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APPLICATION OF WENNER TECHNIQUE IN ASSESSMENT OF STEEL BAR MECHANICAL PROPERTIES IN CHLORIDE-INDUCED CORROSION OF CONCRETE STRUCTURES

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ABSTRACT

Chloride attack is a major concern in reinforced concrete structures and may originate from the constituents of the concrete mix itself or from the diffusion of chloride ions from the surrounding environment. This experimental study examined the introduction of exudates / resin extracts from garcina kola as corrosion inhibitors to embedded reinforcing steel in concrete slab with coated thicknesses of 150µm, 300µm, 450µm, immersed in corrosive media and accelerated for 150 days with non-coated specimens for comparative examinations on surface changes and mechanical properties structural integrities. Results of potential E_{corr} corroded percentile average value is 352.2674% and percentile difference 252.2674% against -71.6125% and -66.5342% of control and coated specimens. Results of concrete resistivity ρ , $k\Omega cm$ percentile averaged value is 58.22311% and percentile difference -41.7769% against 71.75311% and 81.74313% of control and coated specimens. Mechanical properties "ultimate strength" of corroded specimens' percentile average value is 109.4155% and percentile difference 9.415503% against -8.60527% and -8.93228% of control and coated specimens. Mechanical properties "weight loss of steel" of corroded specimens' percentile averaged value is 198.0765% and percentile difference 98.07652% against -49.5145% and -43.9608% of control and coated specimens. Mechanical properties "cross- section area reduction" of corroded percentile average value 87.50926% and percentile difference -12.4907% against 14.27362% and 14.27362%. Cross- section area reduction results showed higher percentile reduction values due to effect of corrosion on the mechanical properties of steel. Results showed high ultimate yielding of corroded specimens to control and coated specimens due to the effect of corrosion on the mechanical properties of the steel reinforcement. 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.

Index Terms: Corrosion, Corrosion inhibitors, corrosion potential, concrete resistivity and Steel Reinforcement

1.0 INTRODUCTION

Chlorides diffusion into reinforced concrete structure forms chloride ions accumulation on the surface of the reinforcing bars and thus the passive film on the reinforcement break down with consequent corrosion of reinforcing steel. Chloride attack is a major concern in reinforced concrete structures. The chloride may originate from the constituents of the concrete mix itself or from the diffusion of chloride ions from the surrounding environment. Corrosion generates tensile stresses in steel reinforcement surroundings concrete thereby resulting to early cracks. Chlorides have been known to be introduced in concrete through several sources [Morris *et al.* 1], [Ann and Song, 2]), stated that concrete cast that contains chloride ions from seawater and aggregates can be used as an accelerative agent. The salt mixture penetrates concrete by different mechanisms. Low water/cement ratio can resist chlorides penetration into reinforcing steel, also provides a barrier against the entry of oxygen and therefore, provides better concrete corrosion resistance ([Canul et.al.3], [Chia and Zhang[4], [Du and Folliard [5], Goto and Roy[6], [Guneyis et. al. [7]). The use of organic compounds to inhibit corrosion of mild steel and iron has assumed great significance due to their application in preventing corrosion under various corrosive environments Ali et al.[8]. The development of corrosion inhibitors is based on organic compounds containing nitrogen, oxygen, sulfur atoms and multiple bonds in the molecules that facilitate adsorption on the metal surface Cruz et al.[9].

Novokshcheo [10] Carried out the investigation of inhibitors in solutions of alkaline and extracts from cement. The extracts from cement experiment revealed corrosion was inhibited using sodium nitrite in the presence of chlorides while sodium benzoate did not. Furthermore, the initiation of corrosion was delayed with sodium nitrite, with the delay increasing with inhibitor content.

Skotinck [11] Studied and showed that calcium nitrite is in no way detrimental to concrete properties as seen in the issue of inhibitors based on sodium or potassium. Latter study by Slater [12] showed that considering long-standing accelerated testing, calcium nitrite was of better quality in terms of strength

Charles et.al [13] 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 strengt 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 [14] 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 150m, 250m, 350m 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 Charles et.al diameter reduction, both showed decreased values of corroded compared to coated specimens.

[15] 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 150m, 250m and 350m, embedded in concrete slab and immersed in sodium chloride and accelerated for 119 days

using Wenner four probes method. When compared to corroded samples, corroded has 75.4% increased values potential Ecorr,mV and 33.54% decreased values of concrete resistivity, yield stress against ultimate strength at in comparison to corrode as 100% nominal yield stress decremented from 108.38% to 90.25% respectively, weight loss at 69.3% against 43.98% and 51.45% to 89.25%, cross-sectional diameter reduction, both showed decreased values of corroded compared to coated specimens.

Charles et.al [16] 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 with required constant current for polarization potential test of -200 mV through 1200mV, with a scan rate of 1mV/s. 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 [17] 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 immersion in sodium chloride and with applied currents potential of -200 mV through 1200mV, with a scan rate of 1mV/s. the results recorded of potential Ecorr,mV, and concrete resistivity of Mangifera indica inhibited specimen, the results indicated a 10% or uncertain probability of corrosion which indicates no corrosion presence or likelihood and concrete resistivity indicated a low probability of corrosion or no corrosion indication. 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 [18] 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. 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 [19] 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 I.

2.0 MATERIALS AND METHODS FOR EXPERINMENT

2.1 Aggregates

The fine aggregate and coarse aggregate were purchased. Both met the requirements of BS 8821[20]

2.1.2 Cement

Portland limestone cement grade 42.5 is the most and commonly type of cement in Nigerian Market. It was used for all concrete mixes in this investigation. The cement met the requirements of BS EN 196-6 [21]

2.1.3 Water

The water samples were clean and free from impurities. The fresh water used was gotten from the tap at the Civil Engineering Department Laboratory, Kenule Beeson Polytechnic, Bori, Rivers State. The water met the requirements of BS 12390 [22]

2.1.4 Structural Steel Reinforcement

The reinforcements are gotten directly from the market in Port Harcourt BS 12390 [23]

2.1.5 Corrosion Inhibitors (Resin / Exudate) Garcinia kola

The study inhibitor is garcinia kola of natural tree resins /exudates substance extracts.

2.2 EXPERIMENTAL PROCEDURES

2.2.1 Experimental method

2.2.2 Sample Preparation For Reinforcement With Coated Exudates /Resins

The corrosion rates were quantified predicated on current density obtained from the polarization curve and the corrosion rate quantification set-up. Fresh concrete mix batch were fully compacted to remove trapped air, with concrete cover of 15mm and projection of 150mm for half cell potential measurement and concrete resistivity tests. The polarization curve was obtained as the relationship between corrosion potential and current density. The samples were designed with sets of reinforced concrete slab of 150mm thick x 350mm width x 900mm long, uncoated and coated specimens of above thicknesses were embedded into the concrete, spaced at 150mm apart. The corrosion cell consisted of a saturated calomel reference electrode (SCE), counter electrode (graphite rod) and the reinforcing steel embedded in concrete specimen acted as the working electrode. Slabs were demoulded after 72 hours and cured for 28 days with room temperature and corrosion acceleration ponding process with Sodium Chloride lasted for 150days with 14 days checked intervals for readings. Mix ratio of 1:2:3 by weight of concrete, water cement ratio of 0.65, and manual mixing was adopted

2.3 Accelerated Corrosion Test

The accelerated corrosion test allows the acceleration of corrosion to reinforcing steel embedded in concrete and can simulate corrosion growth that would occur over decades. In order to test concrete resistivity and durability against corrosion, it was necessary to design an experiment that would accelerate the corrosion process and maximize the concrete's resistance against corrosion until failure. An accelerated corrosion test is the impressed current technique which is an effective technique to investigate the corrosion process of steel in concrete and to assess the damage on the concrete cover. A laboratory acceleration process helps to distinguish the roles of individual factors that could affect chloride induced corrosion. Therefore, for design of structural members and durability against corrosion as well as selection of suitable material and appropriate protective systems, it is useful to perform accelerated corrosion tests for obtaining quantitative and qualitative information on corrosion.

2.4 Corrosion Current Measurements (Half-cell potential measurements)

Classifications of the severity of rebar corrosion rates are presented in Table 2.1. If the potential measurements indicate that there is a high probability of active corrosion, concrete resistivity measurement can be subsequently used to estimate the rate of corrosion. However, caution needs to be exercised in using data of this nature, since constant corrosion rates with time are assumed. This was also stated from practical experience (Figg and Marsden [24], Gower and Millard [25). 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 (Stem and Geary [27]). Corrosion rates have been related to electrochemical measurements based on data first.

Potential E _{corr}	Probability of Corrosion
<i>E</i> corr < –350mV	Greater than 90% probability that reinforcing steel corrosion is occurring in that area at the time of measurement
$-350 \text{mV} \le E c_{\text{orr}} \le$ -200 mV	Corrosion activity of the reinforcing steel in that area is uncertain
$E_{\rm corr}$ > -200mV	90% probability that no reinforcing steel corrosion is occurring in that area at the time of
	measurement (10% risk of corrosion

Table 2.1: Dependence	e between potential a	and corrosion probability
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2.5 Concrete Resistivity Measurement Test

Different readings were taken at different locations at the surface of the concrete. After applying water on the surface of the slabs, the concrete resistivity was measured daily at the reference locations, looking for the saturation condition. These locations were chosen at the side of the slabs, since concrete electrical resistivity measurements could be taken when water was on the top surface of the slab. The mean values of the readings were recorded as the final readings of the resistivity in the study. The saturation level of the slabs was monitored through concrete electrical resistivity measurements, which are directly related to the moisture content of concrete. Once one slab would reach the saturated condition, the water could be drained from that slab, while the other slabs remained ponded. Time limitation was the main challenge to perform all the experimental measurements, as the concrete saturation condition changes with time. In the study, the Wenner four probes method was used; it was done by placing the four probes in contact with the concrete directly above the reinforcing steel bar. Henceforth, these measurements will be referred to as the measurements in «dry» conditions. Since each of the slabs had a different w/c, the time needed to saturate each of the slabs was not the same. Before applying water on the slabs, the concrete electrical resistivity was measured in the dry condition at the specified locations. The electrical resistivity becomes constant once the concrete has reached saturation.

Concrete resistivity $ ho$, k Ω cm	Probability of corrosion
ρ < 5	Very high
5 < <i>ρ</i> < 10	High
10 < <i>ρ</i> < 20	Low to moderate
<i>ρ</i> > 20	Low

Table 2.2: Dependence	between concrete resistivit	v and corrosion	probability
Tubic Lizi Dependence		y unu corrosion	probability

2.6 Tensile Strength of Reinforcing Bars

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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.

3.0 Experimental Results and Discussion

The results of the half-cell potential measurements in table 1 were plotted against concrete resistivity of table 3. 2 for easy interpretation. It used as indication of likelihood of significant corrosion ($\rho < 5$, $5 < \rho < 10$, $10 < \rho < 20$, $\rho > 20$) for Very high, High, Low to moderate and Low, for Probability of corrosion. In the other measuring points, potential *E*corr is high (-350mV $\le E_{corr} \le -200$ mV), which indicates a 10% or uncertain probability of corrosion. Results of the concrete resistivity measurements are shown in Table 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..

3.1 Control Concrete Slab Members

Results obtained from table 3.1 of half-cell potential measurements for and concrete resistivity for 7days to 178 days respectively indicated a 10% or uncertain probability of corrosion which indicates no corrosion presence or likelihood and concrete resistivity which indicated a low probability of corrosion or no corrosion indication. Preliminary and average results gotten from tables 3.1 into 3.2, of control, corroded and exudates/resin coated specimens of 150µm, 300µm, 450µm thicknesses are plotted in figures 1 and 2 of concrete resistivity ρ , k Ω cm versus potential $E_{corr,}^{mV}$. Results of averaged potential E_{corr} of control specimens are -101.494mV, -101.228mV, - 100.694mV, fused into -101.139mV, with percentile average value 28.38753% and percentile difference - 71.6125%. Concrete resistivity ρ , k Ω cm average results from table 3.2 into 3.2A and plotted in figures 3 and 4 are 14.402k Ω cm, 14.15867k Ω cm, 14.432k Ω cm, fused into 14.33089k Ω cm with percentile average value 171.7531% and percentile difference 71.75311%. Mechanical properties "ultimate strength" of control specimens from table 5 into 6 and plotted in figures 3.3 and 3.3A are 549.778N/mm², 549.4117N/mm², 548.9783N/mm², fused into 549.3894N/mm², with percentile average value 91.39473% and percentile difference -8.60527%. Mechanical properties "weight loss of Steel" of control specimen from table 3.4 into 3.4A and plotted in figures 3.4 and 3.5 are 6.368667grams, 6.372grams, 6.322grams, fused into 6.354222grams with percentile average value 50.48554% and

percentile difference -49.5145%. Mechanical properties "cross- section area reduction" of control averaged results from table 5 into 6 and plotted in figures 5 and 6 are 12mm, 12mm, 12mm and fused into 12mm with percentile average value 114.2736% and percentile difference 14.27362%. Control specimens result showed no corrosion potential.

3.2 Corroded Concrete Slab Members

Average values of slab samples of control, corroded and exudates/resin coated specimens of 150µm, 300µm, 450µm as presented tables 3.1 into 3.2 plotted in figures 3.1 and 3.2 of potential $E_{corr,}^{mV}$. Average potential E_{corr} corroded values are -287.413mV, -366.713mV, -414.713mV fused into -356.279mV, with percentile average value 352.2674% and percentile difference 252.2674% against -71.6125% and -66.5342% of control and coated specimens. Potential E_{corr} results showed that the values of non-coated specimens are high with the range of (-350mV $\leq E_{corr} \leq -200$ mV), which indicates a 10% or uncertain probability of corrosion. Average results of concrete resistivity ρ , k Ω cm from table 3.2 into 3.2A and plotted in figures 3.2 and 3.2A are 7.225k Ω cm, 8.301667k Ω cm, 9.505k Ω cm, fused into 8.343889k Ω cm with percentile average value 58.22311% and percentile difference -41.7769% against 71.75311% and 81.74313% of control and coated specimens. Range of values of non-coated 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 averaged values from table 3.3 into 3.3A and plotted in figures 3.4 and 3.4A are 601.761N/mm², 600.1283N/mm², 601.4617N/mm², fused into 601.1172N/mm², with percentile average value 109.4155% and percentile difference 9.415503% against -8.60527% and -8.93228% of control and coated specimens. Results showed high ultimate yielding of corroded specimens to control and coated specimens due to the effect of corrosion on the mechanical properties of the steel reinforcement. Mechanical properties "weight loss of steel" of corroded specimens averaged values from table 3.4 into 3.4A and plotted in figures 3.4 and 3.4A are 12.52933grams, 12.65567grams, 12.57367grams, fused into 12.58622grams with percentile average value 198.0765% and percentile difference 98.07652% against -49.5145% and -43.9608% of control and coated specimens due to the effect of corrosion on the mechanical properties of steel. Mechanical properties "cross- section area reduction" of control averaged values from table 3.5 into 3.5A and plotted in figures 3.5 and 3.5A are 10.38333mm, 10.50333mm, 10.61667mm and fused into 10.50111mm with percentile average value 87.50926% and percentile difference -12.4907% against 14.27362% and 14.27362%. Cross- section area reduction results showed higher percentile reduction values due to effect of corrosion on the mechanical properties of steel.

3.3 Garcinia kola Exudates Steel Bar Coated Concrete Slab Members

Average values of slab samples of control, corroded and exudates/resin coated specimens of 150µm, 300µm, 450 μ m and presented in tables 3.1 into 3.2 in figures 3.1 and 3.2 of concrete resistivity ρ , $k\Omega$ cm versus potential E_{corr},^{mV}. Results of average potential E_{corr},^{mV} control values are -119.28067mV , -119.110mV, -119.304mV fused into -119.232mV, with percentile averaged value 33.46581% and percentile difference -66.5342% over 252.2674% corroded specimen. Results of average concrete resistivity ρ , k Ω cm from table 3.2 into 3.2A and plotted in figures 3.2 and 3.2A are 14.94333k Ω cm15.20k Ω cm, 15.35k Ω cm, fused into 15.16444k Ω cm with percentile average value 181.7431% and percentile difference 81.74313% over -41.7769% corroded specimen. Mechanical properties "ultimate strength" of control specimens from table 3.3 into 3.3A and plotted in figures 3.3 and 3.3A averaged results are 546.196N/mm², 547.496N/mm², 548.5793N/mm², fused into 547.4238N/mm², with percentile averaged value 91.06772% and percentile difference -8.93228% over 9.415503% corroded specimen. Mechanical properties "weight loss of steel" of control from table 5 into 6 and plotted in figures 4 and 5 are 7.041grams, 7.054333grams, 7.064333grams, fused into 7.053222grams with percentile average value 56.03923% and percentile difference -43.9608% over 82.23808% corroded . Mechanical properties "cross- section area reduction" of control from table 3.5 into 3.5A and plotted in figures 3.5 and 3.5A averaged values are 12mm, 12mm, 12mm and fused into 12mm with percentile average value 116.0417% and percentile difference 16.04169% over -13.8241% corroded specimen. Control specimens result showed no corrosion potential, exudates / resin showed inhibitory properties against corrosion effect to steel reinforcement embedded in concrete and accelerated in corrosive media.

		Potential E _{corr,mV}										
		Time Intervals after 28 days curing										
Samples	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8	AC9			
Durations	(7days)	(21days)	(28days)	(58days)	(88days)	(118days)	(148days)	(163days)	(178days)			
		Control Concrete slab Specimens										
CSKA1	-101.994	-102.194	-100.294	-101.194	-101.694	-100.794	-100.294	-101.394	-100.394			
CSKB1				Corroded	Concrete Sl	ab Specimens	5					
	-258.646	-284.846	-318.746	-357.846	-367.646	-374.646	-408.546	-415.746	-419.846			
			Garcin	ia kola Exu	date (steel	bar coated sp	ecimen)					
	(1	50µm) coat	ed	(3	300μm) coat	ed	(4	50µm) coate	d			

Table 3.1 : Potential Ecorr	after 28 days curing and	150 days Accelerated Periods
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CSKC1	-118.324	-115.994	-123.524	-118.694	-115.634	-123.004	-117.924	-121.694	-118.294

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

S/no	Samples	Average A{C(7,8,9)}	A{C(1,2,3)},(4,5,6)},		Summary Average A{C(1,2,3)},(4,5,6)}, A{C(7,8,9)}	Percentile Average Values Average A{C(1,2,3)},(4,5,6)}, A{C(7,8,9)}	Percentile Difference Average A{C(1,2,3)}, (4,5,6)}, A{C(7,8,9)}
CSKA1	Control Specimens	-101.494	-101.228	-100.694	-101.139	28.38753	-71.6125
CSKB1	Corroded Specimens	-287.413	-366.713	-414.713	-356.279	352.2674	252.2674
CSKC1	Coated Specimens	-119.28067	-119.110	-119.304	-119.232	33.46581	-66.5342

Table 3.2: Results of Concrete Resistivity ρ , k Ω cm Time Intervals after 28 days curing and 150 days accelerated Periods

		Concrete Resistivity ρ, kΩcm										
		Time Intervals after 28 days curing										
Samples	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8	AC9			
Durations	(7days)	(21days)	(28days)	(58days)	(88days)	(118days)	(148days)	(163days)	(178 days)			
		Control Concrete slab Specimens										
CSKA2	14.322	14.492	14.392	14.622	14.452	13.402	14.422	14.422	14.452			
CSKB2				Corroded	Concrete S	lab Specimer	is					
	6.855	6.995	7.825	8.135	8.305	8.465	9.205	9.635	9.675			
CSKC2			Garci	nia kola Ex	udate (steel	bar coated s	pecimen)					
	(1	50μm) coat	ed	(3	300µm) coat	ed	(450μm) coa	ted			
	14.75	14.9	15.18	15.31	15	15.29	15.24	15.39	15.42			

Table 3.2B: Results of Concrete Resistivity ρ , k Ω cm Time Intervals after 28 days curingand 150 days accelerated Periods

							159
S/no	Samples	Average A{C(1,2,3)},(4,5,6)}, A{C(7,8,9)}		Summary Average A{C(1,2,3)},(4,5,6)}, A{C(7,8,9)}	Percentile Average Values Average A{C(1,2,3)},(4,5,6)}, A{C(7,8,9)}	Percentile Difference Average A{C(1,2,3)},(4,5,6)}, A{C(7,8,9)}	
CSKA2	Control Specimens	14.402	14.15867	14.432	14.33089	171.7531	71.75311
CSKB2	Corroded Specimens	7.225	8.301667	9.505	8.343889	58.22311	-41.7769
CSKC2	Coated Specimens	14.94333	15.2	15.35	15.16444	181.7431	81.74313

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

				Т	ime Interva	ls after 28 da	ays curing				
Samples	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8	AC9		
Durations	(7days)	(21days)	(28days)	(58days)	(88days)	(118days)	(148days)	(163	(178		
								days)	days)		
		Yiel	d Stress (N/	mm2) for C	ontrol, Corr	oded and Co	ated Specim	ens			
CSKA3	410	410	410	410	410	410	410	410	410		
		Ultimate strength (N/mm2)									
	Control Concrete slab Specimens										
CSKB3	550.245	551.145	547.945	548.145	552.345	547.745	550.745	548.245	547.945		
CSKC3				Corroded (Concrete Sla	b Specimens	5				
	600.695	601.795	602.795	598.795	602.795	598.795	601.395	598.595	604.395		
CSKD3			Garcinia	a kola Exuc	late(steel b	ar coated sp	ecimen)				
	(150µm) coated			(3	00μm) coat	ed	(450µm) coated				
	547.096	546.396	545.096	547.496	547.496	547.496	550.196	547.146	548.396		

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

S/no	Samples	Average A A{C(7,8,9)	{C(1,2,3)},(4 }	,5,6)},	Summary Average A{C(1,2,3)},(4,5,6)}, A{C(7,8,9)}	Percentile Average Values Average A{C(1,2,3)},(4,5,6)}, A{C(7,8,9)}	Percentile Difference Average A{C(1,2,3)}, (4,5,6)}, A{C(7,8,9)}
				Ultimate	strength (N/mm2)		
CSKB3	Control	549.778	549.4117	548.9783	549.3894	91.39473	-8.60527
	Specimens						
CSKC3	Corroded	601.761	600.1283	601.4617	601.1172	109.4155	9.415503
	Specimens						
CSKD3	Coated	546.196	547.496	548.5793	547.4238	91.06772	-8.93228
	Specimens						

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

Weight Loss of Steel (in grams)

	Control Concrete slab Specimens									
CSKA4	6.302	6.422	6.382	6.302	6.312	6.502	6.332	6.232	6.402	
CSKB4	Corroded Concrete Slab Specimens									
	12.403	12.571	12.614	12.651	12.657	12.659	12.61	12.66	12.451	
CSKC4	Garcinia kola Exudate(steel bar coated specimen)									
	(150µm) coated			(300µm) coated			(450µm) coated			
	7.031	7.041	7.051	7.041	7.081	7.041	7.081	7.041	7.071	

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

S/no	Samples	Average A{C(1,2,3)},(4,5,6)},			Summary Average	Percentile	Percentile				
		A{C(7,8,9)}		A{C(1,2,3)},(4,5,6)},	Average Values	Difference					
				A{C(7,8,9)}	Average	Average					
					A{C(1,2,3)},(4,5,6)},	A{C(1,2,3)},					
					A{C(7,8,9)}	(4,5,6)},					
							A{C(7,8,9)}				
		Weight Loss of Steel (in grams)									
CSKA4	Control	6.368667	6.372	6.322	6.354222	50.48554	-49.5145				
	Specimens										
CSKB4	Corroded	12.52933	12.65567	12.57367	12.58622	198.0765	98.07652				
	Specimens										
CSKC4	Coated	7.041	7.054333	7.064333	7.053222	56.03923	-43.9608				
	Specimens										

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

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	Cross- section Area Reduction (Diameter, mm)									
	Control Concrete slab Specimens									
CSKA5	12	12	12	12	12	12	12	12	12	
CSKB5	Corroded Concrete Slab Specimens									
	10.38	10.38	10.39	10.46	10.49	10.56	10.6	10.61	10.64	
	Garcinia kola Exudate (steel bar coated specimen)									
	(1	50μm) coat	ed	(300µm) coated			(450µm) coated			
CSKC5	12	12	12	12	12	12	12	12	12	

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

S/no	Samples	Average A{C(7,8,9)}	A{C(1,2,:	3)},(4,5,6)},	Summary Average A{C(1,2,3)},(4,5,6)}, A{C(7,8,9)}	Percentile Average Values Average A{C(1,2,3)},(4,5,6)}, A{C(7,8,9)}	Percentile Difference Average A{C(1,2,3)}, (4,5,6)}, A{C(7,8,9)}				
		Cross- section Area Reduction (Diameter, mm)									
CSKA5	Control Specimens	12	12	12	12	114.2736	14.27362				
CSKB5	Corroded Specimens	10.38333	10.50333	10.61667	10.50111	87.50926	-12.4907				
CSKC5	Coated Specimens	12	12	12	12	114.2736	14.27362				

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Figure 3.1A: Average Concrete Resistivity versus Potential Relationship



Figure 3.2: Yield Stress versus Ultimate strength



Figure 3.2A: Average Yield Stress versus Ultimate strength



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



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

4.0 CONCLUSION

Experimental results showed the following conclusions:

- i. Results showed high ultimate yielding of corroded specimens to control and coated specimens due to the effect of corrosion on the mechanical properties of the steel reinforcement
- ii. 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
- iii. Cross- section area reduction results showed higher percentile reduction values due to effect of corrosion on the mechanical properties of steel.
- iv. Control specimens result showed no corrosion potential, exudates / resin showed inhibitory properties against corrosion effect to steel reinforcement embedded in concrete and accelerated in corrosive media.

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