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Evaluation of Corrosion Potential Probability of Steel Rebar in an Induced Media

Charles Kennedy[1*], Gloria Inipaitaribia F. Dan- Orawari[2] and Gbimadee NuBari B.P[3]

[1]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
[3]School of Engineering, Chemical/Petrochemical Engineering Department , Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria

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***Corresponding author:** Charles Kennedy

Abstract

This study investigated the potential use Pycnanthus angolensis (African/false nutmeg) exudates/resin as inhibitive materials against corrosion of reinforcing steel founded in the high salinity region. The accelerated corrosion test is an impress current technique, an effective technique for examining the corrosion process of steel in concrete and for assessing damage to the concrete cover protection to the steel bar and mechanical properties if steel bar modifications. The maximum yields obtained from the controlled and coated samples were -110.49mV and -114.7mV, which indicate the relationship between corrosion potential and probability in the reference range $E\text{corr} > -200\text{mV}$; For uncoated samples, the maximum calculated value is -317.5mV, the result is within the reference value of the dependence between corrosion potential and probability of $-350\text{mV} \leq E\text{corr} \leq -200\text{mV}$ indicates a high-value range of 10% or indicates the possibility of unsafe corrosion. The maximum value calculated from the concrete resistance of the controlled sample concrete is 34.33% as compared to the corroded and coated values of 36.6% and 58.32% and the maximum difference percentage of control is 0.4% compared to the corroded and coated value of 0.24% and 0.59%. The results of controlled samples coated with concrete resistance obtained the maximum mean values of 12.47kΩcm and 14.68kΩcm with a description of the value $10 < \rho < 20$ (low) compared to the corrosion value of 9.31kΩcm with Specifications $5 < \rho < 10$ (high). The calculated yield strength maximum percentage value of the controlled yield strength was 3.56% compared to the corroded and coated values -4.88% and 5.34% and the possible difference values of 0.49% controlled, 0.19% corroded, and 0.21% covered. The calculated maximum percentage of the controlled ultimate tensile strength is 3.34% relative to corrosion and the coating value is -5.02% and 5.41% and the possible difference value is 0.12% controlled, 0.11% corroded and 0.12% coated. The maximum calculated strain ration percentage for comparison checked up to -5.86% versus corroded 6.06% and coated -5.83% and different peak values checked up to 0.04%, corroded 0.0079%, and coated 0.08% The comparison results show that the low load carrying capacity is caused by the effect of corrosion attack on the uncoated (corroded) elements, which damage the reinforcing steel fibers, ribs, and passive formation and surface modification. The observed mean values for the coated samples were associated with the corrosion resistance potential to penetrate the reinforcing steel with the formation of a protective membrane; This attribute indicates the efficiency and effectiveness of the exudate/resin as an inhibitor against corrosive effects. of reinforced concrete structures exposed to the edges of strong, high salinity marine areas. The decrease of cross-sectional area in mean and percentage values indicates that the corrosion effect causes a decrease in diameter and cross-sectional area, fiber degradation, rib reduction and surface modification, while the exudate/resin-coated elements are validated in the work due to differences in coating thickness. For comparison the results obtained of unit rebar weight loss/gain steel showed a reduction of mean and percentile values for coatings from 0.063 kg to 0.05 kg and corrosion 29.17% to -20.97% and the aggregate results show that the corrosion effect causes a reduction in weight/reduction of the corroded sample compared to the percentile layer and an increase in mean, resulting in a slight increase in volumearound the layer thickness. This study shows the efficacy and effectiveness of exudate/resin as an anti-corrosion anti-corrosion material in reinforcing steel embedded in samples of concrete slabs exposed to induced corrosion.

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

1.0 INTRODUCTION

The use of organic compounds to resist corrosion of thin metal and metal has taken great importance because of its application in preventing corrosion under various corrosive environments [1]. The development of corrosion inhibitors is based on organic compounds that contain nitrogen, oxygen, sulfur atoms and many bonds to molecules that facilitate adsorption to the metal surface [2] Studies reported that the adsorption of organic inhibitors largely depends on the other molecular structures associated with its functional groups, the steric effects and the

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electronic density of the donor atoms; The adsorption is also thought to depend on the possible interaction of the p-orbitals of the inhibitor with the d-orbitals of the surface atom, which results in the large adsorption of the inhibitor molecules on the surface of the carbon metal, leading to the formation of a corrosion-resistant film.

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 [3]. Approaches to control these factors have used inhibitors, electrochemical protection procedures, scavengers, buffers, and coatings [4].

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[5]. Potentials more positive than +200 mV SCE cause evolution of oxygen on passive steel. The evolution of oxygen causes decline in 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 [6-8]. However, the evolution of the hydrogen can lead to the embrittlement of prestressed steel in both pretensioned and post-tensioned structures and resulting in their sudden failures [9, 10].

The formation of corrosion causes a significant increase in volume (coefficient of about 4), which causes cracks, peeling and staining of the concrete and reduces the effective cross-sectional area of reinforcement and weakens the bond between reinforcement and concrete, greatly affecting the durability and life of the structure [1, 13]. The main concept of corrosion inhibition is the development of stable bonds with metal surfaces and the formation of adsorption complexes with metal oxides. There are three main types of inhibitors: anode, cathode, and mixed. Anode inhibitors work by stopping the reaction at the anode. Ideally, they react with the corrosion products present to form a highly insoluble film that adheres firmly to metal surfaces. This film can act as a barrier against metal dissolution and prevent metal surface contact with corrosive electrolytes.

Rengaswamy et al. Concluded that the coated and sealed cement emulsion leads to greater efficiency than coating economy and other coating systems [14].

Investigated inhibitors in alkaline solutions and semen extracts. Extracts from the cement experiments showed that corrosion was inhibited by sodium nitrite in the presence of chloride, whereas this was not the case with sodium benzoate. In addition, the onset of corrosion is delayed by sodium nitrite, which is intensified by the inhibitory content [15].

Studied and shown that calcium nitrite does not impair the properties of concrete in any way, as shown by the problem of inhibitors based on sodium or potassium [16]. A recent study by [17] and Slater showed that calcium nitrite had better strength in terms of strength after years of accelerated testing.

Conducted and tested 160 x 100 x 1500 mm beams, reinforced with a single 16 mm diameter bottom bar and a pair of 8 mm diameter upper bars with initiated corrosion carbonation and accomplished by placing CO2 filled beams in the pressure chamber (at 80kPa Placed) and provide a current of 400 µA /cm2 [18]. The beams were simultaneously corroded and loaded to 23% and the final load (pu) to 34%, the deflection rates were calculated by dividing the average deflection of the corroded beams. Conclusions attributed this initial increase to the initial crack formation, as the formation and expansion of the cracks improved at a slower rate after a certain point.

Investigated the strengthening steel with the introduction of milicia excelsaudates / resins to reduce surface changes and mechanical properties that reinforce steel in concrete structures built in saltwater environments. The corrosion acceleration process was 150 days and the corrosion potential determined. The flexural strength of the beam failure load results in an average of -39.1172%, 49.51535% and 47.14752% for the non-corroded and milicial excelsa- coated samples. Midspan deflection average values of -47.0149% and -52.6715% versus 88.73239% of corroded and coated samples. Average ultimate tensile strength of -13.5952%, 15.7343% and 15.33289% with non-corrugated and coated specimens. The corrosion properties of the spalling and fractures in the non-coated members showed that the overall experimental results were indicative of the low flexibility failure load; The effect of corrosion on the mechanical properties of reinforcing steel on corroded (controlled) members has not been observed[19].

Investigated the corrosion rate of steel reinforcement embedded in concrete slab structures submerged in a corrosive environment coated with exudates/resins of varying thickness and of non-coated members with the application of Wenner four-probe methods. The estimated range of the corrosion of samples indicates significant corrosion probability (ρ <5, 5 <, <10, 10 <, <20, ρ> 20) for most, high, low to moderate, and low, corrosion potential. The results showed a higher yield of corrosion samples due to corrosion impact on the mechanical properties of steel reinforcement [20].

Evaluated the use of inorganic eco-friendly exudates/resins extract from cola acuminate as a preventive measure for the corrosive action of the saltwater attack on embedded reinforcing steel in concrete structures using an experimental application of half-cell potential Ecorr,mV[21]. The probability of immersion and applied currents for 150 days in a fast corrosive medium embedded in a concrete slab of uncoated and exudates/resins coating samples to observe the changes in the surface condition. The results showed a high ultimate yield of the corrugated specimens to control and coating specimens due to the effect of corrosion on the mechanical properties of steel reinforcement. The results of the weight loss of steel showed a high percentage of values against the control and coating models due to the effect of corrosion on the mechanical properties of the steel.

Comparative evaluation of reinforced steel application performance of celtis zenkeri exudates/resins paste coated and non-coated reinforcing steel embedded in concrete members and accessibility for mechanical properties modification effects due to corrosion attack. The results showed a high corrosion rate of non-coated over coated and controlled members resulted from corrosion impact on the mechanical properties of steel reinforcement. Weight loss results of non-coated steel showed higher percentage values against control and coated members. Cross-sectional reduction results showed higher percentage reduction values due to the impact of corrosion on the mechanical properties of steel[22].

Evaluated the use of environmental inorganic exudates/resins extracted from Invincia gabonensis, layered to reinforced steel with various pits and non-layered members, immersed in sodium chloride for 150 days for rapid corrosion testing with 200 mV by 1200mV with a scan rate of 1mV / s efficiency. The overall results of the exudates/resins coated samples showed no signs of corrosion potential and the results showed that Invincia gabonensis exudates/resins were good corrosion inhibitors, while the non-layered ones showed signs of corrosion. Cross-sectional area reduction results showed higher percentage reduction values as fiber loss was negative on the mechanical properties of steel as a result of corrosion potential[23].

Investigated the environmentally friendly inorganic content of Olibanum exudates/resins, coated with steel and of non-coated members, embedded in a concrete slab and incubated in a corrosive environment for 150 days, with a test flow rate of 1200 -200 mV compared to control samples[24]. Due to the attack on the mechanical properties of steel reinforcement, high yield results have been recorded for coated (corrugated) samples as opposed to coated specimens. The results of the weight loss of steel indicate a higher percentage of values against the control and coating model, which results in a decrease in the fiber / ribbed properties of the steel and thus the surface strength. The cross-sectional expansion of the corrugated specimen results showed high percentage reduction values due to the effect of corrosion on the mechanical properties of the steel.

Studied to reduce passivity loss of reinforcing steel with the evaluation of exudate / natural inorganic resin from Milicia excels paste on reinforcement of diameter 12 mm with coatings of different thicknesses, embedded in a partially submerged concrete sample of slabs, evaluated in a corrosive medium and the investigate half cell potential, concrete resistance and mechanical properties of uncoated (corroded) and coated concrete samples[25]. The results of resistivity, kΩcm versus Ecorr potential, the relationship that shows the average potential value with Ecorr coating is 31.86% and the percentile difference is -68.18% for the corroded sample 232.05%. The average result of the concrete resistance, the average percentile is 185.44% and the percentage difference is 85.44% compared to -41.92% of the corroded sample. The average "maximum strength" mechanical properties of the coated samples were achieved with a percentage of 97.66% and a percentage difference of -2.33% compared to 7.62% of the corroded samples. Average mechanical properties of "Reduction of cross-sectional area" average value of coated percentile is 114.05% and percentile difference is 14.05% compared to 12.32% of corroded samples [19, 22, 25, 22, 20].

2.1 MATERIALS AND METHODS

2.1.1 Aggregates

Fine and coarse aggregates are purchased at landfills. Both meet the requirements of

2.1.2 Cement

Limestone cement grade 42.5 was used for all concrete mixtures. The cement meets the requirements of [26].

2.1.3 Water

Water samples were taken from the Department of Civil Engrg. Laboratory at Kenule Beeson Polytechnic, Bori, Rivers State. Water meets [27] requirements

2.1.4 Structural steel reinforcement

Reinforcement purchased directly from the market at Port Harcourt, Conformed to [28]

2.1.5 Corrosion Inhibitors (Resins / Exudates) Pycnanthus angolensis (African/false nutmeg)

The reddish like gum exudates was obtained from the tree bark by tapping process from the forestry reserves of Trans – Amadi in Port Harcourt, Rivers State

2.2 EXPERIMENTAL PROCEDURE

2.2.1 Experimental method

2.2.2 Prepare samples for reinforcement with coated exudate/resin

This study investigated the potential Pycnanthus angolensis (African/false nutmeg) exudate/resin as inhibitive materials against corrosion of reinforcing steel founded in the high salinity region. The manifest of corrosion is an aging process that spanned many years to fully occur. An induced process of corrosion has proved that the introduction of sodium chloride and other related substance has proved that phenomena can occur within a short time with high damage and degradation of the reinforced concrete structure exposed to it, this level of corrosion rate measured by estimating the current density obtained through the polarization curve and the degree of quantification of the corrosion rate. The studied slabs are produced with concrete mixes of a standard ratio of 1.2.4, and a water-cement ratio of 0.65. Concrete standards are obtained by gradually adding cement, aggregates (fine and coarse), and water to achieve a consistent color. Concrete slabs of 100 mm × 500 mm × 500 mm (thickness, width, and length) are cast into a metal mold, compacted to air and void-free, with a cover of 10 mm, and reinforced with 10 numbers of reinforcing steel of diameter 12 mm, spaced at 100 mm c / c (top and bottom) are placed and de-molded after 72 hours, cured for 28 days at standard room temperature to harden. The hardened concrete slabs are wholly immersed in 5% sodium chloride (NaCl) solution to water and accelerated for a rapid corrosion process for 360 days with interval checks and routine tests of 90 days, 180 days, 270 days, and 360 days for record documentations of comparison.

2.3 Accelerated Corrosion Test

The corrosion process is a natural phenomenon that takes decades to actualize. This is a long-term process, but the fast induced and accelerated corrosion process using sodium chloride (NaCl) solution allows reinforcement embedded in concrete to undergo corrosion and can quicken the increase in corrosion that will occur over decades in a short time. To test the corrosion resistivity of concrete, experimental processes were developed that accelerate the corrosion process and maximize the corrosion resistivity of concrete. The accelerated corrosion test is an impress current technique, an effective technique for examining the corrosion process of steel in concrete and for assessing damage to the concrete cover protection to the steel bar. The laboratory acceleration process helps distinguish the role of individual factors that can influence chloride-induced corrosion. For the construction of structural elements and corrosion resistivity as well as for the selection of suitable materials and suitable protection systems, an accelerated corrosion test is carried out to obtain quantitative and qualitative information on corrosion.

2.4 Corrosion current measurement (Half-Cell Potential Measurement)

The classification of the severity of reinforcing steel corrosion is shown in Table 2.1. If the potential measurement results indicate a high probability of active corrosion, then the degree of corrosion can be assessed by measuring the resistivity of the concrete. However, care must be taken when using these data as it is assumed that the corrosion rate is constant over time. This has also been demonstrated through practical experience [Figg and Marsden [29], Gower and Millard [30]. Measurement of half potential is an indirect method of estimating the probability of corrosion. Recently, there has been much interest in developing tools for carrying out electrochemical measurements of disturbances on the steel itself to obtain a direct estimate of the corrosion rate (Stem and Geary [32]). Corrosion rate refers to electrochemical measurements, the first based on data.

Table-2.1: Dependence between potential and corrosion probability [33]

Potential Ecorr	Probability of Corrosion
Ecorr < −350mV	Greater than 90% probability that reinforcing steel corrosion is occurring in that area at the time of measurement
−350mV ≤ Ec_{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 ofmeasurement (10% risk of corrosion

2.5. Test for measuring the Resistivity of Concrete

Different readings were taken at different locations at the surface of the concrete surface. After the water has been applied to the slab surface, the resistivity of the concrete is measured daily at the reference point to determine its saturation state. This position was chosen on the side of the panel because special measurements of electrical resistivity can be made with water on top of the panel. A reading aid was recorded as the final resistivity measure in this study. The level of slab saturation is monitored by measuring the electrical resistivity of the concrete, which is directly related to the moisture content of the concrete. As soon as one plate reaches a saturated state, water can flow out while the other plate remains closed. The time limit is a major challenge for all experimental measurements because the saturation state of the concrete changes over time. This study used the Wenner method with four probes; for this purpose, the four probes touch the concrete of the reinforcing steel rail directly. Because each slab has a different water-cement ratio, the time required to saturate each slab not the same. Before water is applied to the slab, the electrical resistivity of the concrete is measured at certain points in the dry state. The electrical resistivity becomes constant as soon as the concrete reaches saturation.

Table-2.2: Dependence between concrete resistivity and corrosion probability [34]

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 Reinforcement

To determine the yield strength and ultimate tensile strength peak point of the reinforcing steel bar, the concrete slabs reinforced with 10 numbers of 12mm diameter (top and bottom direction) of uncoated and coated reinforcing steel and tested under stress in an Instron Universal testing machine (UTM) to failure. A digitalized and computerized system records the results of yield strength, ultimate tensile strength, and strain ratio. To ensure stability, the remaining cut portions are used for other parameters examinations of rebar diameter before the test, rebar diameter - after corrosion, cross-sectional area reduction/increase, rebar weights- before the test, rebar weights- after corrosion, weight loss /gain of steel.

3.0 TEST RESULTS AND DISCUSSION

The results of the half-cell potential measurements in Table 1 are plotted against the Resistivity in Table 3 for ease of interpretation. 2. It is used as an indication of the probability of significant corrosion (ρ <5, 5 <ρ <10, 10 <ρ <20, ρ> 20) for very high, high, low to a moderate and low probability of corrosion. At another measurement point, the potential for correction was high (–350 mV ≤ Ecorr ≤ –200 mV), indicating a corrosion probability of 10% or uncertain. The results of concrete resistivity measurements are shown in Table 2. It is proven that if the potential for corrosion is low (<-350 mV) within a certain range, there is a 95% chance of corrosion. Concrete resistivity is usually measured using the four-electrode method. Resistivity study data show whether certain states are conducive to lower ion movement, leading to greater and more corrosion.

Table-3.1: Potential Ecorr, after 28 days curing and 360days Accelerated Periods of Control Concrete slab Specimens

Sample Numbers	**CAS**	**CAS1**	**CAS2**	**CAS3**	**CAS4**	**CAS5**	**CAS6**	**CAS7**	**CAS8**	**CAS9**	**CAS10**	**CAS11**
	Time Intervals after 28 days curing											
Sampling and Durations	**Samples 1 (28 days)**			**Samples 2 (28 Days)**			**Samples 3 (28 Days)**			**Samples 4 (28 Days)**		
Potential Ecorr, mV	-109.88	-115.56	-111.29	-109.89	-112.30	-109.27	-117.72	-113.40	-108.95	-111.26	-115.25	-109.41
Concrete Resistivity ρ, kΩcm	12.35	12.34	12.33	12.33	12.32	12.49	12.48	12.47	12.47	12.46	12.40	12.32
Yield Strength, fy (MPa)	453.47	451.95	452.47	452.77	453.47	452.70	451.57	448.91	450.57	453.09	452.60	452.03
Ultimate Tensile Strength, fu (MPa)	622.64	620.59	622.27	618.05	621.58	622.00	621.80	622.60	621.20	622.75	622.25	622.11
Strain Ratio	1.37	1.37	1.38	1.37	1.37	1.37	1.38	1.39	1.38	1.37	1.38	1.38
Rebar Diameter Before Test (mm)	11.95	11.95	11.96	11.97	11.95	11.97	11.97	11.95	11.95	11.95	11.95	11.96
Rebar Diamete at 28 days(mm)	11.95	11.95	11.96	11.97	11.95	11.97	11.97	11.95	11.95	11.95	11.95	11.96
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rebar Weights- Before Test	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Rebar Weights- After at 28 days (Kg)	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Weight Loss /Gain of Steel (Kg) at 28 days	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table-3.2: Potential Ecorr, after 28 days curing and 360days Accelerated Periods of Corroded Concrete slab Specimens

Sampling and Durations	**Samples 1 (90 days)**			**Samples 2 (180 Days)**			**Samples 3 (270 Days)**			**Samples 4 (360 Days)**		
Potential Ecorr, mV	-315.84	-320.52	-316.25	-313.85	-336.26	-313.23	-321.68	-317.36	-332.91	-345.22	-388.21	-407.37
Concrete Resistivity ρ, kΩcm	**9.29**	**9.18**	**9.17**	**9.16**	**9.16**	**9.32**	**9.32**	**9.31**	**9.30**	**9.30**	**9.24**	**9.16**
Yield Strength, fy (MPa)	437.94	436.42	436.94	437.24	437.94	437.17	438.17	435.47	437.17	437.55	437.06	436.50
Ultimate Tensile Strength, fu (MPa)	601.24	601.19	602.87	598.65	602.18	602.60	602.40	603.20	601.80	603.35	602.85	602.71
Strain Ratio	1.39	1.39	1.39	1.40	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.38
Rebar Diameter Before Test (mm)	11.95	11.95	11.96	11.97	11.95	11.97	11.97	11.95	11.95	11.95	11.95	11.96
Rebar Diameter- After Corrosion(mm)	11.91	11.91	11.92	11.93	11.91	11.93	11.93	11.91	11.91	11.91	11.91	11.92
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Rebar Weights- Before Test(Kg)	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Rebar Weights- After Corrosion (Kg)	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83
Weight Loss /Gain of Steel (Kg)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table-3.3: Potential Ecorr, after 28 days curing and 360days Accelerated Periods of Pycnanthus angolensis(African/false nutmeg) Exudate / Resin Coated Specimens

Sampling and Durations	**Samples 1 (90 days)**			**Samples 2 (180 Days)**			**Samples 3 (270 Days)**			**Samples 4 (360 Days)**		
	150µm (Exudate/Resin) coated			300µm (Exudate/Resin) coated			450µm (Exudate/Resin) coated			600µm (Exudate/Resin) coated		
Potential Ecorr, mV	-118.04	-118.72	-115.45	-114.05	-116.46	-113.43	-121.88	-117.56	-113.11	-115.42	-119.41	-113.57
Concrete Resistivity ρ, kΩcm	14.56	14.55	14.54	14.54	14.53	14.70	14.69	14.68	14.68	14.67	14.61	14.53
Yield Strength, fy (MPa)	459.07	460.31	461.31	458.61	460.31	460.69	460.20	459.64	460.24	460.00	460.53	460.59
Ultimate Tensile Strength, fu (MPa)	635.16	633.07	634.75	630.53	634.06	634.48	634.28	635.08	633.68	635.23	634.73	634.59
Strain Ratio	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38
Rebar Diameter Before Test (mm)	11.95	11.95	11.96	11.97	11.95	11.97	11.97	11.95	11.95	11.95	11.95	11.96
Rebar Diameter- After Corrosion(mm)	12.46	12.46	12.47	12.48	12.46	12.48	12.48	12.46	12.46	12.46	12.46	12.47
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Rebar Weights- Before Test (Kg)	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Rebar Weights- After Corrosion (Kg)	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94

Table-3.4: Average Potential Ecorr, after 28 days curing and 360days Accelerated Periods (Control, Corroded and Exudate/Resin Coated (specimens)

Sampling and Durations	**Control Concrete slab Specimens**				**Corroded Concrete slab Specimens**				**Pycnanthus angolensis(African/false nutmeg) Exudate / Resin Coated Specimens**			
	Average Potential Ecorr, Values of Control Concrete slab Specimens				Average Potential Ecorr, Values of Corroded Concrete slab Specimens				Average Potential Ecorr, Values of Pycnanthus angolensis(African/false nutmeg) Coated Specimens			
Potential Ecorr,mV	-112.25	-110.49	-113.36	-111.97	-317.54	-321.11	-323.98	-380.27	-117.40	-114.65	-117.51	-116.13
Concrete Resistivity ρ, kΩcm	12.34	12.38	12.47	12.39	9.21	9.21	9.31	9.23	14.55	14.59	14.68	14.61
Yield Strength, fy (MPa)	452.63	452.98	450.35	452.57	437.10	437.45	436.93	437.04	460.23	459.87	460.02	460.37
Ultimate Tensile Strength, fu (MPa)	621.83	620.54	621.87	622.37	601.77	601.14	602.47	602.97	634.32	633.02	634.34	634.85
Strain Ratio	1.37	1.37	1.38	1.38	1.38	1.37	1.38	1.38	1.38	1.38	1.38	1.38
Rebar Diameter Before Test (mm)	11.96	11.96	11.96	11.95	11.96	11.96	11.96	11.95	11.96	11.96	11.96	11.95
Rebar Diameter-After Corrosion(mm)	11.96	11.96	11.96	11.95	11.91	11.92	11.92	11.91	12.47	12.47	12.47	12.47
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.04	0.51	0.51	0.51	0.51
Rebar Weights-Before Test(Kg)	0.824	0.833	0.828	0.829	0.831	0.829	0.818	0.824	0.822	0.826	0.832	0.833
Rebar Weights-After Corrosion(Kg)	0.824	0.833	0.828	0.829	0.813	0.803	0.813	0.919	0.924	0.919	0.924	0.931
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.066	0.064	0.063	0.065

Table-3.5: Average Percentile Potential Ecorr, after 28 days curing and 360days Accelerated Periods (Control, Corroded and Exudate/Resin Coated (specimens)

	Control Concrete slab Specimens				**Corroded Concrete slab Specimens**				**Pycnanthus angolensis(African/false nutmeg) Coated Specimens**			
	Percentile Average Potential Ecorr,				Percentile Average Potential Ecorr,				Percentile Average Potential Ecorr,			
Potential Ecorr,mV	-64.65	-65.59	-65.01	-70.55	170.47	180.09	175.70	227.45	-63.03	-64.30	-63.73	-69.46
Concrete Resistivity ρ, kΩcm	33.93	34.33	33.98	34.27	-36.68	-36.84	-36.60	-36.80	57.93	58.32	57.73	58.22
Yield Strength, fy (MPa)	3.55	3.55	3.07	3.56	-5.03	-4.88	-5.02	-5.07	5.29	5.13	5.29	5.34
Ultimate strength (N/mm2)	3.34	3.23	3.22	3.22	-5.13	-5.04	-5.03	-5.02	5.41	5.30	5.29	5.29
Strain Ratio	-5.86	-5.88	-5.90	-5.86	6.05	6.04	6.06	5.98	-5.89	-5.88	-5.91	-5.83
Rebar Diameter Before Test (mm)	0.334	0.337	0.332	0.313	0.314	0.325	0.314	0.319	0.321	0.331	0.327	0.335
Rebar Diameter-After Corrosion(mm)	0.334	0.337	0.332	0.313	-4.427	-4.429	-4.438	-4.452	4.63	4.58	4.67	4.73
Cross- sectional Area Reduction/Increase (Diameter, mm)	0	0	0	0	-20.98	-21.91	-21.99	-22.99	26.43	26.42	26.42	26.43
Rebar Weights-Before Test(Kg)	0.330	0.333	0.326	0.309	0.310	0.321	0.310	0.315	0.317	0.327	0.323	0.331
Rebar Weights-After Corrosion(Kg)	9.80	9.05	9.91	9.05	-11.82	-11.93	-11.90	-11.93	13.41	13.54	13.51	13.54
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	-22.58	-20.97	-20.97	-20.97	29.17	26.53	26.53	26.53

3.1 Results of Potential E_{corr}, mV, and Concrete Resistivity ρ, kΩcm on Concrete Slab Members

Concrete degradation can be caused by a number of processes which can be classified in different ways. One possibility is to classify damage mechanisms into chemical and physical damage mechanisms according to the nature of the damaging factors. Chemical degradation includes chloride attack, carbonization, acid attack, sulfate attack and alkaline aggregate reactions. Physical degradation includes freeze-thaw, leaching, erosion, and cracking [35, 36]. Mechanical wear, i.e. shock, overload and vibration can also be included in this category [37], although the probability of damage is greater than wear in this category. A distinction is made between breakdown and deterioration; the former being associated with sudden changes, which are often caused by unintentional mechanical loads, and the latter referring to progressive, often slow changes caused by some external aggressor. The E_{corr} potential results, mV and concrete resistance, kΩcm, are obtained from Tables 3.1 - 3.3 and summarized into mean and percentile values in Tables 3.4 and 3.5, plotted graphically in Figures 3.1-3.8b, are the results of controlled samples, not coated (corroded) and coated for 36 concrete slabs, divided into 3 sets of 12 controlled samples, which is the determinant reference range, 12 uncoated (corroded) samples and 12 exudate/resin coated samples.

The mean and percentage minimum, maximum, and differential values of the calculated half-cell controlled sample potential measurements were -113.36 mV and -110.49 mV (-70.55% and -64.65%) with a potential difference of 2 .87 mV and 5.9%, the corroded samples were -380.3 mV and -317.5 mV (170.5% and 227.5%) and the difference values were 62.73 mV and 56.98%, and samples coated are -117.5 mV and -114.7 mV and - 114.7 mV and -63.03%) and the potential difference is 2.86 mV and 6.43%. The maximum calculated percentile control value is -64.65% compared to the corroded and coated values of 227.5% and -63.03% and the controlled potential difference value is 5.9%, corroded 227.5%, and coated 6.43%. The maximum yields obtained from the controlled and coated samples were -110.49mV and -114.7mV, which indicate the relationship between corrosion potential and probability in the reference range $E\text{corr} > -200\text{mV}$. The results from these potential E_{corr} results indicate that the controlled and exudate/resin-coated sample values are low with a 90% probability that no corrosion of the reinforcing steel is currently observed during the measurement (10% corrosion risk, indicating 10%) or uncertain corrosion probability For uncoated samples, the maximum calculated value is -317.5mV, the result is within the reference value of the dependence between corrosion potential and probability of $-350\text{mV} \leq E\text{corr} \leq -200\text{mV}$ indicates a high-value range of 10% or indicates the possibility of unsafe corrosion. The comparison results from the reference (controlled) range show that the samples corroded as a result of accelerated corrosion-induced compared to the coated samples which showed no corrosion, indicating corrosion-inhibiting properties against corrosion attack on reinforcing steel attached to the concrete slab, e.g. the corrosive environment to which it is connected with the formation of a resistant layer.

The average value and the percentage of the specific minimum and maximum resistance with the potential difference of the controlled sample are 12.34kΩcm and 12.47kΩcm (33.93% and 34.33%), and the difference value of 0.13kΩcm and 0.4% of the sample is 9.21kΩcm and 9.31kΩcm (-36.84% and -36.6%) and the difference values of 0.1kΩcm and 0.24%., The closed sample valleys were 14.55kΩcm and 14.68kΩcm (57.73% and 58.32%) and the difference values of 0.13 mV and 0.59%.

The maximum value calculated from the concrete resistance of the controlled sample concrete is 34.33% as compared to the corroded and coated values of 36.6% and 58.32% and the maximum difference percentage of control is 0.4% compared to the corroded and coated value of 0.24% and 0.59%. The results of controlled samples coated with concrete resistance obtained the maximum mean values of 12.47kΩcm and 14.68 kΩcm with a description of the value $10 < \rho < 20$ (low) compared to the corrosion value of 9.31kΩcm with Specifications $5 < \rho < 10$ (high) and with a reference range of dependence between concrete resistance and corrosion probability at significant corrosion probability ($\rho < 5$, $5 < \rho < 10$, $10 < \rho < 20$, $\rho > 20$) for very high, high, low to moderate and low, for possible corrosion. From the comparison results of coated and corroded samples, the maximum values obtained for both samples clearly indicate the value of coated samples with a range of $10 < \rho < 20$, which classifies the range of values as low to moderate, with information as significant corrosion probability.

The maximum value of the corroded sample was in the range of $5 < \rho < 10$, indicating high, signs indicating the presence of possible corrosion, confirmed in the work [19, 22, 25, 22, 20]. From the results obtained it can be compared that the effect of corrosion attack was observed in the uncoated samples, while the samples with exudate/resin coating had corrosion protection properties with a highly resistant and water-resistant membrane that prevented corrosion of the reinforcing steel built into the concrete preventing slabs and induced accelerations from being exposed to corrosive media.

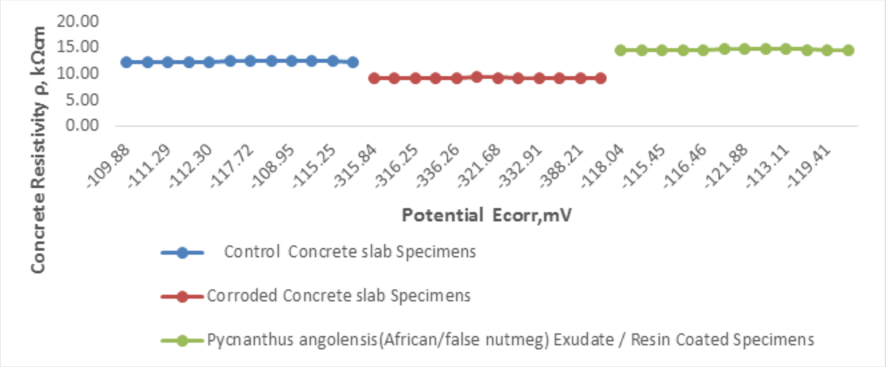

Fig-3.1: Concrete Resistivity ρ, kΩcm versus Potential Ecorr,mV Relationship

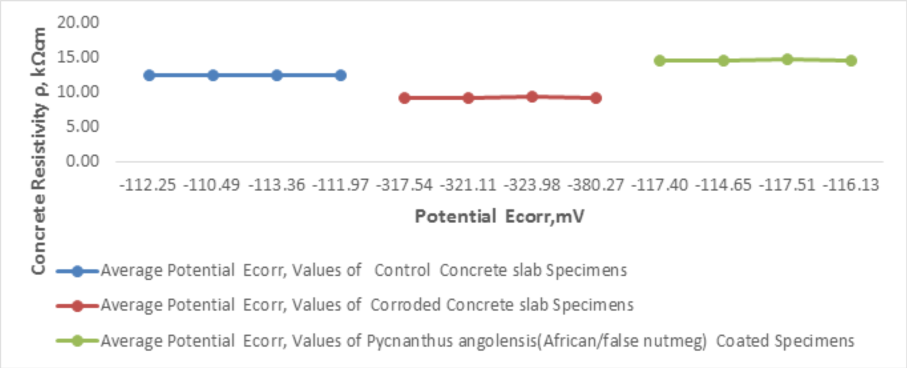

Fig-3.1A: Average Concrete Resistivity versus Potential Relationship

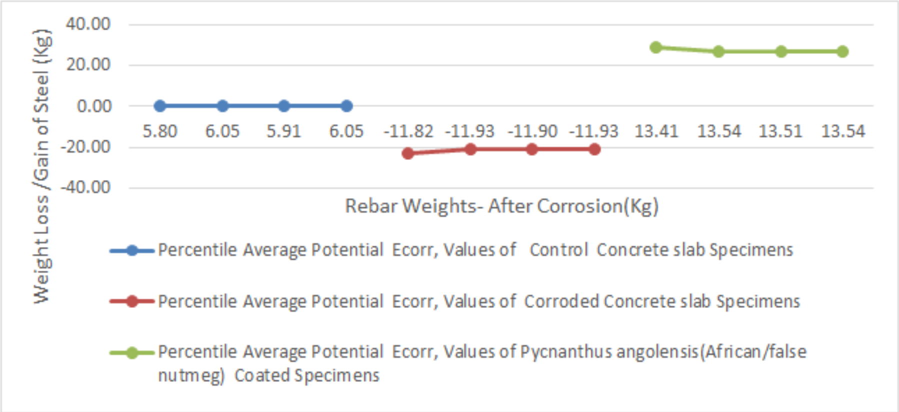

Fig-3.1B: Average Percentile Concrete Resistivity versus Potential Relationship

3.2 Results of Mechanical Properties of Yield Strength, Ultimate Strength and Strain Ratio of Embedded Reinforcing Steel in Concrete Slab

Premature or premature damage to reinforced concrete infrastructure in marine environments have potentially significant economic, environmental and sustainable consequences and should therefore be avoided whenever possible. Despite decades of research, the exact mechanism associated with the initiation and progression of increased corrosion in the marine environment and the possible subsequent structural damage remains unclear. This is not satisfactory. It prevents sound design for long-lasting durability.

The results of the mean, percentile, and the difference between the minimum and maximum yield strength limits, fy (MPa) of the controlled sample were 450.4MPa and 452.98 MPa (3.07% and 3.56%) and the difference values were 2.63MPa and 0.49%, the corroded samples were 436.9 MPa and 437.5MPa (-5.07% and -4.88%) and the difference value was 0.52MPa and 0.19%, the coated sample value was 459.9MPa and 460.4MPa (5.13% and 5.34%) and the difference values are 0.5MPa and 0.21%. The calculated yield strength maximum percentage value of the controlled yield strength was 3.56% compared to the corroded and coated values -4.88% and 5.34% and the possible difference values of 0.49% controlled, 0.19% corroded, and 0.21% covered.

The mean, percentile, and the difference between the minimum and maximum tensile strength, fu (MPa) of the controlled sample were 620.5MPa and 622.4MPa (3.22% and 3.34%) and the difference values were 1.83MPa and 0.12. %, corroded 601.1MPa and 603MPa (-5.13% and -5.02%) and the difference of 1.83MPa and 0.11%, coverage of 633MPa and 634.9MPa (5.29% and 5.41%) and the difference in value 1.83 MPa and 0.12% The calculated maximum percentage of the controlled ultimate tensile strength is 3.34% relative to corrosion and the coating value is -5.02% and 5.41% and the possible difference value is 0.12% controlled, 0.11% corroded and 0.12% coated.

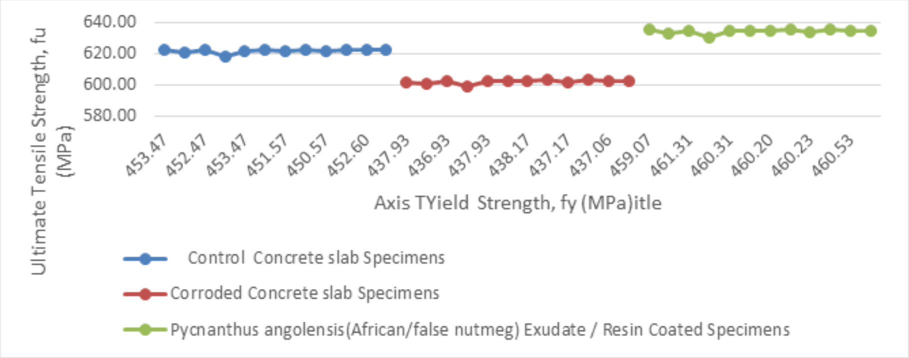

Fig-3.2: Yield Strength versus Ultimate strength

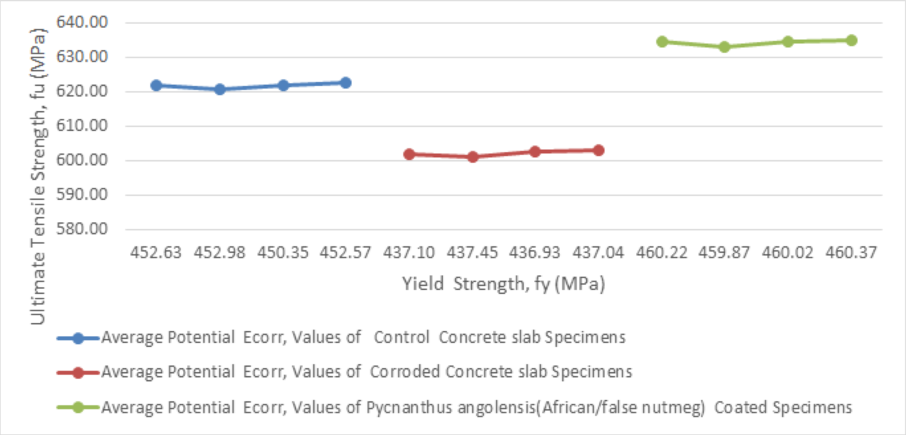

Fig-3.2A: Average Yield Strength versus Ultimate Tensile Strength

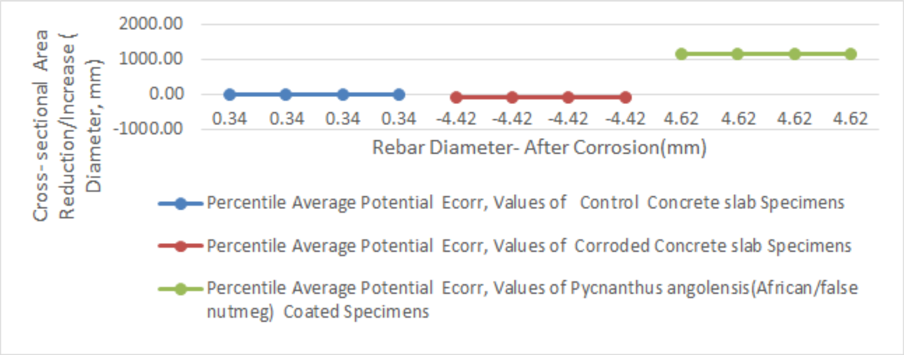

Fig-3.2B: Average Percentile Yield Strength versus Ultimate Tensile Strength

The minimum and maximum mean values of the strain ratio, percentile, and different values of the controlled samples were 1.37 and 1.38 (-5.9% and -5.86%) with a different value of 0.009 and 0.04%, corrosion values samples were 1.4 and 1.4 (5.98% and 6.06%) and the difference values were 0.009 and 0.0079%, coated samples were 1.38 and 1.38 (-5.91% and -5.83%) and the difference value of 0% and 0.08%. The maximum calculated strain ration percentage for comparison checked up to -5.86% versus corroded 6.06% and coated -5.83% and different peak values checked up to 0.04%, corroded 0.0079%, and coated 0.08% as confirmed in the works [19, 22, 25, 22, 20]. From the calculation results obtained, summarized in Tables 3.4 and 3.5 and displayed graphically in Figures 3.1 - 3.8, the yield strength, tensile strength, and strain ratio of the mean, percentile, and controlled differential potential values, uncoated (corroded) and layered concrete slab samples were determined, coated samples had higher failure loads compared to corroded samples with reduced failure load and low load-bearing capacity and with mean and percentile values in relation to the reference range, whereas uncoated (corroded) samples, had a load-bearing capacity which is low and a reduced value compared to the reference range. The comparison results show that the low load carrying capacity is caused by the effect of corrosion attack on the uncoated (corroded) elements, which damage the reinforcing steel fibers, ribs, and passive formation and surface modification. The observed mean values for the coated samples were associated with the corrosion resistance potential to penetrate the reinforcing steel with the formation of a protective membrane; This attribute indicates the efficiency and effectiveness of the exudate/resin as an inhibitor against corrosive effects. of reinforced concrete structures exposed to the edges of strong, high salinity marine areas.

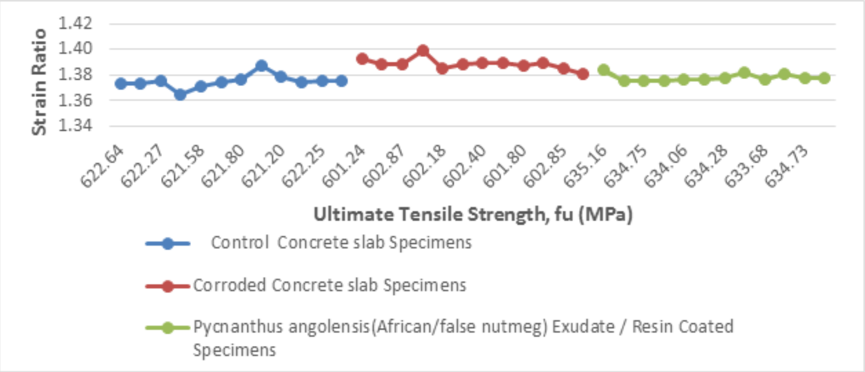

Fig-3.3: Ultimate Tensile Strength versus Strain Ratio

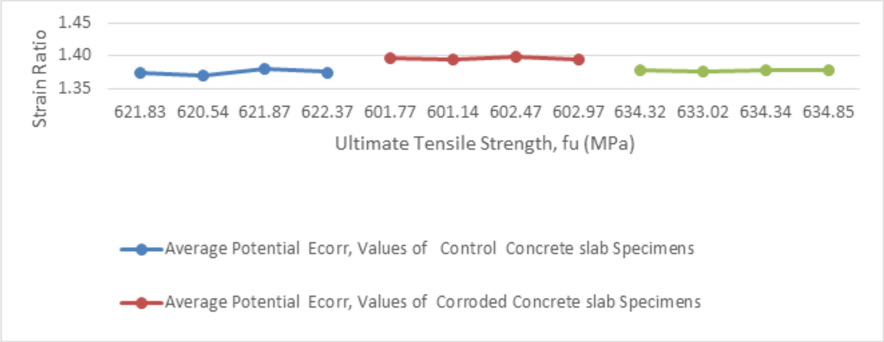

Fig-3.3A: Average Ultimate Tensile Strength versus Strain Ratio

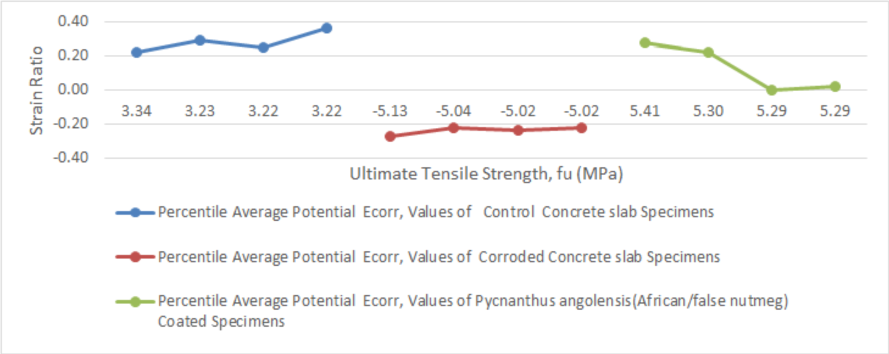

Fig-3.3B: Average percentile Ultimate Tensile Strength versus Strain Ratio

3.3 Results of Mechanical Properties of Rebar Diameter, Cross-Sectional Area and Weight Loss / Increase of Embedded Reinforcing Steel in Concrete Slab

The mechanical properties of corrosion increase with analysis of yield point, maximum strength, and elongation in tensile tests with different degrees of corrosion of steel bars. A relatively consistent understanding is established that With low corrosion rates, corrosion has only a small effect on the mechanical properties of steel bars; when the corrosion rate is high, the nominal yield strength, nominal yield strength, and elongation are reduced. However, different brands, different diameters, and different types of corrosion have different effects on the test results.

With different diameters, fine steel is more sensitive to corrosion. With the same corrosion rate, large-diameter reinforcement has a certain corrosion-reducing effect due to its large strength reserve. For the same type of steel: Diameter of reinforcement before testing (mm) the average value and the minimum and maximum percentage was controlled from 11.95 mm and 11.96 mm (0.313% and 0.337%) with a difference of 0.01 mm and 0.024%, the corroded sample values were 11.95 mm and 11.96 mm (0.314% and 0.325%) and the difference values were 0.01 mm and 0.011%, and the coated sample values were 11.95 mm and 11.96 mm (0.321% and 0.335 mm and different calculated values of 0.01 mm and 0.014%).

The unit weight of the value before the corrosion test showed a small difference in relation to the product and company shape as well as by-products used in the production process were 11.95 mm and 11.96 mm (0.313% and 0.337%), with 100% of the observed reference values, the corroded sample values were 11.91 mm and 11.92 mm (-4.42% and -4.42%) and a difference of 0.009 mm and 0.00%, d values of the coated samples were 12.47 mm and 12.47 mm (4.62% and 4.63%) and the difference was 0.000 mm and 0.009%. The maximum calculated percentile was controlled from 0.337% against –4.42% corroded and 4.63% coated, the difference in the percentage of corroded was 0.00% against 0.009% coated. The results obtained in Tables 3.4 and 3.5, which are summarized in Tables 3.1, 3.2, and 3.3 and shown graphically in Figures 3.3-3.6b, show the effect of corrosion attack on reinforcing steel embedded in concrete slabs, which are subjected to induced corrosion-accelerating activities. For comparison, the results of the corroded sample showed a decrease and decrease in value compared to the diameter of the reinforcement before and after the induction accelerated corrosion test with a percentage decrease in value from 0.337% to -4.42% and an average value in the range from 11.96 mm to 11.931 mm.

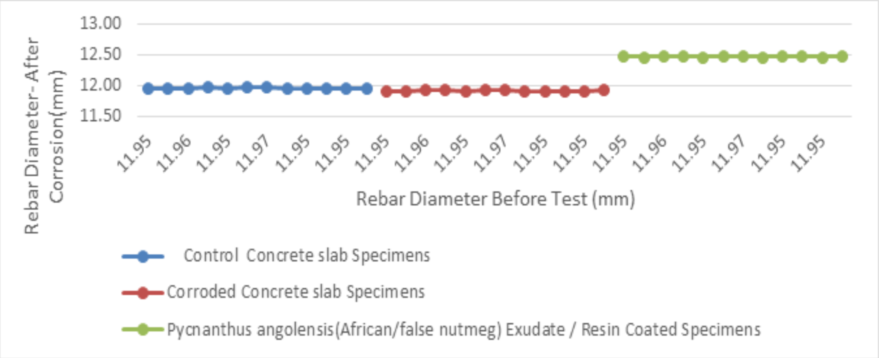

Fig-3.4: Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

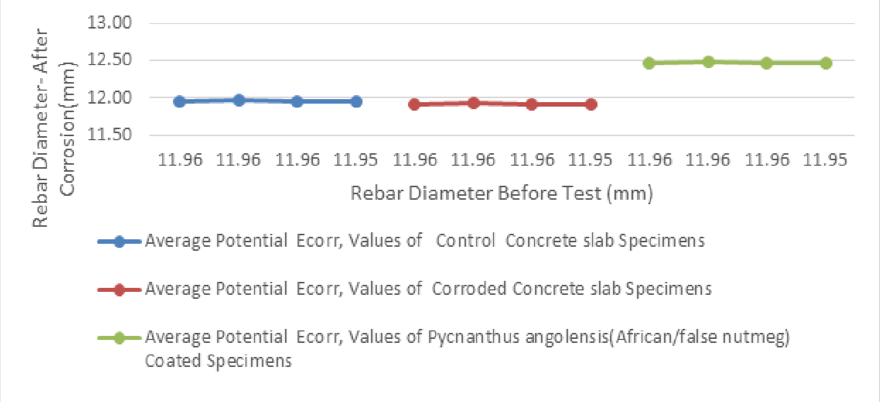

Fig-3.4A: Average Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

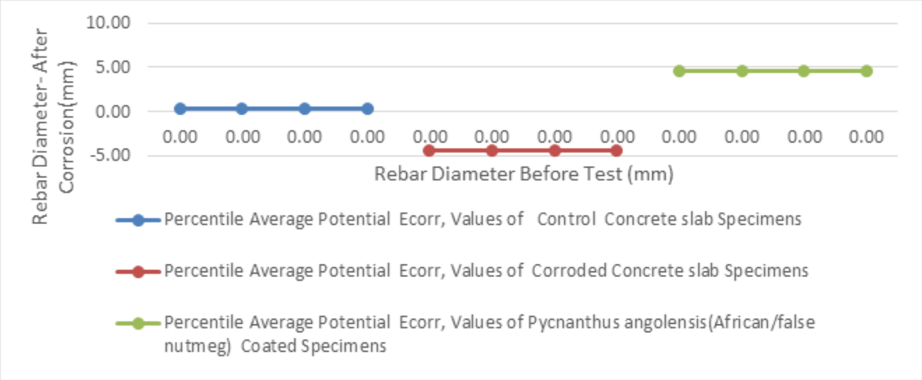

Fig-3.4B: Average Percentile Rebar Diameter Before Test(mm) versus Rebar Diameter- After Corrosion(mm)

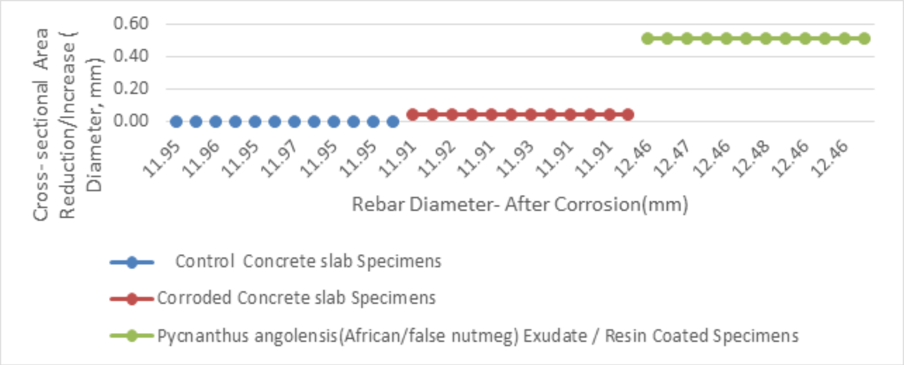

Fig-3.5: Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

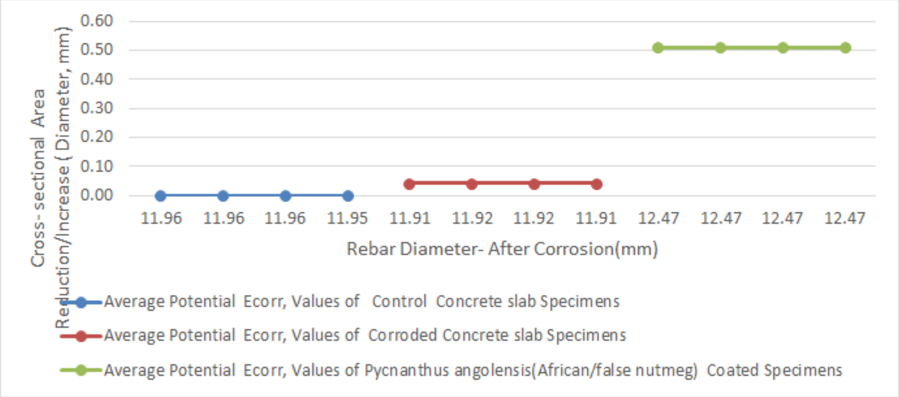

Fig-3.5A: Average Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

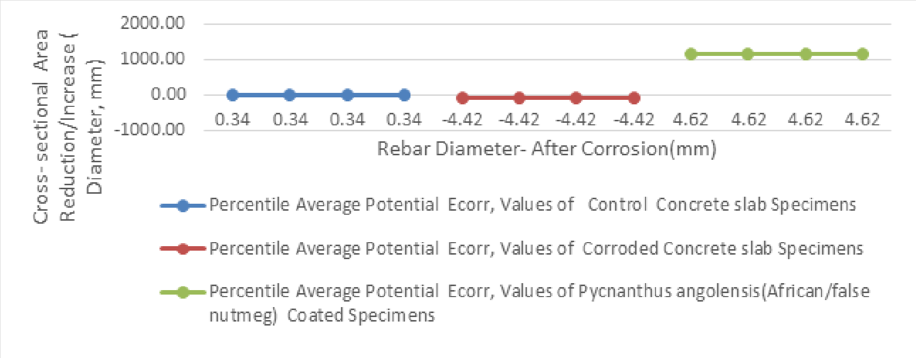

Fig-3.5B: Average Percentile Rebar Diameter- After Corrosion(mm) versus Cross- section Area Reduction/Increase (Diameter, mm)

The decrease/increase (diameter) in cross-sectional area, minimum and maximum mean and percentile values were controlled up to 100%, with no decrease or increase after 360 days of immersion in fresh water. Corroded sample values are 0.04 mm and 0.04 mm (-22.99% and -20.98%) and the difference is 0.0 mm and 2.01% for the corroded, coated sample values are 0.51 mm and 0.51 mm (26.42% and 26.43%) and the difference is 0.00 mm and 0.01%. The relative mean and percentage difference values between coated samples and corrosion range from 26.43% to -20.98%. The decrease of cross-sectional area in mean and percentage values indicates that the corrosion effect causes a decrease in diameter and cross-sectional area, fiber degradation, rib reduction and surface modification, while the exudate/resin-coated elements are validated in the work due to differences in coating thickness [19, 22, 25, 22, 20].

In summary, it can be said that the exudate/resin has inhibitory properties against corrosive effects on reinforcing steel embedded in the concrete slab sample, induced in an environment with high salt content. Valve Weight - Before Test (kg), the mean and percentage of minimum, maximum, and differential of the controlled samples were 0.824 kg and 0.833 kg (0.309% and 0.333%), and the difference was 0.009% and 0.024%, respectively. the corroded samples weighed 0.818 kg and 0.831 kg (0.31% and 0.321%) and the difference was 0.013% and 0.011%, the coated samples were 0.822 kg and 0.833 kg (0.317% and 0.331%) with a difference of 0.011% and 0.014%.

The results of the average value and percentage of rebar weight after corrosion (Kg) and the aggregate difference value of the minimum and maximum values of the controlled sample are 0.824 kg and 0.833 kg (0.309% and 9%) 0.333%) and the difference value is 0.009% and 0.024%, samples the corroded values were 0.803 kg and 0.919 kg (-11.93% and -11.82%) and the difference was 0.116% and 0.11%, the values of the coated samples were 0.919 kg and 0.931 kg (13, 41% and 13 .54%) and the difference between 0.012% and 0.13%.

The mean and the minimum and maximum percent unit rebar weight loss/gain steel (Kg) and the percentage difference in comparison were controlled at 100% of the values obtained by aggregation in freshwater tanks with no trace of corrosion potential relative to the corroded sample values of 0.05kg and 0.05kg (-22.58% and -20.97%), and coated of 0.063 kg and 0.066kg (26.53% and 29.17%). Calculation results from Tables 3.1-3.3 and summarized in 3.4 - 3.5 and plotted graphically in Figure 3.7-3.87 show the effect of corrosion on uncoated (corroded) and coated reinforcing steel and an investigation of the unit weight of reinforcement before and after corrosion and decrease/increase weight. For comparison the results obtained of unit rebar weight loss/gain steel showed a reduction of mean and percentile values for coatings from 0.063 kg to 0.05 kg and corrosion 29.17% to -20.97%, as in the work [19, 22, 25, 22, 20].

The aggregate results show that the corrosion effect causes a reduction in weight/reduction of the corroded sample compared to the percentile layer and an increase in mean, resulting in a slight increase in volume around the layer thickness. This study shows the efficacy and effectiveness of exudate/resin as an anti-corrosion anti-corrosion material in reinforcing steel embedded in samples of concrete slabs exposed to induced corrosion.

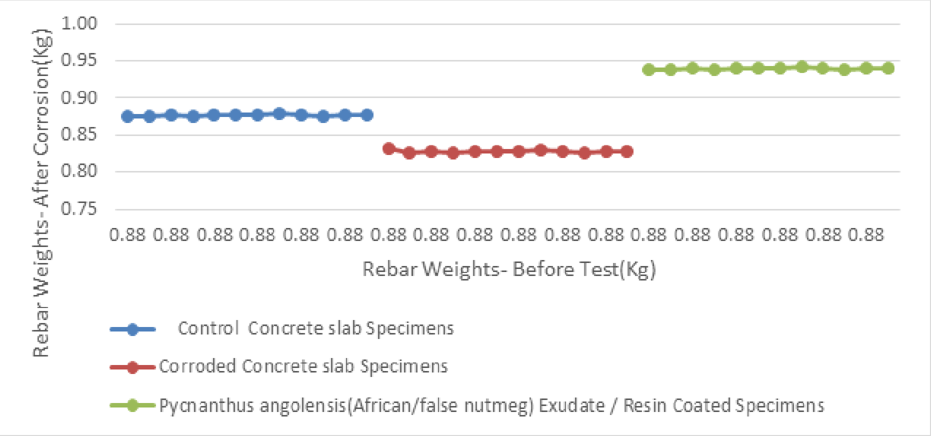

Fig-3.6: Rebar Weights- Before Test(Kg) versus Rebar Weights- After Corrosion(Kg)

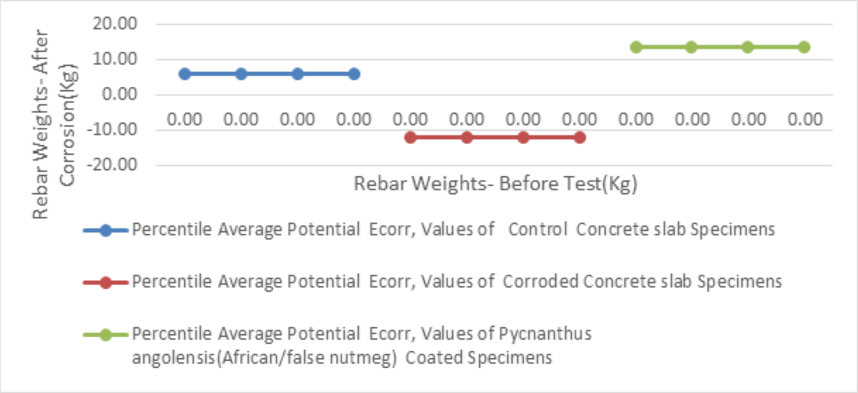

Fig-3.6A: Average Rebar Weights- Before Test(Kg) versus Rebar Weights- After Corrosion(Kg)

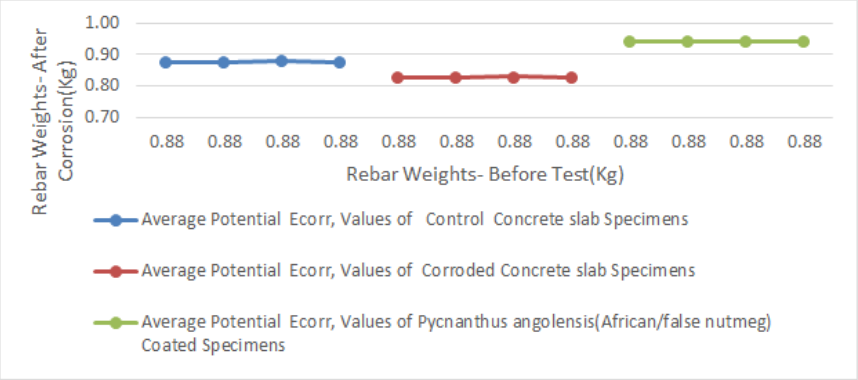

Fig-3.6B: Average Percentile Rebar Weights- Before Test(Kg) versus Rebar Weights- After Corrosion(Kg)

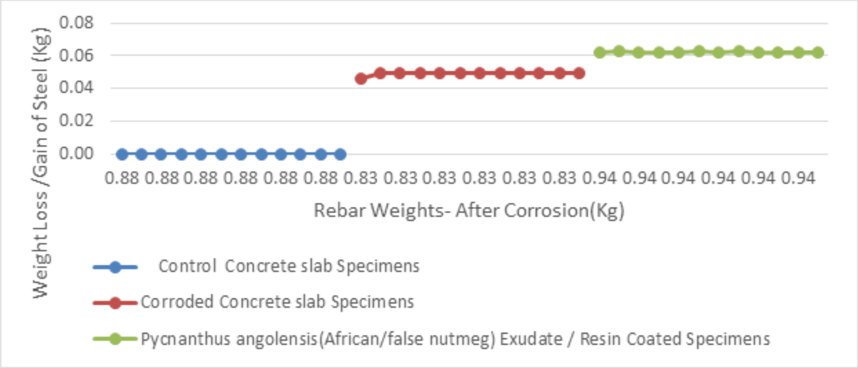

Fig-3.7: Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

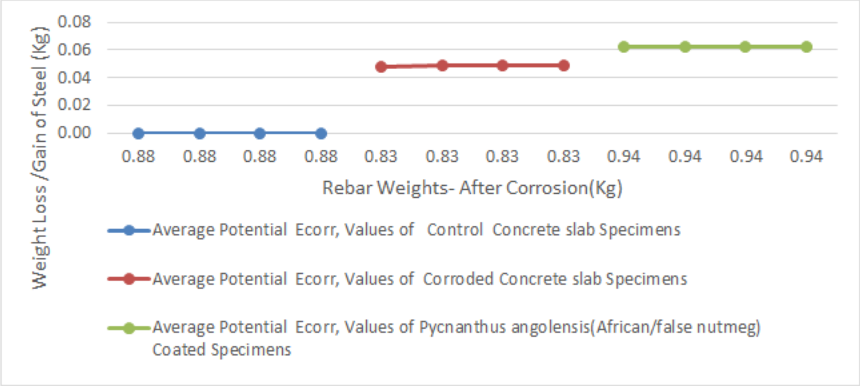

Fig-3.7A: Average Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

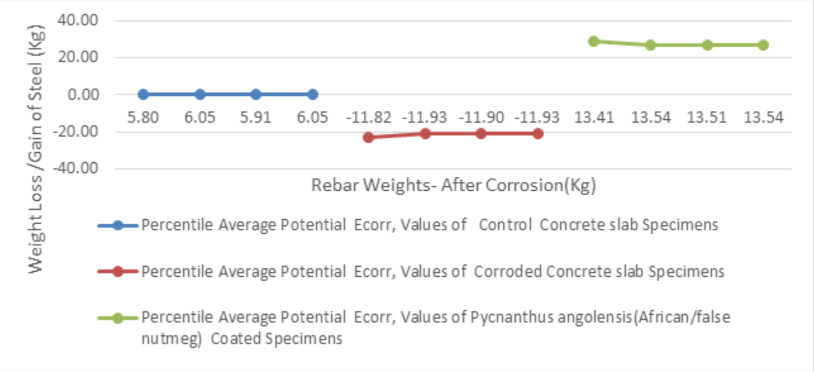

Fig-3.7B: Average Percentile Rebar Weights- After Corrosion(Kg) versus Weight Loss /Gain of Steel (Kg)

4.0 CONCLUSION

Experimental results showed the following conclusions:

i. Coated reinforcing steel showed no indications of corrosion presence
ii. Pycnanthus angolensis(African/false nutmeg) exudates / resins showed an inhibitory properties against corrosion attacks
iii. Reduction in diameter and cross-sectional areas were noticed in corroded samples
iv. Weight loss was witnessed in corroded samples while inhibited samples exhibited minute volumetric increase.
v. Yield strength and ultimate tensile strength reduction was noticed in corroded samples resulting from corrosion effect

REFERENCES

1. Ali, S. A. H., Al-Muallem, A., Rahman, S. U., Saeed, M. T. (2008). Bisisoxazolidines: A new class, of corrosion inhibitors of mild steel in acidic media. Corrosion Sci., 50 (11); 3070-3077.
2. Cruz, J., Martínez,, R., Genesca, J., and García-Ochoa E. (2003). Experimental and theoretical study of 1-(2-ethylamino)-2 methylimidazoline as an inhibitor of 10.
3. Macdonald, D. (2003). Design options for corrosion protection. 8th International Symposium. Australia: 75-83.
4. Domone, P., & Illston, J. (2010). Construction Materials: Their Nature and Behavior. CRC Press, Taylor & Francis, London, UK.
5. Andrade, C., Keddam, M., Novoa, X., Perez, M., Rangel, C., & Takenouti, H. (2001). Electrochemical Behaviour of Steel Rebars in Concrete: Influence of Environmental Factors and Cement Chemistry. Electrochimica Acta, 46, 3965-3972.
6. Saremi, M., & Mahallati, E. (2002). A Study on Chloride–Induced Depassivation of Mild Steel in Simulated Concrete Pore Solution. Cement and Concrete Research, 32; 1915- 1921.
7. Bertolini, L., Elsener, B., Pedeferri, P., & Polder, R. (2004). Corrosion of steel in concrete: Prevention, Diagnosis, Repair. Wiley-VCH, Weinheim
8. Lounis, Z., Zhang, J., & Daigle, L. (2004). Probabilistic Study Chloride-Induced Corrosion of Carbon Steel in Concrete Structures. 9th ASCE Joint Specialty Conference on Probablistic Mechanisms and Structural Reliability, Albuquerque, New Mexico, 1-6.
9. Elsener, B. (2005). Corrosion Rate of Steel in Concrete Measurements beyond The Tafel Low. Corrosion Science, 47; 3019-3033.
10. Schroeder, R.M., & Muller, I. L. (2003). Stress Corrosion Cracking and Hydrogen Embitterment Susceptibility of an Eutectoid Steel Employed in Prestressed Concrete. Corrosion Science, 45; 1969-1983.
11. Ramadan, S., Gaillet, L., Tessier, C., & Idrissi, H. (2008). Detection of Stress Corrosion Cracking of High-Strength Steel Used in Prestressed Concrete Structures by Acoustic Emission Technique. Applied surface Science, 254; 2255-2261.
12. Almusallam, A., Ahmed, S., Gahtani, A., & Rauf, A. (1995), “Effect of reinforcement corrosion on bond strength. Construction and Building Materials, 10; 123-129.
13. Cabrera, J. G. (1996). Deterioration of concrete due to reinforcement steel corrosion. Cement and Concrete Composites, 18; 47–59
14. Rashid, M.H., Khatun, S., Uddin, S.M.K., & Nayeem, M.A. (2010). Effect of strength and covering on concrete corrosion, European Journal of Scientific Research, 40, 492-499
15. Rengaswamy, N.S., Srinivasan, S., & Balasubramanian, T.M. (1988). Inhibited and Sealed Cement Slurry Coating of Steel
16. 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.
17. Ballim, Y., & Reid, J.C. (20030. Reinforcement corrosion and the deflection of RC beams- an experimental critique of current test methods: Cement and Concrete Composites, 25**;** 625-632.
18. Kanee, S., Petaba, L. D., Charles, K. (2019). Inhibitory Action of Exudates / Resins Extracts on

the Corrosion of Steel bar Yield Strength in Corrosive Media Embedded in Concrete, "European Academic Research – 7(7): 3381 – 3398.

19. Letam, L. P., Charles, K., Daso, D. (2019). Non-coated and Coated Reinforcement in Concrete Corrosion Probability Measurement in Accelerated Environment by Wenner Method. International Journal of Research in Engineering & Science, 3(5);15 – 29.
20. Charles, K., Nzidee, L. F., Charles, E. N. (2019). Corrosion Potential Assessment of Reinforcement Mechanical Properties Embedded in Concrete in Accelerated Corrosive Medium, "International Journal of Emerging Trends in Engineering and Development, 6(9) 1-14, 2019.
21. AKARI, N. T., KENNEDY, C., & NWOCHIGZIRI, C. E. Corrosion Resistance of Reinforced Steel in Concrete with Invingia Gabonensis Exudates/Resins Coated Steel.
22. Petaba, L. D., Charles, K., Kanee, S. (2019). Electrochemical Corrosion Measurement of Non-Inhibited and Inhibited Reinforcement Mechanical Properties Embedded in Concrete. International Journal of Scientific and Engineering Research, 10(9); 1180 – 1196.
23. Terence, T. T. W., Kanee, S., Charles, K. (2019). Corrosion Influence on Mechanical Properties of Corroded and Inhibited Steel Bars in Concrete with Applied Currents Potential Measurement. American Journal of Engineering Research, 8(10); 135-145.
24. BS 882. (1992). Specification for aggregates from natural sources for concrete, British Standards Institute. London, United Kingdom.
25. BS EN 196-6. (2010). Methods of Testing Cement, "Determination of fineness, British Standards Institute. London, United Kingdom.
26. Standard, B. (2009). Testing hardened concrete. Compressive Strength of Test Specimens, BS EN, 12390-3.
27. BS 4449:2005+A3 –Steel for Reinforcement of Concrete. British Standards Institute. London, United Kingdom.
28. Figg, J. W., & Marsden, A. F. (1985). Development of inspection techniques for reinforced concrete: a state of the art survey of electrical potential and resistivity measurements for use above water level.
29. Gowers, K. R., & Millard, S. G. (1999). Electrochemical techniques for corrosion assessment of reinforced concrete structures. Proceedings of the Institution of Civil Engineers-Structures and Buildings, 134(2), 129-137.
30. Stern, M., & Geary, A. L. (1957). Electrochemical polarization: I. A theoretical analysis of the shape of polarization curves. Journal of the electrochemical society, 104(1), 56.
31. ASTM Standard C876 2012, Standard test method for corrosion potentials of uncoated reinforcing steel in concrete, A. International, Editor. 2012, ASTM International: West Conshohocken, PA
32. ASTMC876-91. (1999). Standard Test Method for Half-cell Potentials of Uncoated Reinforcing Steel in Concrete,"
33. Basheer, P. A. M., Chidiact, S. E., & Long, A. E. (1996). Predictive models for deterioration of concrete structures. Construction and Building Materials, 10(I), 27–37
34. Takewaka, K., & Mastumoto, S. (1988). Quality and cover thickness of concrete based on the estimation of chloride penetration in marine environments. In 2nd International Conference of Concrete Marine Environment, 381–400.
35. British Standard. (2008). Products and systems for the protection and repair of concrete structures — Definitions, requirements, quality control and evaluation of conformity Part 9: General principles for use of products and systems.