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# Corrosion Influence on Mechanical Properties of Corroded and Inhibited Steel Bars in Concrete with Applied Currents Potential Measurement

Terence Temilade Tam Wokoma[1], Kanee Sorbari[2], Charles Kennedy[3]
[1,3]*School of Engineering, Department of Civil Engineering, Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria.*
[2]*School of Engineering, Department of Mechanical Engineering, Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria*
*Corresponding Author: Terence Temilade Tam Wokoma*

***ABSTRACT:*** *Reinforcing steel passivity is broken down by a loss of alkalinity due to chloride attack or carbonation of concrete structures found in the coastal marine environment. Investigative studies on the diminution of the trend of passivity loss was evaluated with the use of natural inorganic exudates / resins paste of milicia excels on 12mm diameter reinforcement with coated varying thicknesses of 150µm, 300µm and 450µm, embedded in concrete slab specimens, immersed partially in corrosive media with accelerated applied currents potential of -200 mV through 1200mV, with a scan rate of 1mV/s to examined half cell potential, concrete resistivity and tensile strength properties for non- coated ( corroded) and coated concrete specimens. Results of concrete resistivity ρ, kΩcm versus potential $E_{corr,}^{mV}$ relationship which showed average potential $E_{corr}$ coated percentile value of 31.81826% and percentile difference -68.1817% over 232.0581% corroded specimen. Obtained average results of concrete resistivity ρ, percentile average value is 185.4484% and percentile difference 85.44844% over -41.9254% corroded specimen. Obtained average mechanical properties "ultimate strength" of coated specimen percentile value of 97.66965% and percentile difference -2.33035% over 7.621406% corroded specimen. Average mechanical properties "weight loss of steel" of coated percentile value of 58.97121% and percentile difference -41.0288% over 70.73893% corroded. Average mechanical properties "cross- section area reduction" of coated percentile average value 114.0564% and percentile difference 14.05639% over -12.3241% corroded specimen. Coated specimens result showed no corrosion potential. Corroded specimen cross- section area reduction results showed higher percentile reduction values due to effect of corrosion on the mechanical properties of steel. Corroded specimen results of weight loss of steel showed higher percentile values against control and coated specimens due to surface attack and fibre/ribbed removal from corrosion effect on the mechanical properties of steel. High ultimate yields of corroded specimens with low load application to control and coated specimens resulted to corrosion attack on the mechanical properties of steel reinforcement*

***KEY WORDS:****Corrosion, Corrosion inhibitors, Concrete and Steel Reinforcement*

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## I. INTRODUCTION

The effect of corrosion of reinforcing steel embedded in the harsh and salt water environment is protected by a passive layer. Corrosion tends to result in a relatively uniform removal of a surface but specific features in the surface of the metal may be attacked. Reinforced concrete structures in the marine environment are most susceptible to chloride-induced corrosion of reinforcement due to the presence of high chloride concentrations and humid or saturated conditions. The steel passivity can, however, be broken down by a loss of alkalinity due to chloride attack or carbonation of concrete; this phenomenon leads to an increased vulnerability of steel reinforcement to corrosion [1]. Approaches to control these factors have used inhibitors, electrochemical protection procedures, scavengers, buffers, and coatings [2].

[3] Stated that the passive potential range is very wide for steel and it is normally about +200 to -700mV saturated calomel electrode (SCE) at pH =13. Potentials more positive than +200 mV SCE cause

evolution of oxygen on passive steel. The evolution of oxygen causes decline in OH concentration at the steel/concrete interface. The oxygen evolution also causes pool of water at the steel-concrete interface and hence may decrease the local resistivity. The corrosion rate under these conditions is about 0.04mpy at steel surface which is higher for the passive condition with a reduction of oxygen; this value is still low and acceptable for most concrete structure (4], [5], [6]). However, the evolution of the hydrogen can lead to the embrittlement of prestressed steel in both pretensioned and posttensioned structures and resulting in their sudden failures ([7], [8].

[9] 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. 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. 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.

[10] 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 150 m, 250 m, 350 m 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.

[11] 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.

[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. 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 29.9% and 68.74% respectively. 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.

[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. 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. Average percentile results of potential Ecorr,mV, and concrete resistivity are 26.57% and 61.25% respectively.

[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 specimen. 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. When compared to corroded samples, corroded has 70.1% increased values potential Ecorr,mV and 35.5% decreased values of concrete resistivity.

[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.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. When compared to corroded samples, corroded has 70.1% incremented values potential Ecorr,mV and 38.8% decremented values of concrete resistivity.

## II. MATERIALS AND METHODS FOR EXPERINMENT

**Aggregates**

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

**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 [17]

**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 [18]

**Structural Steel Reinforcement**

The reinforcements are gotten directly from the market in Port Harcourt [19]

**Corrosion Inhibitors (Resins / Exudates) Milicia excelsa**

The study inhibitor is Milicia excelsa of natural tree resins /exudates substance extracts.

**Experimental Procedures and Method**

**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

**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.

**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. 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).

**Table 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 |
| $-350mV \leq Ec_{orr} \leq -200mV$ | 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 |

**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 Dependence between concrete resistivity and corrosion probability**

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

**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 1 were plotted against concrete resistivity of table 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 $E$corr is high ($-350\text{mV} \le E_{\text{corr}} \le -200\text{mV}$), which indicates a 10% or uncertain probability of corrosion. Results of the concrete resistivity measurements are shown in Table 3. It is evident that potential $E_{\text{corr}}$ 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.

**Control Concrete Slab Members**

Results obtained from table 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. Results of potential $E_{corr,}^{mV}$ average control specimens derived from tables 3 into 4 are -102.87mV, -104.902mV, -105.51mV, summed up to -104.427mV, with percentile average value 30.11521% and percentile difference -69.8848%. Results of concrete resistivity ρ, kΩcm from table 5 into 6 are 13.776kΩcm, 13.532677kΩcm, 13.8062kΩcm, summed up to 13.70489kΩcm with percentile average value 172.1924% and percentile difference 72.1924%. Mechanical properties "ultimate strength" of control specimens from table 5 into 6 are 545.9283N/mm$^2$, 545.5617N/mm$^2$, 545.1283N/mm$^2$, summed up to 545.5394N/mm$^2$, with percentile average value 92.91832% and percentile difference -7.08168%. Mechanical properties "weight loss of steel" of control from table 7 into 8, 7.028667grams, 7.028667grams, 6.982grams, fused into 7.013111grams with percentile average value 58.56895% and percentile difference -41.4311%. Mechanical properties "cross- section area reduction" of control specimen from table 9 into 10 are 12mm, 12mm, 12mm and summed up to 12mm with percentile average value 114.0564% and percentile difference 14.05639%. Control specimens result showed no corrosion potential. Graphical presentations in figures 1 to 6 are the behaviors of the experimental work for concrete resistivity ρ, kΩcm versus potential $E_{corr}$,mV relationship, average concrete resistivity versus potential relationship, average yield stress versus ultimate strength, weight loss of steel loss versus cross- section area reduction and average weight loss of steel loss versus cross- section area

**Corroded Concrete Slab Members**

Tables 3 into 4 showed the average values derived from 9 slab samples of control, corroded and exudates/resin coated specimens presented in figures 1 and 2 of Potential $E_{corr,}^{mV}$. Results of average corroded potential $E_{corr}$ values are -277.893mV, -357.193mV, -405.193mV summed up to -346.759mV, with percentile value of 332.0581% and percentile difference 232.0581% against -69.8848% and -68.1817% of control and coated specimens. Potential $E_{corr}$ results showed indications corroded specimens are of high values of range ($-350\text{mV} \le E_{\text{corr}} \le -200\text{mV}$), which indicates a 10% or uncertain probability of corrosion. Average results of concrete resistivity ρ, kΩcm from table 3 into 4 and plotted in figures 5 and 6 are 7.506833kΩcm, 7.916833kΩcm, 8.4535kΩcm, summed up to 7.959056kΩcm with percentile average value 58.07457% and percentile difference -41.9254% against 72.1924% and 85.44844% 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. Average mechanical properties "ultimate strength" of control specimens from table 5 into 6 and plotted in figures 3 and 4 are 587.7617N/mm$^2$, 586.1283N/mm$^2$, 587.4617N/mm$^2$, summed up to 587.1172N/mm$^2$, with percentile average value 107.6214% and percentile difference 7.621406% against -7.08168% and -2.33035% of control and coated specimens. High ultimate yields of corroded specimens with low load application to control and coated specimens resulted to corrosion attack on the mechanical properties of steel reinforcement. Average Mechanical properties "weight loss of steel" of corroded specimens from table 7 into 8 and plotted in figures 5 and 6 are 11.95933grams, 11.95933grams, 12.00367grams, summed up to 11.97411grams with percentile average value 170.7389% and percentile difference 70.73893% against -41.4311% and -41.0288% of control and coated specimens. Results of weight loss of steel showed higher percentile values against control and coated specimens due to surface attack and fibre/ribbed removal from corrosion effect on the mechanical properties of steel. Average mechanical properties "cross- section area reduction" of control from table 9 into 10 and plotted in figures 5 and 6 are 10.44333mm, 10.44333mm, 10.67667mm and fused into 10.52111mm with percentile average value 87.67593% and percentile difference -12.3241% against 14.05639% and 14.05639%. Cross- section area reduction results showed higher percentile reduction values due to effect of corrosion on the mechanical properties of steel.

**Milicia Excelsa Exudate Steel Bar Coated Concrete Slab Members**

Results from tables 3 into 4 is the average values derived of control, corroded and exudates/resin coated specimens presented in figures 1 and 2 of concrete resistivity ρ, kΩcm versus potential $E_{corr,}^{mV}$ relationship which showed average potential $E_{corr}$ coated values of -110.382mV , -110.212mV, -110.405mV fused into -110.333mV, with percentile average value 31.81826% and percentile difference -68.1817% over

232.0581% corroded specimen. Obtained average results of concrete resistivity ρ, kΩcm from table 3.2 into 3.2A and plotted in figures 3.2 and 3.2A are 14.53883kΩcm, 14.7955kΩcm, 14.9455kΩcm, fused into 14.759944kΩcm with percentile average value 185.4484% and percentile difference 85.44844% over -41.9254% corroded specimen. Obtained average mechanical properties "ultimate strength" of coated specimens from table 5 into 6 and plotted in figures 3 and 4 are 546.996N/mm$^2$, 585.9883N/mm$^2$, 587.3217N/mm$^2$, fused into 573.4353N/mm$^2$, with percentile average value 97.66965% and percentile difference -2.33035% over 7.621406% corroded specimen. Average Mechanical properties "weight loss of steel" of control from table 7 into 8 and plotted in figures 4 and 5 are 7.0535grams, 7.0535grams, 7.076833grams, fused into 7.061278grams with percentile average value 58.97121% and percentile difference -41.0288% over 70.73893% corroded . Average mechanical properties "cross- section area reduction" of coated from table 11 into 12 and plotted in figures 3 and 4 are 12mm, 12mm, 12mm and fused into 12mm with percentile average value 114.0564% and percentile difference 14.05639% over -12.3241% corroded specimen.

**Table 3 Potential Ecorr, after 28 days curing and 150 days Accelerated Periods**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Potential $E_{corr,mV}$** | | | | | | | | |
| | Time Intervals after 28 days curing | | | | | | | | |
| Samples | AI1 | AI2 | AI3 | AI4 | AI5 | AI6 | AI7 | AI8 | AI9 |
| Durations | ( 7days) | ( 21days) | ( 28days) | ( 58days) | (88days) | (118days) | (148days) | (163days) | (178days) |
| | **Control Concrete slab Specimens** | | | | | | | | |
| CSOA1 | -103.375 | - 103.848 | - 101.385 | -107.088 | -103.785 | -103.832 | -106.368 | -104.224 | -105.937 |
| CSOB1 | **Corroded Concrete Slab Specimens** | | | | | | | | |
| | -249.126 | - 275.326 | - 309.226 | -348.326 | -358.126 | -365.126 | -399.026 | -406.226 | -410.326 |
| | **Milicia excelsa exudates ( steel bar coated specimen)** | | | | | | | | |
| | **(150µm) coated** | | | **(300µm) coated** | | | **(450µm) coated** | | |
| CSOC1 | -109.425 | - 107.095 | - 114.625 | -109.795 | -106.735 | -114.105 | -109.025 | -112.795 | -109.395 |

**Table 4 Average Potential Ecorr, after 28 days curing and 150 days Accelerated Periods**

| S/no | Samples | Average A{I(1,2,3)},(4,5,6)}, A{I(7,8,9)} | | | Summary Average A{I(1,2,3)},(4,5,6)} A{I(7,8,9)} | Percentile Average Values Average A{I(1,2,3)}, (4,5,6)}, A{I(7,8,9)} | Percentile Difference Average A{I(1,2,3)}, (4,5,6)}, A{I(7,8,9)} |
|---|---|---|---|---|---|---|---|
| | **Potential $E_{corr,mV}$** | | | | | | |
| CSOA1 | Control Specimens | -102.87 | -104.902 | -105.51 | -104.427 | 30.11521 | -69.8848 |
| CSOB1 | Corroded Specimens | -277.893 | -357.193 | - 405.193 | -346.759 | 332.0581 | 232.0581 |
| CSOC1 | Coated Specimens | -110.382 | -110.212 | - 110.405 | -110.333 | 31.81826 | -68.1817 |

**Table 5 Results of Concrete Resistivity ρ, kΩcm Time Intervals after 28 days curing and 150 days Accelerated Periods**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Concrete Resistivity ρ, kΩcm** | | | | | | | | |
| | Time Intervals AIter 28 days curing | | | | | | | | |
| Samples | AI1 | AI2 | AI3 | AI4 | AI5 | AI6 | AI7 | AI8 | AI9 |
| Durations | ( 7days) | (21days) | (28days) | (58days) | (88days) | (118days) | (148days) | (163days) | (178days) |
| | **Control Concrete slab Specimens** | | | | | | | | |
| CSOA2 | 13.696 | 13.866 | 13.766 | 13.996 | 13.826 | 12.776 | 13.796 | 13.796 | 13.826 |
| CSOB2 | **Corroded Concrete Slab Specimens** | | | | | | | | |
| | **6.8035** | **6.9435** | **8.7735** | **7.0835** | **8.2535** | **8.4135** | **8.1535** | **8.5835** | **8.6235** |
| CSOC2 | **Milicia excelsa exudates ( steel bar coated specimen)** | | | | | | | | |
| | **(150µm) coated** | | | **(300µm) coated** | | | **(450µm) coated** | | |
| | 14.3455 | 14.4955 | 14.7755 | 14.9055 | 14.5955 | 14.8855 | 14.8355 | 14.9855 | 15.0155 |

**Table 6 Average Results of Concrete Resistivity ρ, kΩcm Time Intervals after 28 days curing and 150 days Accelerated Periods**

| S/no | Samples | Average A{I(1,2,3)},(4,5,6)}, A{I(7,8,9)} | | | Summary Average A{I(1,2,3)},(4,5,6)} A{I(7,8,9)} | Percentile Average Values Average A{I(1,2,3)}, (4,5,6)}, A{I(7,8,9)} | Percentile Difference Average A{I(1,2,3)}, (4,5,6)}, A{I(7,8,9)} |
|---|---|---|---|---|---|---|---|
| | **Concrete Resistivity ρ, kΩcm** | | | | | | |
| CSOA2 | Control Specimens | 13.776 | 13.53267 | 13.806 | 13.70489 | 172.1924 | 72.1924 |
| CSOB2 | Corroded Specimens | **7.506833** | 7.916833 | 8.4535 | 7.959056 | 58.07457 | -41.9254 |
| CSOC2 | Coated Specimens | 14.53883 | 14.7955 | 14.9455 | 14.75994 | 185.4484 | 85.44844 |

**Table 7 Mechanical properties of Control, Corroded and Steel Coated Concrete Slab**

| | Time Intervals after 28 days curing | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Samples | AI1 | AI2 | AI3 | AI4 | AI5 | AI6 | AI7 | AI8 | AI9 |
| Durations | ( 7days) | (21days) | (28days) | (58days) | (88days) | (118days) | (148days) | (163days) | (178days) |
| | **Yield Stress (N/mm2) for Control, Corroded and Coated Specimens** | | | | | | | | |
| CSOA3 | 410 | 410 | 410 | 410 | 410 | 410 | 410 | 410 | 410 |
| | **Ultimate strength (N/mm2)** | | | | | | | | |
| | **Control Concrete slab Specimens** | | | | | | | | |
| CSOB3 | 546.395 | 547.295 | 544.095 | 544.295 | 548.495 | 543.895 | 546.895 | 544.395 | 544.095 |
| CSOC3 | **Corroded Concrete Slab Specimens** | | | | | | | | |
| | 586.695 | 587.795 | 588.795 | 584.795 | 588.795 | 584.795 | 587.395 | 584.595 | 590.395 |
| CSOD3 | **Milicia excelsa exudates ( steel bar coated specimen)** | | | | | | | | |
| | **(150μm) coated** | | | **(300μm) coated** | | | **(450μm) coated** | | |
| | 550.116 | 549.416 | 548.116 | 550.516 | 550.516 | 550.516 | 553.216 | 550.166 | 551.416 |

**Table 8 Average Mechanical properties of Control, Corroded and Coated Concrete Slab**

| S/no | Samples | Average A{I(1,2,3)},(4,5,6)}, A{I(7,8,9)} | | | Summary Average A{I(1,2,3)},(4,5,6)} A{I(7,8,9)} | Percentile Average Values Average A{I(1,2,3)}, (4,5,6)}, A{I(7,8,9)} | Percentile Difference Average A{I(1,2,3)}, (4,5,6)}, A{I(7,8,9)} |
|---|---|---|---|---|---|---|---|
| | **Ultimate strength (N/mm2)** | | | | | | |
| CSOB3 | Control Specimens | 545.9283 | 545.5617 | 545.1283 | 545.5394 | 92.91832 | -7.08168 |
| CSOC3 | Corroded Specimens | 587.7617 | 586.1283 | 587.4617 | 587.1172 | 107.6214 | 7.621406 |
| CSOD3 | Coated Specimens | 546.996 | 585.9883 | 587.3217 | 573.4353 | 97.66965 | -2.33035 |

**Table 9 Mechanical properties of Control, Corroded and Coated Concrete Slab**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Weight Loss of Steel (in grams)** | | | | | | | | |
| | **Control Concrete slab Specimens** | | | | | | | | |
| CSOA4 | 6.962 | 7.082 | 7.042 | 6.962 | 6.972 | 7.162 | 6.992 | 6.892 | 7.062 |
| CSOB4 | **Corroded Concrete Slab Specimens** | | | | | | | | |
| | 11.833 | 12.001 | 12.044 | 12.081 | 12.087 | 12.089 | 12.04 | 12.09 | 11.881 |
| CSOC4 | **Milicia excelsa exudates ( steel bar coated specimen)** | | | | | | | | |
| | **(150μm) coated** | | | **(300μm) coated** | | | **(450μm) coated** | | |
| | 7.0435 | 7.0535 | 7.0635 | 7.0535 | 7.0935 | 7.0535 | 7.0935 | 7.0535 | 7.0835 |

**Table 10 Average Mechanical properties of Control, Corroded and Coated Concrete Slab**

| S/no | Samples | Average A{I(1,2,3)},(4,5,6)}, A{I(7,8,9)} | | | Summary Average A{I(1,2,3)},(4,5,6)}A{I(7,8,9)} | Percentile Values Average Average A{I(1,2,3)}, (4,5,6)}, A{I(7,8,9)} | Percentile Difference Average A{I(1,2,3)}, (4,5,6)}, A{I(7,8,9)} |
|---|---|---|---|---|---|---|---|
| | **Weight Loss of Steel (in grams)** | | | | | | |
| CSOA4 | Control Specimens | 7.028667 | 7.028667 | 6.982 | 7.013111 | 58.56895 | -41.4311 |
| CSOB4 | Corroded Specimens | 11.95933 | 11.95933 | 12.00367 | 11.97411 | 170.7389 | 70.73893 |
| CSOC4 | Coated Specimens | 7.0535 | 7.0535 | 7.076833 | 7.061278 | 58.97121 | -41.0288 |

**Table 11 Mechanical properties of Control, Corroded and Coated Concrete Slab**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Cross- section Area Reduction ( Diameter, mm)** | | | | | | | | |
| | **Control Concrete slab Specimens** | | | | | | | | |
| CSOA5 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| CSOB5 | **Corroded Concrete Slab Specimens** | | | | | | | | |
| | 10.44 | 10.44 | 10.45 | 10.52 | 10.55 | 10.62 | 10.66 | 10.67 | 10.7 |
| | **Milicia excelsa exudates ( steel bar coated specimen)** | | | | | | | | |
| | **(150µm) coated** | | | **(300µm) coated** | | | **(450µm) coated** | | |
| CSOC5 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |

**Table 12 Average Mechanical properties of Control, Corroded and Coated Concrete Slab**

| S/no | Samples | Average A{I(1,2,3)},(4,5,6)}, A{I(7,8,9)} | | | Summary Average A{I(1,2,3)},(4,5,6)} A{I(7,8,9)} | Percentile Average Values Average A{I(1,2,3)}, (4,5,6)}, A{I(7,8,9)} | Percentile Difference Average A{I(1,2,3)}, (4,5,6)}, A{I(7,8,9)} |
|---|---|---|---|---|---|---|---|
| | **Cross- section Area Reduction ( Diameter, mm)** | | | | | | |
| CSOA5 | Control Specimens | 12 | 12 | 12 | 12 | 114.0564 | 14.05639 |
| CSOB5 | Corroded Specimens | 10.44333 | 10.44333 | 10.67667 | 10.52111 | 87.67593 | -12.3241 |
| CSOC5 | Coated Specimens | 12 | 12 | 12 | 12 | 114.0564 | 14.05639 |

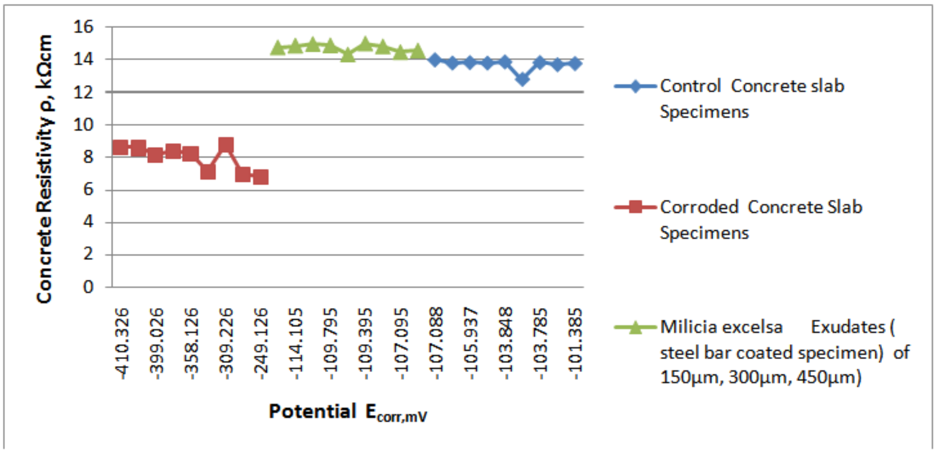


**Fig. 1. Concrete Resistivity ρ, kΩcm versus Potential Ecorr,mV Relationship**

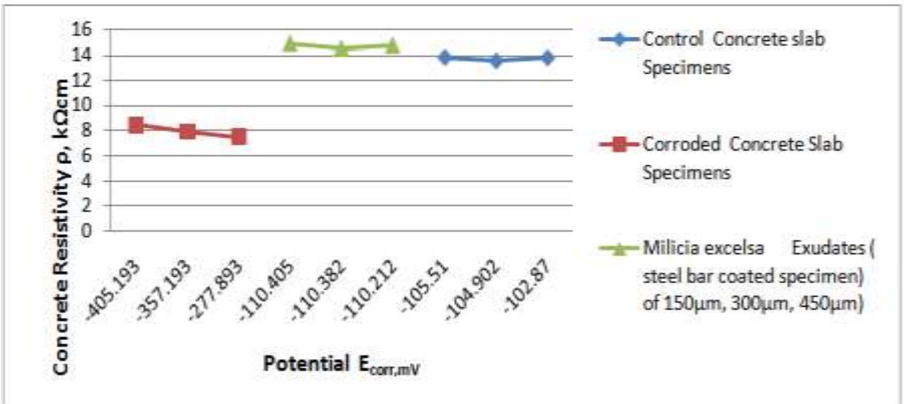


**Fig. 2. Average Concrete Resistivity versus Potential Relationship**

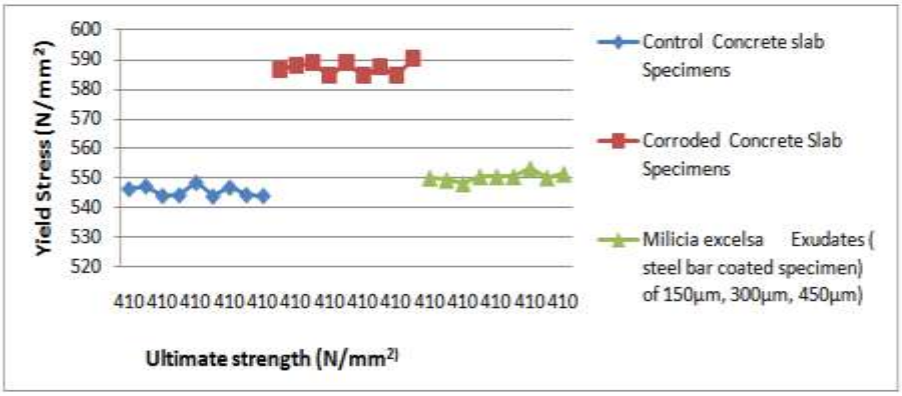


**Fig. 3. Yield Stress versus Ultimate strength**

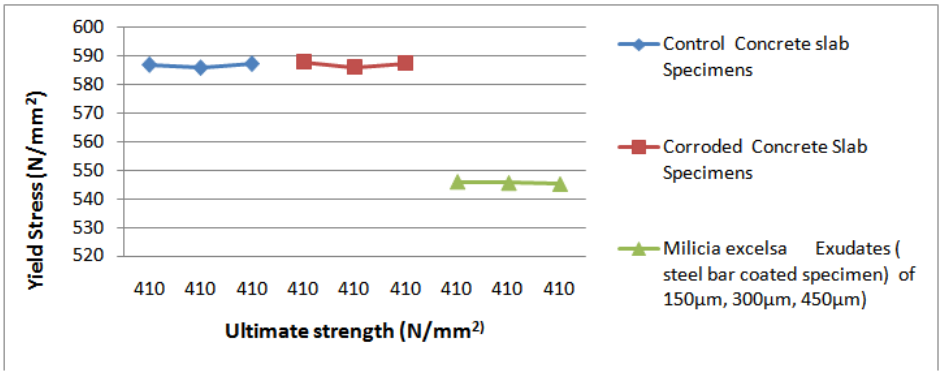


**Fig.4. Average Yield Stress versus Ultimate strength**

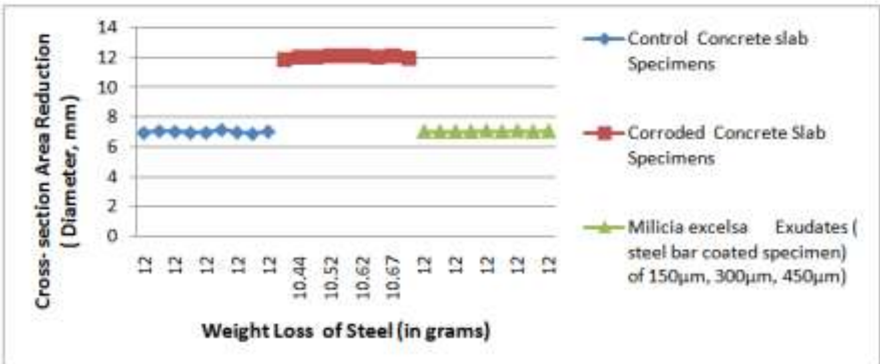


**Fig. 5. Weight Loss of Steel versus Cross- section Area Reduction**

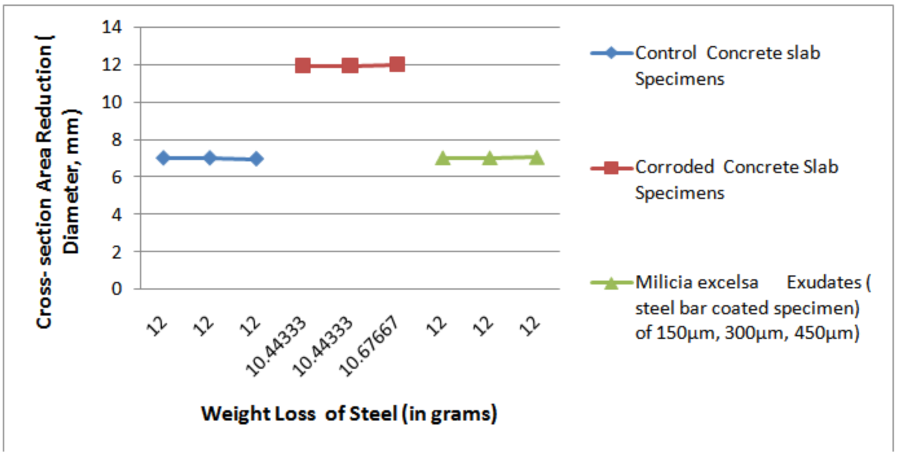


**Fig. 6. Average Weight Loss of Steel versus Cross- section Area Reduction**

## IV. CONCLUSION

Experimental results showed the following conclusions:

i. Cross- section area reduction results showed higher percentile reduction values due to effect of corrosion on the mechanical properties of steel
ii. Results of weight loss of steel showed higher percentile values against control and coated specimens due to surface attack and fibre/ribbed removal from corrosion effect on the mechanical properties of steel
iii. High ultimate yields of corroded specimens with low load application to control and coated specimens resulted to corrosion attack on the mechanical properties of steel reinforcement
iv. Corrosion potential was obtained from non-inhibited specimens
v. Results justified the effective use of resins of trees extract as corrosion inhibitors
vi. Entire results showed higher values of non-corroded and coated to corroded specimens
vii. In comparison, tensile strength of inhibited reinforcements is higher to the corroded specimens.

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