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Corrosion Resistance of Reinforced Steel in Concrete with Invingia Gabonensis Exudates / Resins Coated Steel

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Abstract

Greener approach inhibitors of environmentally friendly, toxic free and inexpensive has greater demand to organic ones due to their biodegradable properties. This experimental work evaluated the use of environmentally inorganic exudates / resins extracted from trees bark of invingia gabonensis, layered to reinforcing steel with varying thicknesses, immersed in sodium chloride (NaCl) for corrosion examinations in comparison with non-coated and control samples for 150 days accelerated process with applied currents potential of -200 mV through 1200mV, with a scan rate of 1mV/s. Results of corroded and exudates/resin coated specimens concrete resistivity ρ, kΩcm against potential $E_{corr,}{}^{mV}$ relationship showed average potential E_{corr} control percentile average value of 32.27042% and percentile difference -67.7296% over 259.7082% corroded specimen. Concrete resistivity ρ, kΩcm averaged results percentile average value of 182.7709% and percentile difference 82.7709% over -36.4744% corroded specimen. Mechanical properties "ultimate strength" of control specimen percentile average value 91.55303% and percentile difference -8.44697% over 9.104398% corroded specimen. Mechanical properties "weight loss of steel" of control with percentile average value 50.9558%

and percentile difference -49.0442% over 97.67224% corroded. Mechanical properties "cross- section area reduction" of control percentile average value 113.1957% and percentile difference 13.19568% over -11.6574% corroded specimen. Entire results of exudates / resin coated specimens showed indications of no corrosion potential, results proved invingia gabonensis exudates / resins as good corrosion inhibitor. Cross- section area reduction results showed higher percentile reduction values due to adverse in fibre loss on the mechanical properties of steel resulting from corrosion potentials. Results of weight loss of steel showed higher percentile values against control and coated specimens due to the effect of corrosion on the mechanical properties of steel. Results showed little loads to high ultimate yielding of corroded specimens to control and coated specimens resulting from reduction of mechanical properties of the steel reinforcement.

Keywords: Corrosion, Corrosion Inhibitors, Corrosion Potential, Concrete Resistivity and Steel Reinforcement.

INTRODUCTION

The occurrence of corrosion may be the result of chloride contamination or carbonation of the reinforced concrete structures which in turns affect the durability and life shortening .Inorganic inhibitors and Greener approach inhibitors has shown highly and environmentally friendly, toxic free, generally, widely and inexpensive for future use, based on this properties, there is great demand of green inhibitors to organic ones due to their biodegradable properties. (Uhlig, 2004). Environmental concerns worldwide are increasing and are likely to influence the choice of corrosion inhibitors in the future. Environmental requirements are still being developed but some elements have been established (Uhlig, 2004). The use of these natural products such as extracted compounds from leaves or seeds as corrosion inhibitors have been widely reported by several authors (El-Etre, 2003, 2006; Gunasekaran and Chauhan, 2004; Moretti *et al*. 2004; El-Etre *et al.*2005; Sethuraman and Raja, 2005, Ismail, 2007; Ashassi-Sorkhabi and Asghari, 2008; Raja and Sethuraman, 2008a, 2008b, 2008c, 2009; Oguzie, 2008; Okafor et al.2008; Radojcic *et al.*2008; Zhang *et al.*2008; Eddy, 2009; Ostovari *et al.*2009; Satapathy *et al.*2009; Solomon *et al.*2009; Olusegun and James, 2010).

Charles et al. (2018) 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. Average results on comparison showed incremental values of 70.1% against 27.2% control 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.

Charles et al. (2018) investigated the corrosion potential, concrete resistivity and tensile tests of control, corroded and coated reinforcing steel of concrete slab member. Direct application of corrosion inhibitor of dacryodes edulis resins thicknesses 150µm, 250µm, 350µm were coated on 12mm diameter reinforcement, embedded into concrete slab and exposed to severe corrosive environment for 119 days for accelerated corrosion test, half-cell potential measurements, concrete resistivity measurement and tensile 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.

Charles et al. (2018) investigated the effects of chloride attack on reinforcing steel embedded in reinforced concrete structures built in the marine environment. An experimental work simulated the quick process by acceleration process on non-inhibited and inhibited reinforcement of acardium occidentale l. resins extracts with polished thicknesses of 150µm, 250µm and 350µm, embedded in concrete slab and immersed in sodium chloride (NaCl) and accelerated for 119 days using Wenner four probes method,. Average percentile results of potential Ecorr,mV, and concrete resistivity are 27.45% and 68.45% respectively. When compared to corroded samples, corroded has 75.4% increased values potential Ecorr,mV and 33.54% decreased values of concrete resistivity, yield stress against ultimate strength at in comparison to corrode as 100% nominal yield stress decremented from 108.38% to 90.25% respectively, weight loss at 69.3% against 43.98% and 51.45% to 89.25%, cross-sectional diameter reduction, both showed decreased values of corroded compared to coated specimens.

Charles et al. (2018) investigated corrosion level probability assessment potential through half cell potential corrosion measurement, concrete resistivity test and tensile strength test mechanical properties of Control, corroded and inhibited reinforcement with Moringa Oleifera lam resin paste of trees extract. Specimens were embedded in concrete and accelerated in corrosive environment medium for 119 days. Average percentile results of potential Ecorr,mV, and concrete resistivity are 29.9% and 68.74% respectively. When compared to corroded samples, corroded has 70.1% increased values potential Ecorr,mV and 35.5% decreased values of concrete resistivity. Results of computed percentile average values of yield stress against ultimate strength, when compared to corrode as 100% nominal yield stress decremented from 105.75 % to 96.12% and weight loss at 67.5% against 48.5% and 48.34% to 94.82%, cross-sectional diameter reduction, both showed decreased values of corroded compared to coated specimens.

Charles et al. (2018) 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. Examinations and assessments were done on concrete reinforced slab with the application of half cell potential, concrete resistivity and tensile strength mechanical properties of reinforcement surface condition after 119 days. Average percentile results of potential Ecorr,mV, and concrete resistivity are 26.57% and 61.25% respectively. When compared to corroded samples, corroded has 70.1% increased values potential Ecorr,mV and 38.8% decreased values of concrete resistivity, yield stress against ultimate strength at summary and average state of corroded slab with nominal values of 100% and decremented in ultimate strength from 105.36% to 96.12%, weight loss versus cross-section diameter reduction decreased due to attack from sodium chloride from 64.8% to 44.45% and 46.76% to 86.43% respectively.

Charles et al. (2018) investigated corrosion probability level assessments of three different resins extracts of trees from dacryodes edulis, mangifera indica and moringa oleifera lam using half cell potential corrosion measurement, concrete resistivity measurement and tensile strength test to ascertain the surface condition of the mechanical properties of Control, corroded and inhibited reinforcement coated thicknesses of 150µm, 250µm and 350µm specimens. Arbitrarily and computed percentile average values of yield stress against ultimate strength, when compared to corrode as 100% nominal yield stress decreased from100.95% to 96.12% dacryodes edulis inhibited, 105.36% to 96.12% mangifera indica inhibited, and 105.75 % to 96.12% moringa oleifera lam inhibited and weight loss of dacryodes edulis inhibited are 67.5% against 48.5% and 98.7% to 94.82%, cross-sectional diameter reduction, mangifera indica inhibited specimen 64.8% to 44.45% and 46.76% to 86.43% cross-sectional diameter reduction and moringa oleifera lam inhibited specimen 67.5% against 48.5% and 48.34% to 94.82%, cross-sectional diameter reduction, all showed decreased values of corroded compared to coated specimens.

Charles et al. (2018) examined the effectiveness in the utilization of three eco-friendly inorganic inhibitors tree extract exudates / resins of Symphonia globulifera linn, Ficus glumosa and Acardium occidentale l. Non-inhibited and inhibited reinforcements with exudates / resins of 150µm, 250µm and 350µm thicknesses were embedded in concrete slab with exposed sections, immersed sodium chloride solution and accelerated using Wenner four probe method General and compute percentile average values of yield stress against ultimate strength at in comparison to corrode as 100% nominal yield stress decremented ultimate strength from 103.06% to 96.12% , 112.48% to 89.25%, and 108.38% to 90.25% of Symphonia globulifera linn, Ficus glumosa and Acardium occidentale l respectively, weight loss at of corroded against inhibited Symphonia globulifera linn specimens at 67.5% against 48.5% and 47.80% to 94.82%, inhibited Ficus glumosa 69.5% to 47.29%, 48.95% to 77.89% and inhibited acardium occidentale l.

MATERIALS AND METHODS FOR EXPERINMENT

Aggregates

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

Cement

Portland limestone cement grade 42.5 is the most and commonly type of cement in Nigerian Market. It was used for all concrete mixes in this investigation. The cement met the requirements of BS EN 196-6

Water

The water samples were clean and free from impurities. The fresh water used was gotten from the tap at the Civil Engineering Department Laboratory, Kenule Beeson Polytechnic, Bori, Rivers State. The water met the requirements of BS 3148

Structural Steel Reinforcement

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

2.1.5 Corrosion Inhibitors (Resins / Exudates) Invingia Gabonensis

The study inhibitor is Invingia Gabonensis of natural tree resins /exudates substance extracts.

EXPERIMENTAL PROCEDURES

Experimental 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
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 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 ρ, 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 Control, corroded and coated were tested in tension in a Universal Testing Machine and were subjected to direct tension until failure; the yield, maximum and failure loads being recorded. To ensure consistency, the remaining cut pieces from the standard length of corroded and Control steel bars were subsequently used for mechanical properties of steel.

Experimental results and discussion

The results of the half-cell potential measurements in table 3.1 were plotted against concrete resistivity of table 3.2 for easy interpretation. It used as indication of likelihood of significant corrosion ($\rho < 5$, $5 < \rho < 10$, $10 < \rho < 20$, $\rho > 20$) for Very high, High, Low to moderate and Low, for Probability of corrosion. In the other measuring points, potential Ecorr is high ($-350\text{mV} \le E_{corr} \le -200\text{mV}$), 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_{corr} if low (< −350mV) in an area measuring indicates a 95% probability of corrosion. Concrete resistivity is commonly measured by four-electrode method. Resistivity survey data gives an indication of whether the concrete condition is favorable for the easy movements of ions leading to more corrosion.

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. Summarized average results of sampled concrete from tables 1 into 2, of control, corroded and exudates/resin coated specimens are plotted in figures 1 and 2 of concrete resistivity ρ, kΩcm against potential $E_{corr,}{}^{mV}$. Potential E_{corr} of control specimens average results are -101.215mV,, -101.04mV, -100.715mV, fused into -100.993mV, with summed percentile value of 27.80031% and averaged percentile difference -72.1997%. Concrete resistivity ρ, kΩcm results from table 2 into 3, plotted in figures 2 and 3 are 13.572kΩcm, 13.32867kΩcm, 13.60533kΩcm, summarized into 13.502kΩcm with summarized percentile value of 157.4169% and percentile difference 57.41693%. Mechanical properties "ultimate strength" of control specimens from table 3 into 4, plotted in figures 3 and 4 are 548.374333N/mm^2, 548.0077N/mm^2, 547.5743N/mm^2, summarized into 547.9854N/mm^2, with percentile average value 91.65533% and percentile difference -8.34467%. Average Mechanical properties "weight loss of steel" of control from table 3.4 into 3.4A and plotted in figures 3.4 and 3.4A are 6.768667grams, 6.7720grams, 6.7220grams, fused into 6.754222grams with percentile average value 50.58879% and percentile difference -49.4112%. Average mechanical properties "Cross- section Area Reduction" of Control from table 3.5 into 3.5A and plotted in figures 3.5 and 3.5A are 12mm, 12mm, 12mm and fused into 12mm with percentile average value 113.1957% and percentile difference 13.19568%. Control specimens result showed no corrosion potential.

Corroded Concrete Slab Members

Average potential E_{corr} corroded values results are -294.4126mV, -373.713mV, 421.713mV fused into -363.279mV, control, corroded and exudates/resin coated specimens as represented in figures 1 and 2 and tables 1 into 2 of potential $E_{corr,}$^{mV} with percentile average value 359.7082% and percentile difference 259.7082% versus -72.1997% and -67.7296% of control and coated specimens. Potential E_{corr} results showed indication that the values of non-coated specimens are high with the range of ($-350mV \leq E_{corr} \leq -200mV$), which indicates a 10% or uncertain probability of corrosion. Concrete resistivity ρ, kΩcm averaged results from table 3.2 into 3.2A, plotted in figures 3.2 and 3.2A are 7.4253kΩcm, 8.501667kΩcm, 9.805kΩcm, fused into 8.577222kΩcm with percentile average value 63.52557% and percentile difference -36.4744% against 57.41693% and 82.7709% of control and coated specimens. Range of values of corroded specimens showed indication of likelihood of significant corrosion ($\rho < 5$, $5 < \rho < 10$, $10 < \rho < 20$, $\rho > 20$) for very high, high, low to moderate and low, for probability of corrosion. Mechanical properties "ultimate strength" of control specimens from table 3.3 into 3.3A and plotted in figures 3.3 and 3.3A are the averaged results as thus; 598.520667N/mm^2, 596.8873N/mm^2, 598.2207N/mm^2, fused into 597.8762N/mm^2, with percentile value of 109.1044% and percentile difference 9.104398% against -8.34467% and -8.44697% of control and coated specimens. Results showed little loads to high ultimate yielding of corroded specimens to control and coated specimens resulting from reduction of mechanical properties of the steel reinforcement. Mechanical properties "weight loss of steel" of corroded specimens as shown from table 3.4 into 3.4A, plotted in figures 3.4 and 3.4A are 13.29433grams, 13.42067grams, 13.33867grams, fused into 13.35122grams with percentile average value 197.6722% and percentile difference 97.67224% against -49.4112% and -49.0442% of control and coated specimens. Results of Weight Loss of Steel showed higher percentile values against control and coated specimens due to the effect of corrosion on the mechanical properties of steel. Average mechanical properties "cross- section Area Reduction" of control from table 3.5 into 3.5A and plotted in figures 3.5 and 3.5A are 10.48333mm, 10.60333mm, 10.71667mm and fused into 10.60111mm with percentile average value 88.34259% and percentile difference -11.6574% against 13.19568% and 13.19568%. Cross- section area reduction results showed higher percentile reduction values due to adverse in fibre loss on the mechanical properties of steel resulting from corrosion potentials.

Invingia Gabonensis Exudate Steel Bar Coated Concrete Slab Members

Control, corroded and exudates/resin coated specimens from tables 1 into 2, presented in figures 1 and 2 of concrete resistivity ρ, kΩcm against potential $E_{corr,}{}^{mV}$ relationship showed average potential E_{corr} control values of -117.2806mV, -117.11mV, -117.304mV fused into -117.232mV, with percentile average value 32.27042% and percentile difference -67.7296% over 259.7082% corroded specimen. Results Concrete resistivity ρ, kΩcm averaged results from table 3.2 into 3.2A, plotted in figures 3.2 and 3.2A are 15.4433333kΩcm, 15.700kΩcm, 15.88667kΩcm, fused into 15.67667kΩcm with percentile average value 182.7709% and percentile difference 82.7709% over -36.4744% corroded specimen. Mechanical properties "ultimate strength" of control specimens from table 3 into 4, plotted in figures 3 and 4are 546.146N/mm^2, 547.446N/mm^2, 548.5293N/mm^2, fused into 547.3738N/mm^2, with percentile average value 91.55303% and percentile difference -8.44697% over 9.104398% corroded specimen. Mechanical properties "weight loss of steel" of control from table 3.4 into 3.4A, plotted in figures 4 and 5 are 6.791grams, 6.804333grams, 6.814333grams, fused into 6.803222grams with percentile average value 50.9558% and percentile difference -49.0442% over 97.67224% corroded. Mechanical properties "cross- section area reduction" of control from table 5 into 6, plotted in figures 5 and 6 are 12mm, 12mm, 12mm and fused into 12mm with percentile average value 113.1957% and percentile difference 13.19568% over -11.6574% corroded specimen. Entire results of exudates / resin coated specimens showed indications of no corrosion potential, results proved invingia gabonensis exudates / resins as good corrosion inhibitor.

Table 3: Potential $E_{corr\ mV}$, after 28 days curing and 150 days accelerated Periods

	Potential $E_{corr,mV}$								
	Time Intervals after 28 days curing								
Samples	AB1	AB2	AB3	AB4	AB5	AB6	AB7	AB8	AB9
Durations	(7days)	(21days)	(28days)	(58days)	(88days)	(118days)	(148days)	(163days)	(178days)
	Control Concrete slab Specimens								
CSA1	-101.715	-101.915	-100.015	-100.915	-101.415	-100.515	-100.015	-101.115	-100.115
CSB1	**Corroded Concrete Slab Specimens**								
	-265.646	-291.846	-325.746	-364.846	-374.646	-381.646	-415.546	-422.746	-426.846
	Invingia Gabonensis Exudate (steel bar coated specimen)								
	(150µm) coated			**(300µm) coated**			**(450µm) coated**		
CSC1	-116.324	-113.994	-121.524	-116.694	-113.634	-121.004	-115.924	-119.694	-116.294

Table 4: Average Potential $E_{cor\ mV}$, after 28 days curing and 150 days accelerated Periods

S/no	Samples	Average A{B(1,2,3)}, (4,5,6)}, A{B(7,8,9)}			Summary Average A{B(1,2,3)},(4,5,6)}, A{B(7,8,9)}	Percentile Average Values A{B(1,2,3)}, (4,5,6)}, A{B(7,8,9)}	Percentile Difference Average A{B(1,2,3)}, (4,5,6)}, A{B(7,8,9)
	Potential $E_{corr,mV}$						
CS A1	Control Specimens	-101.215	-101.04	-100.715	-100.993	27.80031	-72.1997
CS B1	Corroded Specimens	-294.4126	-373.713	-421.713	-363.279	359.7082	259.7082
CS C1	Coated Specimens	-117.2806	-117.11	-117.304	-117.232	32.27042	-67.7296

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 after 28 days curing								
Samples	AB1	AB2	AB3	AB4	AB5	AB6	AB7	AB8	AB9
Durations	(7days)	(21days)	(28days)	(58days)	(88days)	(118days)	(148days)	(163days)	(178days)
	Control Concrete slab Specimens								
CSA2	13.492	13.662	13.562	13.792	13.622	12.572	13.592	13.592	13.622
CSB2	**Corroded Concrete Slab Specimens**								
	7.055	7.195	8.025	8.335	8.505	8.665	9.405	9.835	9.875
CSC2	**Invingia Gabonensis Exudate (steel bar coated specimen)**								
	(150μm) coated			**(300μm) coated**			**(450μm) coated**		
	15.25	15.4	15.68	15.81	15.5	15.79	15.74	15.89	15.92

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{B(1,2,3)},(4,5,6)}, A{B(7,8,9)}			Summary Average A{B(1,2,3)}, (4,5,6)}, A{B(7,8,9)}	Percentile Average Values Average A{B(1,2,3)}, (4,5,6)}, A{B(7,8,9)}	Percentile Difference Average A{B(1,2,3)},(4,5,6)}, A{B(7,8,9)}
	Concrete Resistivity ρ, kΩcm						
CSA2	Control Specimens	13.572	13.3286	13.60533	13.502	157.4169	57.41693
CSB2	Corroded Specimens	7.425	8.50166	9.805	8.577222	63.52557	-36.4744
CSC2	Coated Specimens	15.4433	15.7	15.8866	15.67667	182.7709	82.7709

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

	Time Intervals after 28 days curing								
Samples	AB1	AB2	AB3	AB4	AB5	AB6	AB7	AB8	AB9
Durations	(7days)	(21days)	(28days)	(58days)	(88days)	(118days)	(148dys)	(163days)	(178days)
	Yield Stress (N/mm2) for Control, Corroded and Coated Specimens								
CSAA3	410	410	410	410	410	410	410	410	410
	Ultimate strength (N/mm2)								
	Control Concrete slab Specimens								
CSA3	548.841	549.741	546.541	546.741	550.941	546.341	549.341	546.841	546.541
CSB3	**Corroded Concrete Slab Specimens**								
	597.454	598.554	599.554	595.554	599.554	595.554	598.154	595.354	601.154
CSC3	**Invingia Gabonensis Exudate (steel bar coated specimen)**								
	(150μm) coated			**(300μm) coated**			**(450μm) coated**		
	547.046	546.346	545.046	547.446	547.446	547.446	550.146	547.096	548.346

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

S/no	Samples	Average A{B(1,2,3)},(4,5,6)}, A{B(7,8,9)}		Summary Average A{B(1,2,3)},(4,5,6)}, A{B(7,8,9)}		Percentile Average Values Average A{B(1,2,3)},(4,5,6)}, A{B(7,8,9)}	Percentile Difference Average A{B(1,2,3)},(4,5,6)}, A{B(7,8,9)}
	Ultimate strength (N/mm2)						
CSA3	Control Specimens	548.374333	548.0077	547.5743	547.9854	91.65533	-8.34467
CSC3	Corroded Specimens	598.520667	596.8873	598.2207	597.8762	109.1044	9.104398
CSC3	Coated Specimens	546.146	547.446	548.5293	547.3738	91.55303	-8.44697

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

	Weight Loss of Steel (in grams)								
	Control Concrete slab Specimens								
CSA4	6.702	6.822	6.782	6.702	6.712	6.902	6.732	6.632	6.802
CSB4	**Corroded Concrete Slab Specimens**								
	13.168	13.336	13.379	13.416	13.422	13.424	13.375	13.425	13.216
CSC4	**Invingia Gabonensis Exudate (steel bar coated specimen)**								
	(150µm) coated			**(300µm) coated**			**(450µm) coated**		
	6.781	6.791	6.801	6.791	6.831	6.791	6.831	6.791	6.821

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

S/no	Samples	Average A{B(1,2,3)},(4,5,6)}, A{B(7,8,9)}		Summary Average A{B(1,2,3)},(4,5,6)}, A{B(7,8,9)}		Percentile Average Values Average A{B(1,2,3)},(4,5,6)}, A{B(7,8,9)}	
		Weight Loss of Steel (in grams)					
CSA4	Control Specimens	6.768667	6.772	6.722	6.754222	50.58879	-49.4112
CSB4	Corroded Specimens	13.29433	13.42067	13.33867	13.35122	197.6722	97.67224
CSC4	Coated Specimens	6.791	6.804333	6.814333	6.803222	50.9558	-49.0442

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

	Cross- section Area Reduction (Diameter, mm)								
	Control Concrete slab Specimens								
CSA5	12	12	12	12	12	12	12	12	12
CSB5	**Corroded Concrete Slab Specimens**								
	10.48	10.48	10.49	10.56	10.59	10.66	10.7	10.71	10.74
CSC5	**Invingia Gabonensis Exudate (steel bar coated specimen)**								
	(150µm) coated			**(300µm) coated**			**(450µm) coated**		
	12	12	12	12	12	12	12	12	12

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

S/no	Samples	Average A{B(1,2,3)},(4,5,6)}, A{B(7,8,9)}		Summary Average A{B(1,2,3)},(4,5,6)}, A{B(7,8,9)}		Percentile Average Values Average A{B(1,2,3)},(4,5,6)}, A{B(7,8,9)}	Percentile Difference Average A{B(1,2,3)}, (4,5,6)}, A{B(7,8,9)}
	Cross- section Area Reduction (Diameter, mm)						
CSA4	Control Specimens	12	12	12	12	113.1957	13.19568
CSB4	Corroded Specimens	10.48333	10.60333	10.71667	10.60111	88.34259	-11.6574
CSC4	Coated Specimens	12	12	12	12	113.1957	13.19568

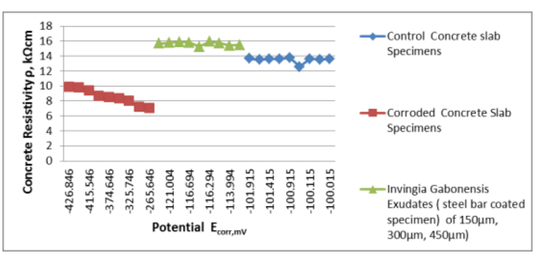

Figure 1: Concrete Resistivity versus Potential Relationship

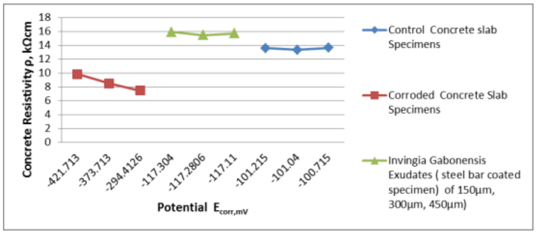

Figure 2: Average Concrete Resistivity versus Potential Relationship

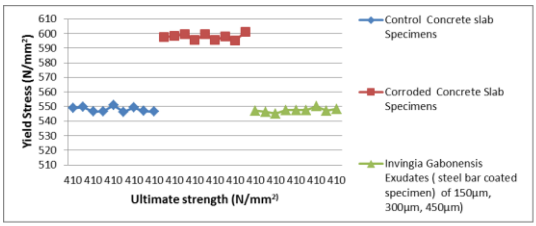

Figure 3: Yield Stress versus Ultimate strength

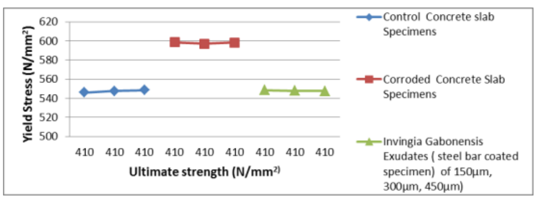

Figure 4: Average Yield Stress versus Ultimate strength

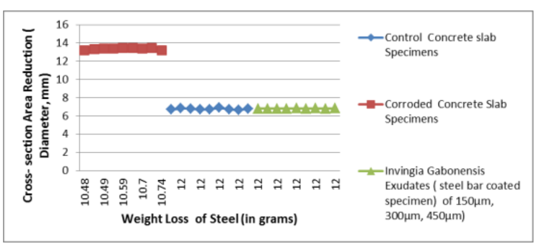

Figure 5: Weight Loss of Steel versus Cross- section Area Reduction

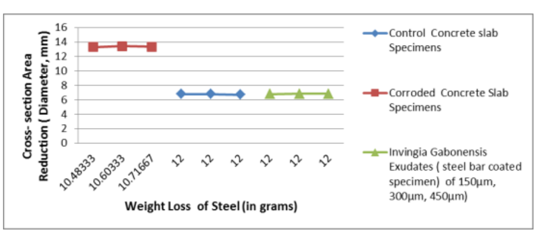

Figure 6: Average Weight of Steel Loss versus Cross- section Area Reduction

CONCLUSION

Experimental results showed the following conclusions:

i. Entire results of exudates / resin coated specimens showed indications of no corrosion potential, results proved invingia gabonensis exudates / resins as good corrosion inhibitor.
ii. Cross- section area reduction results showed higher percentile reduction values due to adverse in fibre loss on the mechanical properties of steel resulting from corrosion potentials.
iii. Results of weight loss of steel showed higher percentile values against control and coated specimens due to the effect of corrosion on the mechanical properties of steel.
iv. Results showed little loads to high ultimate yielding of corroded specimens to control and coated specimens resulting from reduction of mechanical properties of the steel reinforcement.

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