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# Comparative Corrosion Probability Variance of Non-Inhibited and Inhibited Reinforcement in Concrete and Exposed to Accelerated Medium Using Wenner Method

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## Abstract

***This research work 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. Half cell potential, concrete resistivity measurement and tensile strength tests were performed to assessed corrosion potential levels and the mechanical properties of the embedded steel bars 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. 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.. When compared to corroded samples, corroded has 70.1% incremented values potential $E_{corr}$,$^{mV}$ and 38.8% decremented values of concrete resistivity. 69.3% against 43.98% and 51.45% to 89.25%, cross-sectional diameter reductions, both showed decremented values of corroded compared to coated specimens. Results recorded of potential $E_{corr}$,$^{mV}$, .concrete resistivity and tensile strength of symphonia globulifera linn, ficus glumosa and acardium occidentale l inhibited specimen, the results indicated a 10% or dubious probability of corrosion which denotes no corrosion presence or likelihood and concrete resistivity designated a low probability of corrosion or no corrosion denotement. General and computed***

***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.***

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

## 1.0 Introduction

The rate of corrosion provides information on local corrosive conditions and on the best remedial action to acheive the most effective corrosion prevention. Corrosion measurements can provide early warning of damage in process that result in corrosion induced failure. Determining corrosion rate by measuring weight loss of samples is still in use because it is simple and effective in some situations. However, weight loss only gives an average corrosion of an entire metal sample over the entire test period. The less corrosive medium the longer it would take to get a meaningful test result. Linear polarization resistance (LRP) and potentiodynamic polarization curve measurements are the main electrochemical techniques used to evaluate corrosion rates. Scully [1] suggested a range of ±5mV to ±10mV to be normally used, but Trethwey and Chamberlain [2] used ±30mV. Gonzalez [3] proposed that for the active state the B value in the Stern-Geary equation be 26mV, and for the passive state 52mV. Using equation (2.21), the value B = 26mV can be obtained if both Tafel slopes are equal to 120mV/decade; and for B = 52mV one of the Tafel slopes could be infinity and the other 120mV/decade.

Andrade and Alonso [4] have claimed that using B =26mV had a maximum error factor of 2 when determining the corrosion rate. Song [5] suggested that B value for steel in concrete might range from as low as 8mV to approaching infinity under different conditions.

Gouda *et al*. [6] investigated the corrosion in reinforced slag cement concrete containing 0-5% $CaCl_2$ using a LRP technique. They reported that the calculated corrosion rate was in the range of 0.05 to 0.34mpy. Locke and Simon (1980) was found for steel in concrete mixed with 0 to 1% NaCl by total weight of concrete, the estimated corrosion rate of embedded steel based on LRP was in the range of 0.03 to 0.52mpy. Wheat and Eliezer [7] carried out potentiodynamic polarization measurements in potential ranging from -250mV to 1200mV (based on SCE) at a scan rate of 1mV/s with concrete specimens (w/c = 0.52) immersed in 10% NaCl solution for 30 and 150 days. They reported that the corrosion rate varied from 0.04mpy for 30 day to 3mpy for 150 days.

Jarrah et al. [8] investigated the corrosion behaviour of steel rebars in plain andsilica fume blended cement concrete exposed to 13.7% Cl for 2 years using potentiodynamic curves.

Aprael and Hasan [9] performed anodic polarization tests on mild steel in saturated Ca(OH)2 solution with 0.10 to 3% NaCl by weight of water, and concluded that a thin passive film of few nano meters (nm) of oxides covers the metal surface. There have been numerous studies undertaken to determine the effect of chloride concentration on corrosion of reinforcing steel in alkaline solutions, with the purpose to establish unique critical chloride for pitting initiation (Li and Sagues [10] , Saremi and Mahallati [11]). However, the chloride threshold depends on several variables and, for this reasons values reported by different researchers showed a significant sector. It has been also found (Saremi and Mahallati [11] ) that the breakdown of passive film on mild steel in $Ca(OH)_2$ is at $[Cl^-]/[OH^-]$ ratio of 0.60. Hausman [12] reported that steel immersed in a pH =13.2 solution with the addition of 0.25M NaCl remained in the passive state while Goudi [16] found that the maximum amount of sodium chloride that can be tolerated in a NaOH solution with pH =13.9 was 0.12M. Moreno et al. This layer is responsible for the passive nature of the metal at low level of NaCl, and increasing NaCl content to 3% NaCl destroys the passive film and shifts the corrosion potential to more negative value of ~ -550mV. It was reported Li and Sagues [10], that the critical concentration of chloride in simulated concrete pore solutions with pH = 13.6 would be 0.4 to 0.6M (mole/liter), while in saturated calcium hydroxide Ca(OH)2 somewhat between 0.01 to 0.04M.

## 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

The cement used was Ordinary Portland Cement, it 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) Symphonia globulifera linn , Ficus glumosa and Acardium occidentale l.

The study inhibitors are Symphonia globulifera linn, Ficus glumosa and Acardium occidentale l 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 test was performed utilizing scanning potential of -200 mV through 1200mV, with a scan rate of 1mV/s. 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. Coating was done by direct application on the ribbed reinforcement rough surface with 150µm, 250µm and 350µm coated thicknesses of Symphonia globulifera linn paste were polished and allowed to dry for 72 hours before embedded into concrete slab. Mix ratio of 1:2:3 by weight of concrete, water cement ratio of 0.65, and manual mixing was adopted. The polarization curve was obtained as the relationship between corrosion potential and current density. The data were recorded for a fine-tuned duration of 1hr at ambient temperature. Corrosion test was conducted on high tensile reinforcing steel bar of 12mm, specimens rough surface were treated with sandpaper and wire brush, washed with acetone to remore rust and dried to enable proper adhesion of coated / inhibitive materials. 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. Slabs were demoulded after 72 hours and cured for 28 days with room temperature and corrosion acceleration ponding process with Sodium Chloride lasted for 119days with 14 days checked intervals for readings.

## 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. (Care and Raharinaivo [17] Reinforcement corrosion normally requires long exposure period of time, and

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usually by the first crack observed on the concrete surface. A laboratory acceleration process helps to distinguish the roles of individual factors that could affect chloride induced corrosion. 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. 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 resistance in a relatively shorter period of time. 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.

### 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. This was also stated from practical experience (Figg and Marsden [18] and Langford and Broomfield [19]. 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 [20] ). Corrosion rates have been related to electrochemical measurements based on data first reported by Stern and Geary [21].

**Table 2.1: Dependence between potential and corrosion probability**

| Potential $E_{corr}$ | Probability of corrosion |
|---|---|

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| | |
|---|---|
| $E$corr < −350mV | Greater than 90% probability that reinforcing steel corrosion is occurring in that area at the time of measurement |
| −350mV ≤ $E$c$_{orr}$ ≤ −200mV | Corrosion activity of the reinforcing steel in that area is uncertain |
| $E_{corr}$ > −200mV | 90% probability that no reinforcing steel corrosion is occurring in that area at the time of measurement (10% risk of corrosion |

## 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 $\rho$, 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.



**3.0 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 $E$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 3.2. 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..

**3.1 Non-corroded Concrete Slab Members**

Results obtained from table 3.1 of half-cell potential quantifications for and concrete resistivity for 7 days to 119 days respectively designated a 10% or skeptical probability of corrosion which denotes no corrosion presence or likelihood and concrete resistivity which denoted a low probability of corrosion or no corrosion clue.

Tables 3.1, 3.2 and tables 3.3 are the results of average values derived from desultorily slab samples from A-I of control, corroded and coated specimens of 150µm, 250µm, 350µm summarized to A, B and C from ABC, DEF and GHI. Figures 3.1 and 3.2 are the plots representations of Concrete Resistivity ρ, kΩcm versus Potential $E_{corr},^{mV}$ Relationship which showed average of 27.2% Potential $E_{corr},^{mV}$ and 87.8% Concrete Resistivity. Figure 3.3 and 3.4 are the plots of yield stress and ultimate strength of mechanical properties of non-corroded specimens at 100.3% and 100.68%, while figures 3.5 and 3.6 are the plots of weight loss versus cross-section diameter reduction at 67.1% and 98.2% respectively.

### 3.2 Corroded Concrete Slab Members

Tables 3.1, 3.2 and 3.3 are the results recorded of potential $E_{corr},^{mV}$, and concrete resistivity and tensile strength properties for non- inhibited concrete specimens on the mapping areas for the expedited periods of 7days to 119 days which designated 95% probability of corrosion and betokening a high or moderate probability of corrosion. Average results on comparison showed incremental values of 70.1% against 27.2% non-corroded of Potential Ecorr, mV and 87.8% to 38.8%, decreased values in concrete resistivity. Figures 3.1 and 3.2 are the plots representations of concrete resistivity ρ, kΩcm versus Potential $E_{corr}, ^{mV}$ Relationship. Figures 3.3 and 3.4 are the plots of yield stress against ultimate vigor at summary and average state of corroded slab with nominal values of 100% and decremented in ultimate strength from 100.68% to 96.12%, while figures 3.5 and 3.6 presented the 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.

### 3.3 Symphonia globulifera linn, Ficus glumosa and Acardium occidentale l Steel Bar Coated Concrete Cube Members

Tables 3.1, 3.2 and 3.3 are the results recorded of potential $E_{corr},^{mV}$, and concrete resistivity and tensile strength of Symphonia globulifera linn, Ficus glumosa and Acardium occidentale l inhibited specimen, the results betokened a 10% or dubious probability of corrosion which

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denotes no corrosion presence or likelihood and concrete resistivity designated a low probability of corrosion or no corrosion denotement. Average percentile results of potential $E_{corr,}{}^{mV}$, 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 $E_{corr,}{}^{mV}$ and 38.8% decremented values of concrete resistivity. Figures 3.1 and 3.2 are the plots representations of Concrete Resistivity ρ, $k_{\Omega}$cm versus Potential $E_{corr,}{}^{mV}$ Relationship. Figures 3.3 and 3.5 represented the plots for arbitrarily and computed 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, figures 3.5 and 3.6 respectively presented 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. 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.



**Table 3.1 : Potential $E_{corr,}$ after 28b days curing and 119 days acceleration Ponding**

| s/no | Inhibitor (resin/exudates) and controlled sample | **Potential $E_{corr,mV}$** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Time Intervals after 28 days curing | | | | | | | | |
| | | A (7days) | B (21days) | C (35days) | D (49days) | E (63days) | F (77days) | G (91days) | H (105 days) | I (119 days) |
| 1 | Control Concrete slab | -102 | -102.2 | -100.3 | -101.2 | -101.7 | -100.8 | -100.3 | -101.4 | -100.4 |
| 2 | Non-inhibitor | -268.5 | -294.7 | -328.6 | -367.7 | -377.5 | -384.5 | -418.4 | -425.6 | -429.7 |
| | | 150µm, | | | 250µm, | | | `350µm, | | |
| 3 | Symphonia globulifera linn | -113.5 | -117.4 | -111.9 | -115.5 | -111.6 | -118.6 | -111.7 | -118.2 | -109.7 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | Acardium occidentale l. | -104.5 | -103.5 | -104.2 | -101. | -114.7 | -103.7 | -116.5 | -100.8 | -108.5 |
| 5 | Ficus glumosa | -124.78 | -122.45 | -129.98 | -125.15 | -122.09 | -129.46 | -124.38 | -128.15 | -124.75 |
| **Average values Potential $E_{corr,mV}$** | | | | | | | | | | |
| | | ABC = A | | | `DEF = B | | | GH1 = C | | |
| 1A | Control Concrete slab | -101.5 | | | -102.2 | | | -100.7 | | |
| 2A | Non-inhibitor | -297.3 | | | -393.5 | | | -424.6 | | |
| | | 150µm, | | | 250µm, | | | `350µm, | | |
| 3A | Symphonia globulifera linn | -114.3 | | | -115.2 | | | `-113.2 | | |
| 4A | Acardium occidentale l | -110.7 | | | -111.4 | | | `-116.8 | | |
| 5A | Ficus glumosa | -125.7 | | | -125.9 | | | `-125.95 | | |



**Table 3.2 : Results of Concrete Resistivity ρ, kΩcm Time Intervals after 28 days curing curing and 119 days acceleration ponding**

| s/no | Inhibitor (resin/exudates) and controlled sample | **Concrete Resistivity ρ, kΩcm** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Time Intervals after 28 days curing | | | | | | | | |
| | | A ( 7days) | B ( 21days) | C ( 35days) | D ( 49days) | E (63days) | F ( 77days) | G (91days) | H (105 days) | I (119 days) |
| 1 | Control Concrete slab | 15.35 | 15.52 | 15.42 | 15.65 | 15.48 | 14.43 | 15.45 | 15.45 | 15.48 |
| 2 | Non-inhibitor | 6.77 | 6.91 | 7.74 | 8.05 | 8.22 | 8.38 | 9.12 | 9.55 | 9.59 |

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| | | 150µm, | | | 250µm, | | | `350µm, | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | Symphonia globulifera linn | 13.26 | 13.29 | 13.46 | 14.24 | 14.18 | 14.23 | 14.39 | 14.45 | 14.78 |
| 4 | Acardium occidentale l. | 13.3 | 13.22 | 13.41 | 14.18 | 14.26 | 14.44 | 14.46 | 14.58 | 14.32 |
| 5 | Ficus glumosa | 14.02 | 14.17 | 14.45 | 14.58 | 14.27 | 14.56 | 14.51 | 14.66 | 14.69 |

**Average values Concrete Resistivity ρ, kΩcm**

| | | ABC = A | `DEF = B | GH1 = C |
|---|---|---|---|---|
| 1B | Control Concrete slab | 15.43 | 15.19 | 15.46 |
| 2B | Non-inhibitor | 7.14 | 8.21 | 9.42 |
| | | 150µm, | 250µm, | `350µm, |
| 3B | Symphonia globulifera linn | 13.34 | 14.22 | 14.54 |
| 4B | Acardium occidentale l. | 13.3 | 14.3 | 14.5 |
| 5B | Ficus glumosa | 14.1 | 14.5 | 14.8 |



**Table 3.3 : Mechanical properties of Non-Corroded, Corroded and Coated Beam**

| s/no | Inhibitor (resin/exudates) and controlled sample | Yield Stress (N/mm$^2$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Time Intervals after 28 days curing | | | | | | | | |
| | | A (7days) | B (21days) | C (35days) | D (49days) | E (63days) | F (77days) | G (91days) | H (105 days) | I (119 days) |
| 1 | Control Concrete slab | 410.4 | 410.1 | 410.3 | 410.0 | 410.3 | 410.7 | 410.0 | 410.5 | 410.4 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Non-inhibitor | 4.10.2 | 410.0 | 410.0 | 410.4 | 410.0 | 410.3 | 410.0 | 410.3 | 410.2 |
| | | **150µm,** | | | **250µm,** | | | **`350µm,** | | |
| 3 | Symphonia globulifera linn | 410.6 | 410.2 | 410.7 | 410.7 | 410.7 | 410.4 | 410.2 | 410.2 | 410.4 |
| 4 | Acardium occidentale l. | 13.3 | 13.22 | 13.41 | 14.18 | 14.26 | 14.44 | 14.46 | 14.58 | 14.32 |
| 5 | Ficus glumosa | 410.6 | 410.2 | 410.7 | 410.7 | 410.7 | 410.4 | 410.6 | 410.7 | 410.9 |
| | | **Average values Yield Stress (N/mm$^2$)** | | | | | | | | |
| | | ABC = A | | | `DEF = B | | | GH1 = C | | |
| 1C | Control Concrete slab | 410.27 | | | 410.33 | | | 410.3 | | |
| 2C | Non-inhibitor | 410.01 | | | 410.23 | | | 410.17 | | |
| | | 150µm, | | | 250µm, | | | `350µm, | | |
| 3C | Symphonia globulifera linn | 410.45 | | | 410.60 | | | 410.27 | | |
| 4C | Acardium occidentale l. | 13.3 | | | 14.3 | | | 14.5 | | |
| 5C | Ficus glumosa | 410.50 | | | 410.60 | | | 410.77 | | |
| | | **Ultimate strength (N/mm$^{2)}$** | | | | | | | | |
| 1 | Control Concrete slab | 564.7 | 565.6 | 562.4 | 562.6 | 566.8 | 562.2 | 565.2 | 562.7 | 562.4 |
| 2 | Non-inhibitor | 584.7 | 585.8 | 586.8 | 582.8 | 586.8 | 582.8 | 585.4 | 582.6 | 588.4 |
| | | **150µm,** | | | **250µm,** | | | **`350µm,** | | |
| 3 | Symphonia globulifera linn | 560.9 | 566.4 | 568.4 | 566.7 | 569.5 | 568.7 | 568.5 | 564.9 | 563.5 |
| 4 | Acardium occidentale l. | 567.7 | 562.8 | 562.9 | 569.8 | 567.1 | 563.8 | 562.1 | 563.8 | 564.4 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | Ficus glumosa | 565.4 | 564.7 | 563.4 | 565.8 | 565.8 | 565.8 | 568.5 | 565.45 | 566.7 |
| | **Average value of Ultimate strength (N/mm$^{2}$)** | | | | | | | | | |
| | | ABC = A | | | `DEF = B | | | GH1 = C | | |
| 1D | Control Concrete slab | 564.23 | | | 563.87 | | | 563.43 | | |
| 2D | Non-inhibitor | 585.77 | | | 584.13 | | | 585.47 | | |
| | | 150µm, | | | 250µm, | | | `350µm, | | |
| 3D | Symphonia globulifera linn | 565.23 | | | 568.3 | | | 567.97 | | |
| 4D | Acardium occidentale l. | 564.47 | | | 566.9 | | | 563.43 | | |
| 5D | Ficus glumosa | 564.5 | | | 565.8 | | | 566.08 | | |
| | | **Weight Loss of Steel Loss (in grams)** | | | | | | | | |
| 1 | Control Concrete slab | 10.628 | 10.796 | 10.839 | 10.876 | 10.882 | 10.884 | 10.835 | 10.885 | 10.676 |
| 2 | Non-inhibitor | 7.25 | 7.37 | 7.33 | 7.25 | 7.26 | 7.45 | 7.28 | 7.18 | 7.35 |
| | | **150µm,** | | | **250µm,** | | | **`350µm,** | | |
| 3 | Symphonia globulifera linn | 7.29 | 7.29 | 7.25 | 7.30 | 7.26 | 7.26 | 7.31 | 7.29 | 7.28 |
| 4 | Acardium occidentale l. | 7.21 | 7.23 | 7.29 | 7.24 | 7.29 | 7.32 | 7.24 | 7.18 | 7.27 |
| 5 | Ficus glumosa | 7.24 | 7.25 | 7.26 | 7.25 | 7.29 | 7.25 | 7.29 | 7.25 | 7.28 |
| | | **Average values of Weight Loss of Steel Loss (in grams)** | | | | | | | | |
| | | ABC = A | | | `DEF = B | | | GH1 = C | | |
| 1E | Control Concrete | 7.32 | | | 7.33 | | | 7.27 | | |

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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | slab | | | | | | | | | |
| 2E | Non-inhibitor | 10.754 | | | 10.681 | | | 10.799 | | |
| | | **150µm,** | | | **250µm,** | | | **`350µm,** | | |
| 3E | Symphonia globulifera linn | 7.27 | | | 7.27 | | | 7.29 | | |
| 4E | Acardium occidentale l. | 7.24 | | | 7.28 | | | 7.23 | | |
| 5E | Ficus glumosa | 7.27 | | | 7.26 | | | 7.27 | | |
| | | **Cross- section Area Reduction ( Diameter, mm)** | | | | | | | | |
| 1 | Control Concrete slab | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| 2 | Non-inhibitor | 11.53 | 11.53 | 11.54 | 11.61 | 11.64 | 11.71 | 11.75 | 11.76 | 11.79 |
| | | **150µm,** | | | **250µm,** | | | **`350µm,** | | |
| 3 | Symphonia globulifera linn | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| 4 | Acardium occidentale l. | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| 5 | Ficus glumosa | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| | | **Average Values of Cross- section Area Reduction ( Diameter, mm)** | | | | | | | | |
| | | ABC = A | | | `DEF = B | | | GH1 = C | | |
| 1F | Control Concrete slab | 12 | | | 12 | | | 12 | | |
| 2F | Non-inhibitor | 11.587 | | | 11.563 | | | 11.662 | | |
| | | **150µm,** | | | **250µm,** | | | **`350µm,** | | |
| 3F | Symphonia globulifera linn | 12 | | | 12 | | | 12 | | |

| | | | | |
|---|---|---|---|---|
| 4F | Acardium occidentale l. | 12 | 12 | 12 |
| 5F | Ficus glumosa | 12 | 12 | 12 |

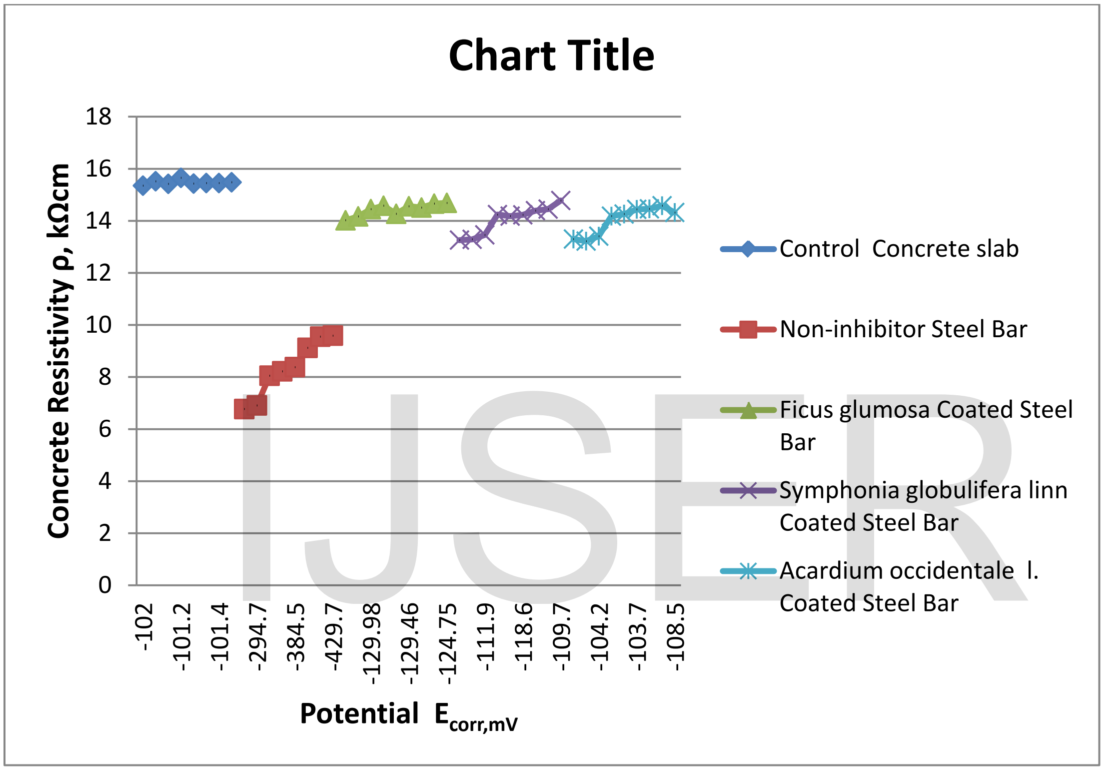


**Figure 3.1: Concrete Resistivity versus Potential Relationship Concrete Resistivity ρ, kΩcm versus Potential $E_{corr,}{}^{mV}$ Relationship**

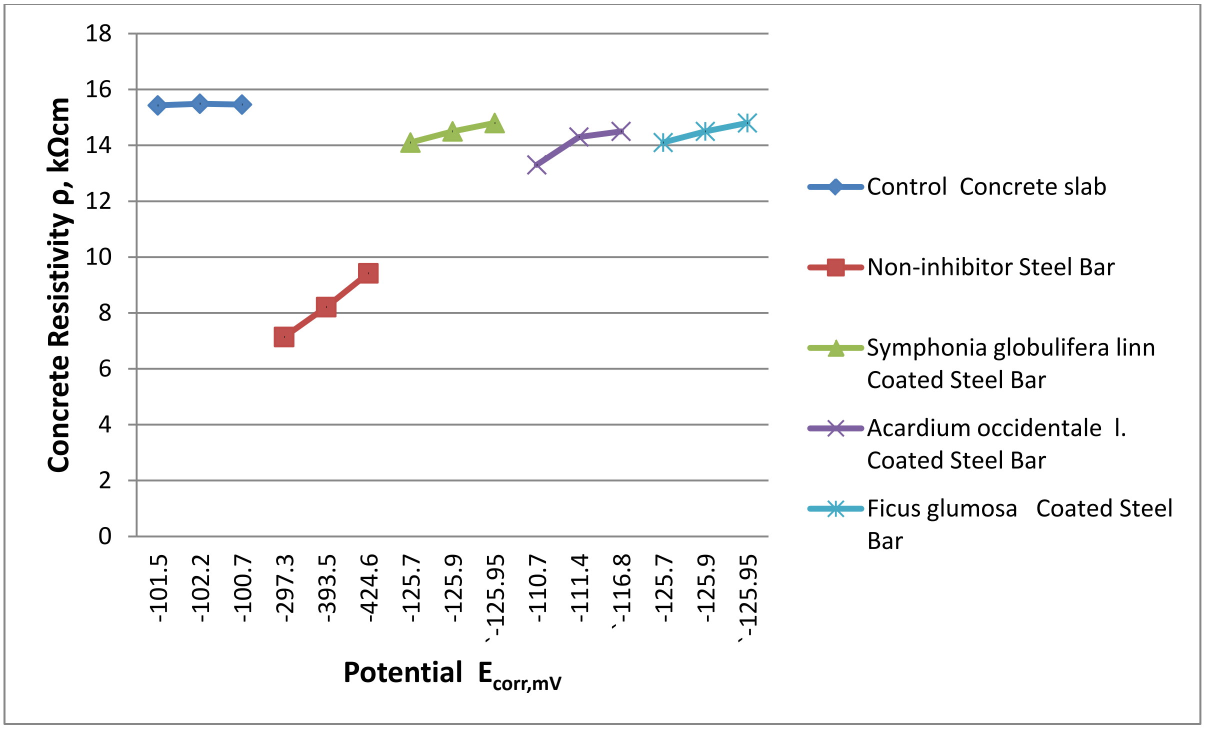


**Figure 3.2: Average Concrete Resistivity versus Potential Relationship**

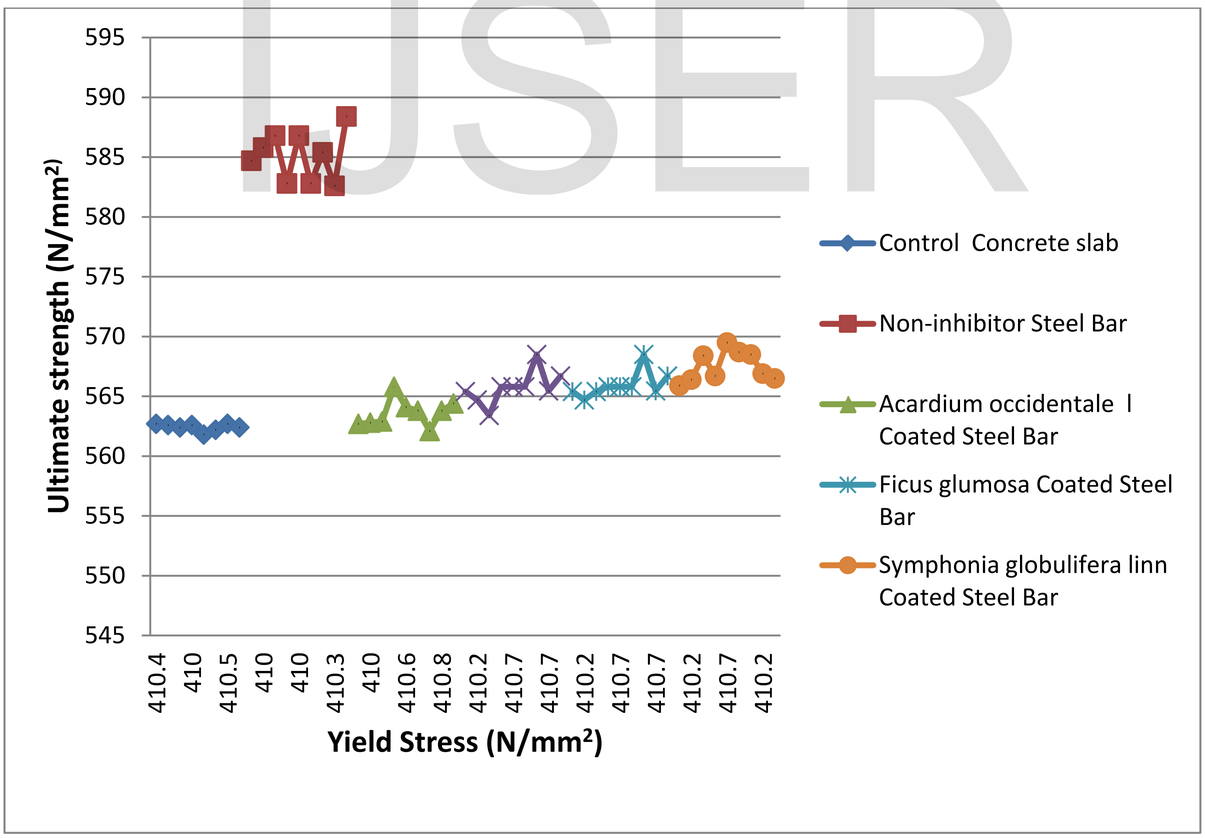

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**Figure 3.3: Yield Stress versus Ultimate strength.**

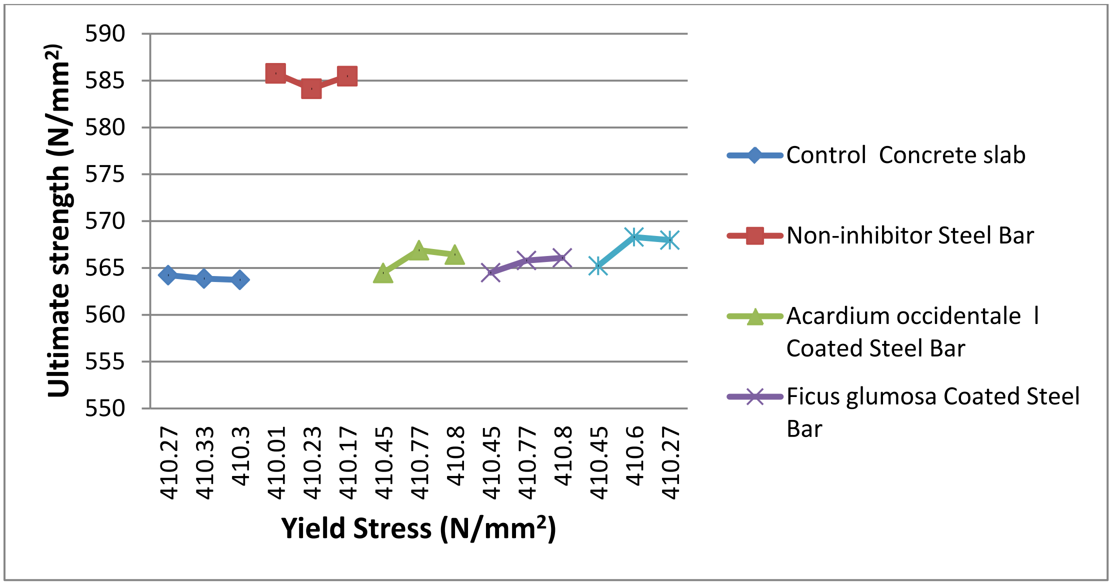


**Figure 3.4: Average Yield Stress versus Ultimate strength.**



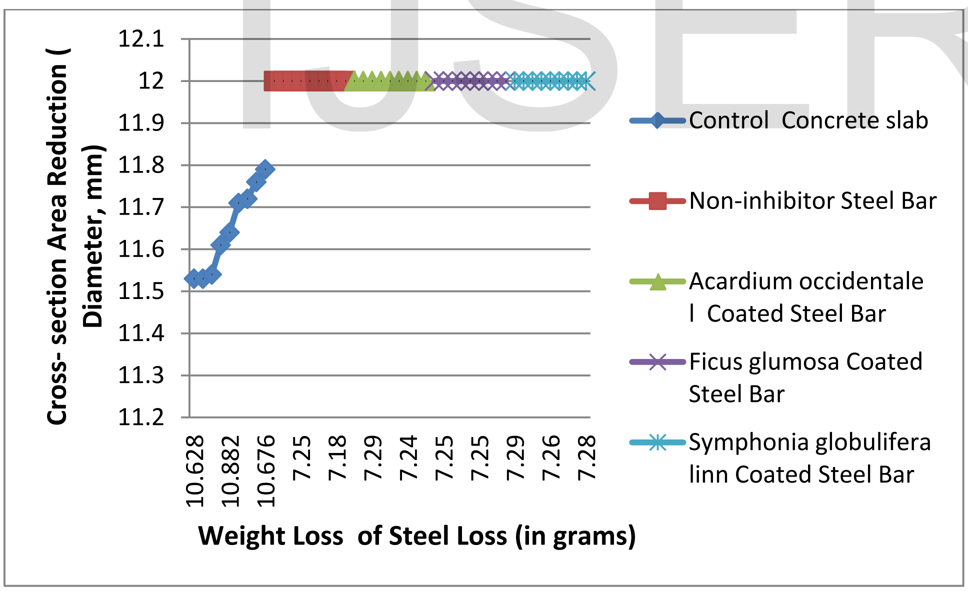


**Figure 3.5: Weight Loss of Steel Loss versus Cross- section Area Reduction**

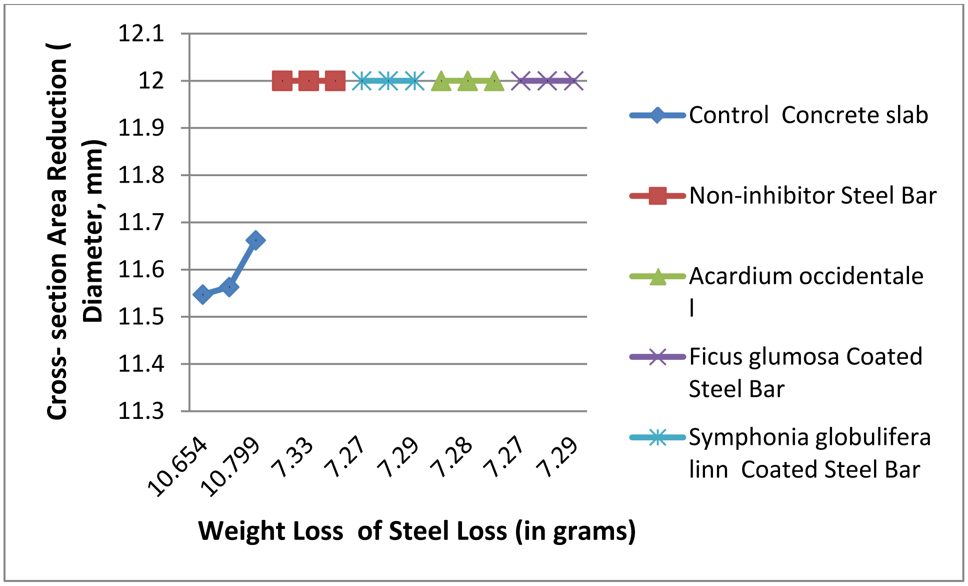


**Figure 3.6: Average Weight Loss of Steel Loss versus Cross- section Area Reduction**



## 4.0 Conclusion

Experimental results showed the following conclusions:

i. Three experimented reins indicated a 10% or uncertain probability of corrosion which indicates no corrosion presence.

ii. Concrete resistivity indicated a low probability of corrosion or no corrosion indication.

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

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

v. Results showed the effectiveness of resins extracts of tree as inhibitive materials

vi. Resins form protective coat membrane towards corrosion effects

vii. Corroded specimens showed reduction in cross-section area of the reinforcement due to severe attacks

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