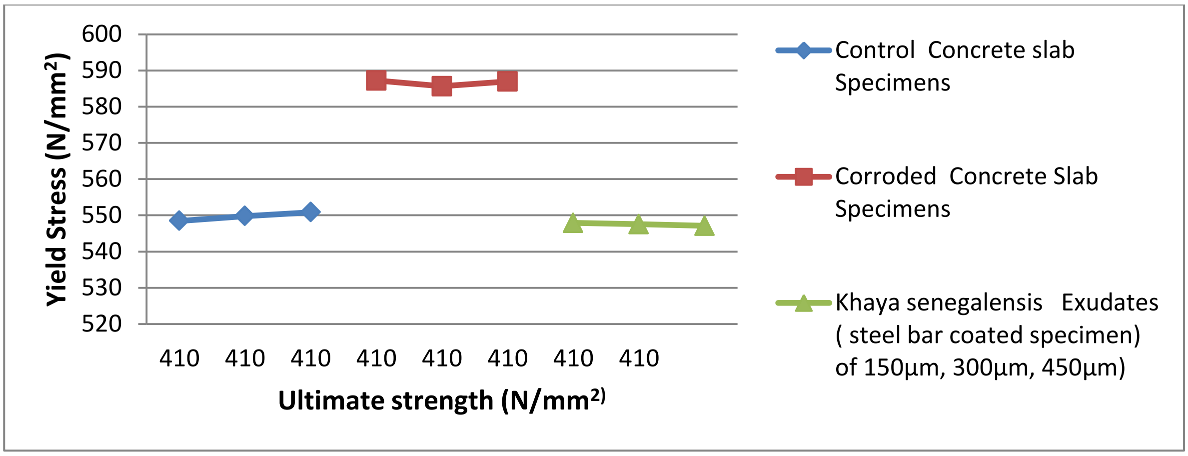


Figure 3.2A: Average Yield Stress versus Ultimate strength

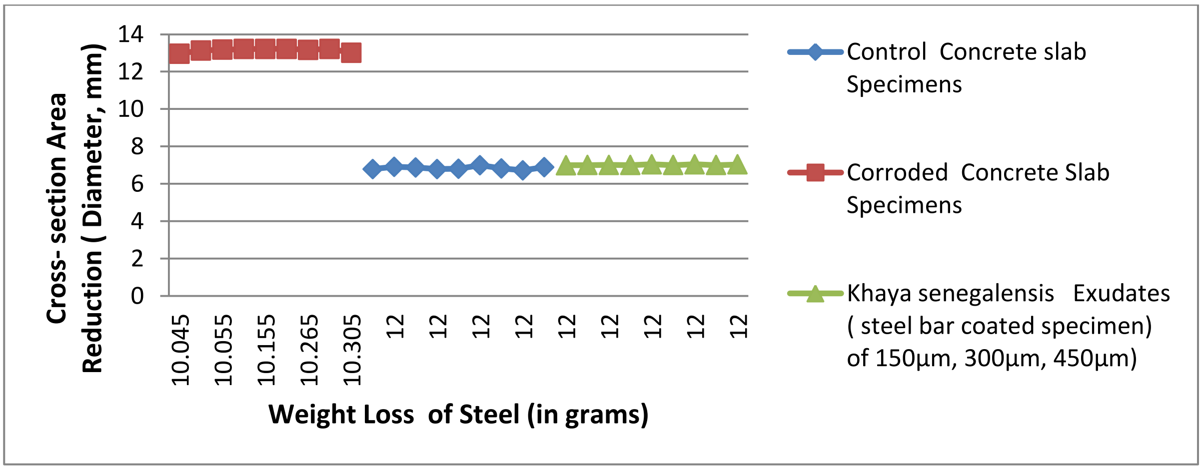


Figure 3.3: Weight Loss of Steel versus Cross- section Area Reduction

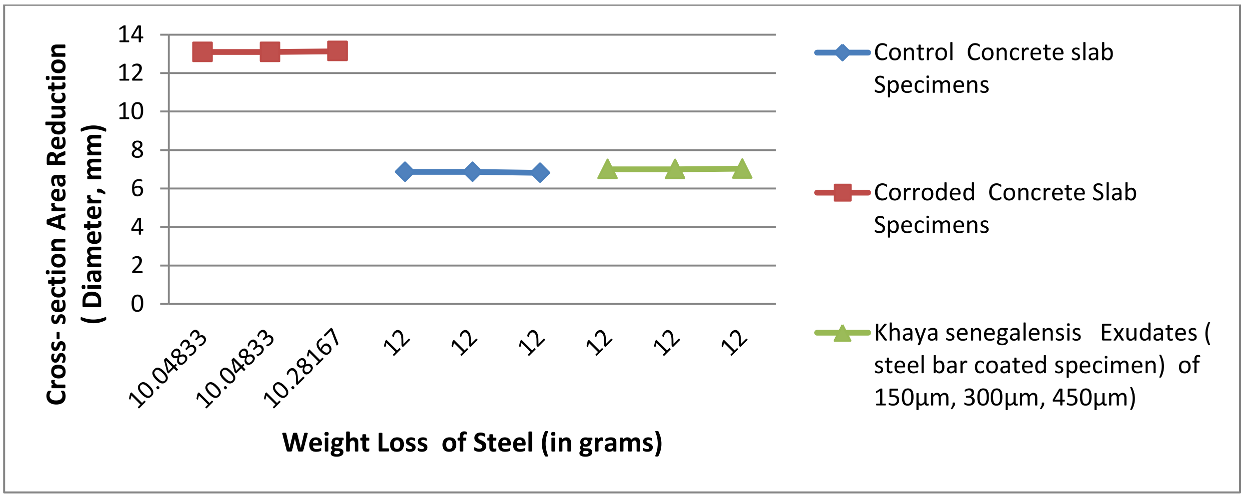


Figure 3.3A: Average Weight Loss of Steel versus Cross- section Area Reduction

4. CONCLUSION

Experimental results showed the following conclusions:

i. Control specimens result showed no corrosion potential due to the presence of inhibitory exudates / resins that acted as an insulator to reinforcing steel embedded in corrosive environment

ii. Cross- section area reduction results showed higher percentile reduction values resulting from corrosion attack on mechanical properties of reinforcing steel due to effect of corrosion on the mechanical properties of steel.

iii. Results of weight loss of steel showed higher percentile values against control and coated specimens resulting from mechanical properties degradation of reinforcing steel from corrosion attack.

iv. Entire results showed lower percentages in corroded and higher in coated members.

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

vi. Entire results showed higher values tensile strength values in non-corroded and coated to corroded specimens.

vii. Corrosion potential witnessed in corroded specimens.

REFERENCES

[1] Cabrera, J. G. (1999) .Deterioration of concrete due to reinforcement steel corrosion. Cement and Concrete Composites. 18:47-59.

[2] Chung, L., Kim, J. H., Yi, S.T. (2008). Bond Strength Prediction for Reinforced Concrete Members with HighlyCorroded Reinforcing Bars. Cement and Concrete Composites. 2008.

[3] Almusallam, A., Ahmed, S., Gahtani, A. and Rauf, A. (1995). Effect Of Reinforcement Corrosion on Bond Strength.Construction and Building Materials, 10:123-129.

[4] Rashid, M. H., Khatun, S., Uddin, S. M. K., and Nayeem, M. A. (2010). Effect of Strength and Covering on Concrete Corrosion. European Journal of Scientific Research, 40, 492-499

[5] Charles, K., Bright, A., and Irimiagha, P, G. (2018). Investigation on Mechanism of Steel Bar Corrosion of Reinforced Concrete Structures in Aqueous Solution Using Wenner Technique. *International Journal of Scientific & Engineering Research*, 9(4):1731-1748.

[6] Charles, K., Nwinuka, B., and Philip, K. F. O. (2018). Investigation of Corrosion Probability Assessment and Concrete Resistivity of Steel Inhibited Reinforcement of Reinforced Concrete Structures on Severe Condition. *International Journalof Scientific & Engineering Research*, 9(4): 1714 -1730.

[7] Macdonald, D. (2003). Design options for corrosion protection. 8th International Symposium. Australia:, 75-83.

[8] Charles, K., Irimiagha, and P. G., Bright, A. (2018). Investigation of Corrosion Potential Probability and Concrete Resistivity of Inhibited Reinforcement Chloride threshold in Corrosive Environment. *International Journal of Scientific and Engineering Research*, 9(4):1696 -1713.

[9] Novokshcheov, V. (2000). Salt Penetration and Corrosion in Pre-Stressed Concrete Member. Washington, D. C. Federal Highway.

[10] Skotinck, A. (2000). Corrosion of Concrete and its Prevention. 6th International Conference on Corrosion. Moscow, Russia:18-25.

[11] Slater, J. (2001). Corrosion of Metals in Association with Concrete. New Jerse, Prentice-Hall Inc. Stem M and Geary AL.Electrochemical polarisation: a theoretical analysis of the shape of polarisation curves. *Journal of the Electrochemical Society*, 104: 56-63.

[12] Charles, K., Taneh, A. N., and Watson, O. (2018). Electrochemical Potential Investigation of Inhibited Reinforcement Properties Embedded in Concrete in Accelerated Corrosive Medium. *International Journal of Scientific & Engineering Research*, 9(4):1608 -1625.

[13] Charles, K., Philip, K. F.O., and Taneh, A. N. (2018). Corrosion Potential Assessment of Eco-friendly Inhibitors Layered Reinforcement Embedded in Concrete Structures in Severe Medium. *International Journal of Scientific & EngineeringResearc*h, 9(4): 1590 -1607.

[14] Charles, K., Philip, K. F. O., and Watson, O. (2018). Comparative Half Cell Potential and Concrete Resistivity Corrosion Probability Assessment of Embedded Coated Steel Reinforcement in Concrete Accelerated Environment. *International Journal of Scientific & Engineering Research*, 9(4):141 -159.

[15] Charles, K., Gbinu, S. K., and Bright, A. (2018). Comparative Corrosion Probability Variance of Non-Inhibited and Inhibited Reinforcement in Concrete and Exposed to Accelerated Medium Using Wenner Method. *International Journal of Scientific & Engineering Research*, 9(4):160 -179.

[16] BS 882; - Specification for aggregates from natural sources for concrete, British Standards Institute. London, United Kingdom. 1992.

[17] BS EN 196-6; - Methods of Testing Cement. Determination of fineness, British Standards Institute. London, United Kingdom. 2010.

[18] BS 12390-5; 2005 – Testing Hardened Concrete: Flexural Strength Test of Specimens, British Standards Institute. London, United Kingdom. 2005.

[19] BS 4449:2005+A3 – (2010). Steel for Reinforcement of Concrete. British Standards Institute. London, United Kingdom,