Electro-Mechanical Corrosion Degree Rate Measurement Effects on Residual Flexural Capacity of Reinforcing Steel

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ABSTRACT

Corrosion of steel reinforcement in reinforced concrete is one of the most significant problems affecting structures and infrastructure worldwide, especially coastal structures. This causes cracks to form in the concrete, reduces the effective cross-sectional area of steel reinforcement and weakens the interaction between steel and concrete and further causes low load bearing capacity. This study evaluates the application of resins from natural plants that have environmentally friendly properties from non-hazardous materials obtained from tree trunks. Exudates / resin is then embedded in concrete beams of various thickness layers and applied directly to steel reinforcement. Its usefulness is evaluated as corrosion-resistant reinforced concrete structures that are exposed to harsh regional marine environments and to determine the role of exudates/resins in curbing the attacks on reinforcement by water tightness and durability (resistance) as well as modification of steel reinforcement surface due to coating. From the flexural strength test, the maximum relative value was 28.04% compared to the corroded and coated sample values of -20.88% and 28.05%, respectively. The mean differential range and percentile controlled are (0.56kN and 1.46%), corroded (0.68kN and 1.02%), coated (0.52kN and 1.67%). The comparison results show that the maximum value of midspan deflection obtained for the failed state is controlled -48.34% versus corroded 95.62% and coated -47.72%. The results show lower elongation loads in the case of controlled and coated samples with reduced values over corrosion samples with higher elongation loads and increased values compared to the reference range (controlled) and coated samples. The comparison results obtained during and after the corrosion test of the maximum value of the diameter of the reinforcing steel checked equals 0.77% compared to the corroded -0.66% and the sample with the coating equals 0.86%. The calculated mean differential and percentile values were checked (0.01% and 0.02%), corrosion values (0.03kN and 0.23%) and closed values (0.01kN and 0.04%). The results showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in diameter and a decrease in both the mean value and the recorded percentage of corroded samples with the reinforcing steel deformed ribs peeled off, whereas the controlled and coated samples showed a preserved state with an increase in coating diameter due to different thicknesses of the exudates/resins coated layers. The cross-sectional area of reinforcing steel shows a different mean and percentile value of the corroded value (0.01 and 3.54%) and the coated value (0.01 mm and 3.34%). The results obtained showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in the diameter of the reinforcement in the corroded sample, while the coated sample showed an increase due to the thickness of the exudates paste layers. Differentially, calculated mean and percentage values of yield point and maximum tensile strength (1.0MPa and 1.59%) and (2.55MPa and 0.01%) were checked, the corrosion value was (5.5MPa and 0.09%) and (2.57MPa and 0.02%), the values coated are (1.04MPa and 1.6%) and (2.53MPa and 0.02%).

The calculated data showed a decrease in the values of the samples corroded due to corrosion attack, which led to a decrease in the recorded weight, whereas the coated samples showed an increase in weight due to the different coating thickness compared to the reference values of the controlled samples.

Key Words: Corrosion, Corrosion inhibitors, Flexural Strength, Concrete and Steel Reinforcement

INTRODUCTION

The effect of corrosion on concrete reinforcing steel is one of the most serious causes of premature deterioration and failure of structures in the environment with chloride. The effects of steel corrosion include a decrease in bar diameter, a decrease in the mechanical properties of the reinforcing steel (e.g., a change from the normal elastic response of low carbon steel bars to a relatively brittle response in bars damaged by pitting, cracking, and bonded concrete and steel at the steel-concrete interface). This corrosion deterioration can lead to damage resulting in capacity loss or even failure, this issue creates justified concern in societies with harsh environments as found in Niger Deltaic region of Nigeria. The corrosion of rebar (reinforcement) in a concrete structure takes many forms and their product effects occur when there is a chemical reaction between the metal and its environment. The corrosion products build up in the bar, expand their volume and create pressure on the surrounding concrete causing cracks, elevations and placement of the concrete, and reduce the effective area of the reinforcing section, thus having less bearing capacity. The corrosion of reinforcement bars in concrete is affected by various parameters such as water-to-concrete ratio, durability, concrete cover, aggregate width and use of cement additives.

^[1] Established that the binding is likely to affect the strength of the structure rather than the decrease in the minimum strength of the stiffness arising from corrosion. Experimental results showed that the corrosion rate does not affect the strength of the steel bars (calculated at the correct cross section), but reinforcing steel bars with corrosion.

^[2] Concluded that the strength ratio and the elastic modulus of elasticity are not significantly affected by corrosion and consequently the strength and modulus of elasticity of

^[3] Investigated the residue of the primary yield strength for lead-free, corrosion-resistant steel casting. The results of composite steel bars with three different exudates / resins of (*Symphonia globulifera* linn, *ficus glumosa* and *acardium occidentale* l.). The results overall showed that the coated members' exhibits increased values of failure load and corrosion strength while corroded decrease in elongation and midspan deflection.

^[4] Carried out investigations into the flexural nature of the combined effect of the corrosion and the heavy loads of concrete beam. Experimental results have shown that the presence of a stable load and the associated crack fracture during corrosion exposure significantly reduced the time of the corrosion cracking. They found that the crack width spread 22% faster in the loaded cases, noting that with 8.9% and 22.2% of the weight loss, the strength loss of 6.4% and 20.0% respectively.

^[5] Investigated the effect of the residual strength of the stiffness / yield strength residual effect of *dacryode edulis* trees, *moringa oleifera*, and *mangifera indica* paste coated strengthens the concrete member. The decrease in stiffness of most joints with *dacryode edulis*, *moringa oleifera* lam, *mangifera indica* is 35.78%, 27.09%, 29.42% compared with 22.30% decrease in frailty, the top 28.75%, 31.50%, 31.60 as compared to 46.30% increase in mold strength and 14.18%, 12.29%, 12.08% as decreased and 10.17% reduced by fishing respectively. Overall results indicate that little or low load yield grater deflection and elongation of steel members.

^[6] Conducted the test at 63 mm × 305 mm × 711 mm, which supported only single-use plates (center to center with a span of 610 mm) reinforced with five rods with a diameter of 6 mm, in the center of which 57 mm were placed. The plate sample was partially immersed in a 5% NaCl solution and a direct current of 2 A was applied to the reinforcement. Corroded strips were observed to change the failure mode in the control samples to break up the shear defects in the corroded panels, and a decrease in the final flexural strength of the panels was also observed; 25% and 60% reduction in final strength by 5% and 25% of the corrosion of reinforcing steel, respectively

^[7] Investigated the effect of corrosion on the flexural strength of reinforced concrete beams in a total of 111 single girders. The beam samples were tested with a four-point load and all beams were subjected to an accelerated corrosion technique in the laboratory. Flexibility compared to the control sample (0% corrosion) was reduced to about 25% at residual strength, and the final flexural strength was significantly reduced to about 75% at 10% corrosion.

^[8] conducted to confirm the use of natural resin / exudates to evaluate the yield strength of reinforced concrete members under accelerated corrosion phenomena with resins / exudates of thickness ranges of 150µm, 250µm and 350 µm are directly layered to the steel bar, placed inside the concrete and subjected to a corrosion accelerated process. Corroded and coated members when compared coated members increased in flexural failure load capacity over corroded members with low load and high yield.

^[9] Conducted a series of tests on steel bar plates with a diameter of 10 mm, where the plates were tested with a four-point load. The sample was exposed to a 3% saline solution and the accelerated corrosion method was used. The corrosion rate varied from 0% for control samples to 15% for other samples. You find that up to a 2% corrosion rate the resistance decreases rapidly. The results of the analysis showed a clear influence of the degree of corrosion on bond strength and development time. Even if the corrosion rate reaches more than 2%, the resistance quickly decreases.

^[10] Investigated the comparative effectiveness of reinforcing steel coated with Khaya senegalensis exudates / resins and the decreased residual flexural strength after 150 days of corrosion fast periods. Decreased members overestimated the overall results; Flexural failure loads against coated and corroded specimens, midspan deflection against coated and corroded specimens, and ultimate tensile strength of coated and corroded specimens. Corrosion attack on the mechanical properties of reinforcing steel embedded in concrete has led to the behavior of the tested properties.

^[11] Tested 70 plates with simple supports with 10 mm diameter strips under four-point load. It has been observed that the corrosion behavior of the reinforcing plate can be predicted with good accuracy. They found that low corrosion increased the flexural capacity of the panels, but when the significant loss of reinforcement area exceeded 2%, the capacity of the panels decreased with higher corrosion rates.

^[12] Evaluated the flexural characteristic of reinforcing steel of non-coated and composite coated with different thicknesses of acacia senegal exudates /resins paste, embedded in concrete members, immersed into concentrated corrosive media and accelerated for 150days. The results obtained confirmed corrosion potential led to deterioration and cracks. The summarized results of the simulated showed higher loads of convergence failure against the corroded and coated specimens, the average values are much higher for the non-corroded and composite models, the overall strength of the considered rigidity is higher than the non-corrode and composite models. Full diagnostic tests showed that the mechanical properties of the reinforcing steel are adversely affected by the presence of corrosion.

^[13] Reported the interaction of mechanical stress and corrosion of steel reinforcement on the serviceability of reinforced concrete beams. It has been found that both load grade and load

history can significantly affect corrosion propagation speed. Moreover, as the corrosion rate increases, the failure mode is switched from shear defects to bond cleavage.

^[14] Investigated the effect of reinforcement corrosion on the performance of reinforced concrete beams with respect to simultaneous loading and different corrosion conditions. At the initial stage, 6% of the mass of the steel bar is corroded; the deformation of the beam (with SLS) is 40-70% higher than the deformation of the control sample

^[15] Introduced coated reinforced steel of 150 μm , 300 μm , and 450 μm thick exudates/ resins aimed at reducing the corrosion of steel reinforcement in the saltwater area. Explored the impact of corrosion on concrete beam and coated and non-coated members. Extensive test results have shown potential corrosion resistance with coating members on mechanical properties that strengthen the effects of weight loss, cracking, and spalling and weight loss. Experimental results showed signs of corrosion with corrosive properties that reduced the thickness of the reinforcing steel surface, resulting in weight loss and cracking. These features failed variable load and high retention potential with low average usage, high levels of stresses, elongation, and midspan deflection.

^[16] Investigated the use of eco-friendly inorganic products of *Artocarpus altilis* exudates/resins in preventing corrosion attack on reinforcing steel embedded in concrete. The results of the deteriorating members on the mechanical properties of reinforcing steel embedded in corrosive media have shown the ultimate tensile strength against high flexibility loads, midspan deflection. Controlled and coated members result include higher midspan deflection, higher yield strength, and lower strain rate compared to corroded members. The overall results showed fractures and tremendous resistance to corrosion attack on reinforcing steel members from the exudates/resin coated members.

^[17] Evaluated the reinforcing behavior of non-coated and acacia senegal exudates/resins paste plated members of varying thicknesses, embedded in a concrete beam, and immersed in corrosive media for 150 days. The results obtained after the exponential period confirm that the coating members do not have the corrosion potential of cracking and spalling. Non-coated high flexural loads are shown against the coated specimens, the midspan deflection rates are higher for the corrugated members, and the ultimate tensile strength of the corrugated members. Overall, experimental tests have shown that the presence of corrosion strikes negatively affects the mechanical properties of steel reinforcement.

^[18] Investigated the strength of steel with the introduction of *milicia excelsa* exudates/resins to reduce the surface modifications and mechanical properties of reinforcing steel in concrete structures. The corrosion acceleration process was 150 days and corrosion efficiency was determined. The flexural strength of the beam failure load leads to an average of -39.1172%, 49.51535%, and 47.14752% for non-corroded and *milicia excelsa* exudates/resins coated samples. Overall, experimental results have shown that spills and fracture corrosion properties in coated members represent a low flexibility failure load.

MATERIALS AND METHODS FOR EXPERINMENT

Aggregate

Fine and coarse are purchased. Both met ^[19] requirements

Cement

Class 42.5., Limestone cement is the most common type of cement in the Nigerian market. It is used for all concrete mixes in this test. Cement complies with ^[20] requirements

Water

Samples of clean and contaminated free water. Clean water utilization is obtained from Kenpoly, Bori, Rivers State, Civil Engineering Laboratory. Water meets ^[21] requirements

Structural steel reinforcement

Reinforcements are obtained directly from the Port Harcourt market. Confirmed as per ^[22]

Corrosion Inhibitors (Resins / Exudates) *Boswellia dalzielii* Hutch

The tree barks yielded whitish gummy Exudates / Resins. They are gotten from tree trunks by tapping from Ardo-Kola Village in Ardo Kola Local Government of Taraba State, Nigeria

Method

This study evaluates the application of resins from natural plants that have environmentally friendly properties from non-hazardous materials obtained from tree trunks. Exudate / resin is then embedded in concrete beams of various thickness layers and applied directly to steel reinforcement. Its usefulness is evaluated as corrosion-resistant reinforced concrete structures that are exposed to harsh regional marine environments.

This study aims to use locally available sourced materials to prevent the negative effects of corrosion attack on steel reinforcement at the highest salt concentrations (sodium chloride) in the marine environment. Concrete beams measuring 175 mm x 175 mm, 750 mm, thickness, width, and length were embedded with four (4) numbers of 16 mm diameter of reinforcing steel and fully immersed in 5% sodium chloride (NaCl) for 360 days after 28 days of treatment. Corrosion is a natural, long-term process that lasts for years. However, the introduction of synthetic sodium chloride (NaCl) accelerates and stimulates the corrosion rate, i.e. the concentration of salt in the coastal area, and this process will take as soon as possible. Also, the purpose of this study is to determine the role of exudates/resins in damaging attacks on reinforcement by water tightness and durability (resistance) as well as modification of steel reinforcement surface due to coating.

Sample Preparation and Concrete Beam Casting

Concrete mixing ratio and standard methods for manual manipulation of material weight are followed. The ratio of concrete mix is 1: 2: 4, the water-cement ratio is 0.65. Manual mixing is used to clean the concrete pavement and the mix is examined and water is slowly added to form a complete concrete mix. By adding cement, water, and fine/coarse, consistent color and consistency are achieved. The test beam is cast into a steel mold measuring 175 mm x 175 mm x 750 mm and supplied with suction air, and reinforced steel with 4 numbers of diameter 16 mm. Samples were demolded after 72 hours and were preserved at room temperature and samples were preserved in 5% sodium chloride for 360 days with 3 months interval checks and testings for 90 days, 180 days, 270 days, and 360 days.

Bending Beam test

According to BS EN 12390-2, the Universal Testing Machine is used for bending tests and a total of 36 beam models are tested. After 28 pretreatments and standards, 12 (controlled) controls remained under control to prevent corrosion-related reinforcement, while 24 uncoated and exudate/resin coated samples were fully immersed in 5% sodium chloride (surface) NaCl for 360 days with regular testing after 90 days, 180 days, 270 days, and 360 days and examining the effect of changes in mechanical properties on uncoated (corroded) and coated samples. The bending test was conducted on an Instron Universal Testing Machine with a capacity of 100 kN. The sample is placed in the machine according to the specifications and the bending test is carried out. Crack and flexural strength, average span deformation and all related tests of reinforcement diameter measured before testing by digitally recorded and computerized system, reinforcement diameter - after corrosion, decrease/increase in cross-sectional area, deformation ratio of stress power, amplitude, before testing, the weight of reinforcement - after corrosion and weight loss/gain of steel is observed and recorded.

Table 3.1 : Flexural Strength of Beam Specimens (Control)

Samples	Samples A			Samples B			Samples C			Samples D		
Items	BDH	BDH1	BDH2	BDH3	BDH4	BDH5	BDH6	BDH7	BDH8	BDH9	BDH10	BDH11
Flexural Strength Load (KN)	84.76	83.95	83.46	85.68	83.88	81.90	84.70	84.02	84.95	84.89	82.90	83.99
Midspan Deflection (mm)	5.23	5.32	5.92	6.03	5.12	6.06	5.15	5.32	5.12	5.20	5.20	6.05
Nominal Bar Diameter (mm)	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Measured Rebar Diameter Before Test(mm)	15.94	15.98	15.97	15.96	15.96	15.96	15.97	15.97	15.90	15.96	15.96	15.96
Rebar Diameter at 28 days(mm)	15.94	15.98	15.97	15.96	15.96	15.96	15.97	15.97	15.90	15.96	15.96	15.96
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
Yield Strength, fy (MPa)	409.92	409.03	405.90	407.80	408.97	408.92	408.51	409.32	408.91	409.73	409.54	408.29
Ultimate Tensile Strength, fu (MPa)	580.03	574.98	566.66	572.44	575.97	566.39	566.19	566.99	565.59	578.14	570.64	579.50
Strain Ratio	1.41	1.41	1.40	1.40	1.41	1.39	1.39	1.39	1.38	1.41	1.39	1.42
Elongation (%)	9.54	9.61	9.74	8.94	10.74	11.08	8.54	9.11	8.04	10.64	9.58	8.87
Rebar Weights- Before Test	1.56	1.56	1.54	1.56	1.56	1.56	1.56	1.56	1.55	1.56	1.56	1.56
Rebar Weights- After at 28 days (Kg)	1.56	1.56	1.54	1.56	1.56	1.56	1.56	1.56	1.55	1.56	1.56	1.56
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 : Flexural Strength of Beam Specimen (Corroded specimens)

	BDH1A	BDH1B	BDH1C	BDH1D	BDH1E	BDH1F	BDH1G	BDH1H	BDH1I	BDH1J	BDH1K	BDH1L
Flexural Strength Load (KN)	67.03	66.37	65.74	65.72	66.16	65.27	66.98	66.30	67.23	64.18	64.68	67.96
Midspan Deflection (mm)	10.62	10.70	11.30	11.41	10.50	11.44	10.53	10.70	10.50	10.58	10.58	11.43
Nominal Rebar Diameter	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Measured Rebar Diameter Before Test(mm)	15.98	15.98	15.99	15.98	15.98	15.92	15.98	15.99	15.96	16.00	15.98	15.99
Rebar Diameter- After Corrosion(mm)	15.93	15.94	15.94	15.93	15.93	15.87	15.93	15.94	15.91	15.95	15.93	15.94
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Yield Strength, fy (MPa)	382.87	381.98	381.48	381.50	4062.12	382.10	382.69	381.61	382.49	381.31	382.40	382.42
Ultimate Tensile Strength, fu (MPa)	560.55	555.50	547.18	552.96	556.49	546.91	546.71	547.51	546.11	558.66	551.16	560.02
Strain Ratio	1.46	1.45	1.43	1.45	0.14	1.43	1.43	1.44	1.43	1.47	1.44	1.46
Elongation (%)	19.43	19.50	19.63	18.83	20.63	20.97	18.43	19.00	17.93	20.53	19.47	18.76
Rebar Weights- Before Test(Kg)	1.56	1.54	1.56	1.56	1.56	1.55	1.56	1.56	1.56	1.56	1.56	1.56
Rebar Weights- After Corrosion(Kg)	1.52	1.50	1.51	1.52	1.51	1.51	1.52	1.51	1.51	1.52	1.52	1.51
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 : Flexural Strength of *Boswellia dalzielii* Hutch Exudate / Resin Coated Beam Specimens

	BDH1A1	BDH1B2	BDH1C3	BDH1D4	BDH1E5	BDH1F6	BDH1G7	BDH1H8	BDH1I9	BDH1J10	BDH1K11	BDH1L12
	150µm (Exudate/Resin) coated			300µm (Exudate/Resin) coated			450µm (Exudate/Resin) coated			600µm (Exudate/Resin) coated		
Flexural Strength Load (KN)	84.76	83.45	83.47	85.69	83.89	81.91	84.71	84.03	84.96	84.10	82.41	83.00
Midspan Deflection (mm)	5.30	5.38	5.98	6.09	5.18	6.12	5.21	5.38	5.18	5.26	5.26	6.11
Nominal Rebar Diameter	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Measured Rebar Diameter Before Test(mm)	15.96	15.98	15.98	15.98	16.00	15.98	15.99	15.98	15.92	15.99	15.99	15.98
Rebar Diameter- After Corrosion(mm)	16.03	16.05	16.05	16.05	16.07	16.05	16.06	16.05	15.99	16.06	16.06	16.05
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.073	0.073	0.075	0.076	0.075	0.07	0.074	0.073	0.077	0.074	0.077	0.073
Yield Strength, fy (MPa)	409.92	409.03	405.90	407.80	408.98	408.92	408.51	409.32	408.91	409.73	409.54	408.29
Ultimate Tensile Strength, fu (MPa)	581.84	576.79	568.47	574.25	577.78	568.20	568.00	568.80	567.40	579.95	572.45	581.31
Strain Ratio	1.42	1.41	1.40	1.41	1.41	1.39	1.39	1.39	1.39	1.42	1.40	1.42
Elongation (%)	9.47	9.54	9.67	8.87	10.67	11.01	8.47	9.04	7.97	10.57	9.51	8.80
Rebar Weights- Before Test(Kg)	1.56	1.56	1.56	1.56	1.56	1.55	1.56	1.56	1.54	1.56	1.56	1.56
Rebar Weights- After Corrosion(Kg)	1.62	1.63	1.62	1.62	1.62	1.62	1.63	1.62	1.61	1.63	1.63	1.62
Weight Loss /Gain of Steel (Kg)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

Table 3.4 : Average Flexural Strength of Beam Specimens (Control, Corroded and Exudate/Resin Coated (specimens)

	Average Flexural Strength of Control Beam Specimens				Average Flexural Strength of Corroded Beam Specimens				Average Flexural Strength of Exudate/Resin Coated Beam			
Flexural Strength Load (KN)	84.05	84.36	84.34	83.82	66.38	65.94	65.87	65.72	83.89	84.20	84.35	83.83
Midspan Deflection (mm)	5.49	5.75	5.69	5.73	10.87	11.13	11.07	11.11	5.56	5.82	5.75	5.80
Nominal Rebar Diameter	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Measured Rebar Diameter Before Test(mm)	15.96	15.97	15.96	15.96	15.99	15.99	15.98	15.96	15.97	15.98	15.98	15.98
Rebar Diameter- After Corrosion(mm)	15.96	15.97	15.96	15.96	15.94	15.94	15.93	15.91	16.04	16.05	16.05	16.05
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.07	0.07	0.07	0.07
Yield Strength, fy (MPa)	408.28	407.58	407.56	408.56	382.11	381.65	388.36	388.57	408.29	407.58	407.56	408.57
Ultimate Tensile Strength, fu (MPa)	573.89	571.36	571.69	571.60	554.41	551.88	552.21	552.12	575.70	573.17	573.50	573.41
Strain Ratio	1.41	1.40	1.40	1.40	1.45	1.45	1.01	1.01	1.41	1.41	1.41	1.40
Elongation (%)	9.63	9.43	9.81	10.26	19.52	19.32	19.70	20.15	9.56	9.36	9.74	10.18
Rebar Weights- Before Test(Kg)	1.55	1.56	1.55	1.56	1.55	1.56	1.56	1.56	1.56	1.56	1.56	1.56
Rebar Weights- After Corrosion(Kg)	1.55	1.56	1.55	1.56	1.51	1.51	1.51	1.51	1.62	1.62	1.62	1.62
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06

Table 3.5 : Average Percentile Flexural Strength of Beam Specimens (Control, Corroded and Exudates Coated (specimens)

	Average Percentile Flexural Strength of Control Beam Specimens				Average Percentile Flexural Strength of Corroded Beam Specimens				Average Percentile Flexural Strength of Exudate/Resin Coated Beam Specimens			
Flexural Strength Load (KN)	26.63	27.93	28.04	27.55	-20.88	-21.68	-21.90	-21.61	26.38	27.69	28.05	27.56
Midspan Deflection (mm)	-49.52	-48.34	-48.64	-48.43	95.62	91.28	92.34	91.60	-48.88	-47.72	-48.01	-47.81
Nominal Rebar Diameter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Measured Rebar Diameter Before Test(mm)	0.3795	0.3915	0.3825	0.3875	0.3945	0.3995	0.3875	0.3925	0.3935	0.3925	0.3915	0.3945
Rebar Diameter- After Corrosion(mm)	0.75	0.75	0.77	0.75	-0.66	-0.71	-0.75	-0.89	0.86	0.82	0.85	0.82
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-28.33	-28.33	-28.33	-28.33	39.52	39.52	39.52	39.52
Yield Strength, fy (MPa)	6.34	6.75	7.44	7.93	-8.07	-8.43	-9.02	-9.43	6.34	6.75	7.45	7.93
Ultimate Tensile Strength, fu (MPa)	2.39	2.40	2.40	2.40	-4.81	-4.83	-4.83	-4.83	2.71	2.73	2.73	2.73
Strain Ratio	-5.38	-5.40	-5.44	-5.45	5.18	5.21	5.25	5.27	-5.08	-5.10	-5.14	-5.15
Elongation (%)	-50.66	-51.18	-50.20	-49.09	104.23	106.46	102.34	97.85	-51.04	-51.56	-50.58	-49.46
Rebar Weights- Before Test(Kg)		0.069	0.070	0.067	0.064	0.069	0.069	0.070	0.070	0.070	0.067	0.071
Rebar Weights- After Corrosion(Kg)	3.04	3.10	2.71	3.11	-7.02	-6.98	-6.63	-6.64	5.55	5.50	5.10	5.11
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	-27.08	-27.08	-27.08	-27.08	37.13	37.13	37.13	37.13

3.1 Results and Discussion of Concrete Beam Members and Midspan Deflection

Corrosion of reinforced concrete or concrete has led to the sudden collapse of many of the exposed structures in coastal areas with severe weather. The effect of corrosion on flexural forces has been investigated by a large number of investigators and is well understood. Many studies conducted in this area have been described by critical tests of their effectiveness in the effects of corrosion on the flexibility of reinforced concrete beams. These corrosion factors and the failure state-led ^[24], investigated the loss of strength of steel due to embedded steel corrosion using concrete members with a cross-section of 100 mm × 150 mm and 1500 mm.

^[8] also examined the effect/impact of corrosion inhibitors on the flexural strength of load, midspan deflection, tensile strength, and reinforcing steel stiffening resins coated with *Mangifera indica* extracts as corrosion inhibitors. The full results showed the effect of corrosion on the flexural strength of reinforcing which led to low load loading and high deviation midspan in damaged joints and flexural load in the failure of the load and lower midspan in the concrete beam members without barrel and binding led to attacks from facial stiffness. Considering the effect of corrosion on reinforced concrete structures built within the coastal areas of Niger Delta, Nigeria, with high salinity, the application of *Boswellia dalzielii* Hutch exudates/resin extracts of tree sources with eco-friendly was introduced, applied directly to embedded reinforcing steel in concrete beams and assessed its effectiveness as an inhibitory substance against corrosion.

3.2 Results Flexural Strength Load and Midspan Deflection

The deterioration to reinforced concrete structure by chloride(s) of reinforced concrete infrastructure is affected by aggravating corrosion, particularly exposed to coastal/marine of severe and corrosive conditions. In a chloride-containing environment, daily and seasonal fluctuations in temperature and humidity are triggered resulting to expansion-contraction and hydration-dehydration cycles leading to the initiation and spread of reinforcement corrosion resulting in cracking, disintegration and loss of load bearing capacity of reinforced concrete structures. To protect reinforcing steel from corrosion, the mechanism of chloride entry into the concrete and influencing factors must be understood and curbed with the application of inhibitive materials.

Experimental data for flexural tests on concrete beam samples are shown in Tables 3.1, 3.2 and 3.3, summarized in 3.4, mean and percentile values in 3.5, and the results are shown graphically in Figures 3.1 - 3.7b.

The average value and the minimum and maximum percentage calculated are the flexural strength of the Instron universal testing machine with compression of 100kN under pressure to failure, the controlled samples are 83.82kN and 84.36kN (26.63% and 28.04 %), the corroded values of the samples were 65.72kN and 66.38kN (-21.9% and -20.88%) and the samples coated with exudates/resin were 83.83kN and 84.35kN (26.38 % and 28.05%). From the flexural strength test, the maximum relative value was 28.04% compared to the corroded and coated sample values of -20.88% and 28.05%, respectively. The mean differential range and percentile controlled are (0.56kN and 1.46%), corroded (0.68kN and 1.02%), coated (0.52kN and 1.67%) . The results showed that the percentage the reference sample was controlled in fresh water according to BS 3148 and no corrosion effect was observed and was therefore used as a reference value for uncoated and coated samples immersed in a corrosive environment as described in the test program. Corroded specimens fail with a lower load, whereas coated specimens have a higher load if failure occurs. The results further confirm that the flexural rupture load of the controlled and coated specimen maintains a narrow range of values over the corroded specimen at moderate, reduced and lower loads.

The minimum and maximum average yields and the percentage of midspan deflection loads recorded on the uncoated material were 5.49kN and 5.75kN (-49.52% and -48.34%), corrosion samples were 10.87kN and 11.13kN (91.28% and 95.62%) and the coated samples were 5.56kN and 5.82 -48.88% and -47.72%). The comparison results show that the maximum value of midspan deflection obtained for the failed state is controlled -48.34% versus corroded 95.62% and coated -47.72% . The recorded mean and percentile difference values were monitored (0.26kN and 1.18%), corroded (0.28kN and 4.34%) and coated (0.26kN and 1.16%). The results show lower elongation loads in the case of controlled and coated samples with reduced values over corrosion samples with higher elongation loads and increased values compared to the reference range (controlled) and coated samples. The change in the failure regime in the tested samples was due to the corrosive effect on the reinforcing steel which had led to severe reinforcing steel surface modifications with the ribs affected. The results of the comparison of flexural strength and midspan deflection due to deformation in the middle of corroded samples show the effect of corrosion on the mechanical properties of reinforcing steel with detached ribs, high surface modification, which causes low load bearing capacity and high deformation of reinforcing steel middle area with respect to the studies of ([16], [15], [8], [10]). From the results obtained, *Boswellia dalzielii* Hutch exudates / resin is proven to be a corrosion protection material in reinforced concrete structures exposed to highly resistant corrosive media and as an insulating membrane against the effects of corrosion.

Figure 3.1: Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

Figure 3.1A: Average Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Figure 3.1B: Average Percentile Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

3.3 Results of Measured Rebar Diameter Before and After Corrosion Test

Reinforcement corrosion alters some of the main parameters used in the construction of structures, and its frequency leads to several significant consequences, for example: loss of cross-sectional area of reinforcement; increased radial tensile forces in the concrete - with subsequent cracking of the overburden due to rust on the reinforcement surface and along the surrounding porous concrete structure - which ultimately leads to pouring of concrete at a later stage; and loss of connection between concrete and reinforcement. The results obtained from the minimum and maximum mean and percentage values for the nominal reinforcing steel value size are 16 mm (100%) for all standards. The diameters measured from reinforcing steel before testing for controlled samples were 15.96mm and 15.97mm (0.379% and 0.391%), the corroded ones were 15.96mm and 15.99mm (0.3875% and 0.3995%) and the coated values are 15.97mm and 15.98mm (0.391% and 0.394%). The results obtained indicate that the diameter of the reinforcing steel varies in the minute range due to the production of reinforcement by different companies, the production mold used produces an average value and the percentage difference is not significant. The average values and the minimum and maximum percentages of the reinforcing steel diameter - after the controlled corrosion test were 15.96mm and 15.97mm (0.75% and 0.77%), the corroded sample values were 15.91mm and 15.94 mm (-0.89% and -0.66%), coated sample values were 16.04mm and 16.05mm (0.82% and 0.86%). The comparison results obtained during and after the corrosion test of the maximum value of the

diameter of the reinforcing steel checked equals 0.77% compared to the corroded -0.66% and the sample with the coating equals 0.86%. The calculated mean differential and percentile values were checked (0.01% and 0.02%), corrosion values (0.03kN and 0.23%) and closed values (0.01kN and 0.04%).

The results showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in diameter and a decrease in both the mean value and the recorded percentage of corroded samples with the reinforcing steel deformed ribs peeled off, whereas the controlled and coated samples showed a preserved state with an increase in coating diameter due to different thicknesses of the exudates/resins coated layers. The use of exudates / resin protects the reinforcing steel from severe corrosion damage. The mean and percentile values determined after and before the correction check have a negative effect on the diameter of the reinforcing steel, which leads to a reduction and an increase in the cross-sectional area.

The minimum and maximum resulting “reduction/increase in cross-sectional area (diameter)” of the controlled sample is 0.00 mm, which indicates (100%) for all samples that the corroded sample is 0.05mm and 0.05mm (28.33 % and -28.33%) and coated samples measuring 0.07mm and 0.07mm (39.52% and 39.52%). The cross-sectional area of reinforcing steel shows a different mean and percentile value of the corroded value (0.01 and 3.54%) and the coated value (0.01 mm and 3.34%).

The results obtained showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in the diameter of the reinforcement in the corroded sample, while the coated sample showed an increase due to the thickness of the exudates paste layers. The reduction in cross-sectional area is due to the corrosive effect on reinforced concrete structures constructed in marine coastal environments and the increased protective layer by work-related exudates/resins with respect to the studies of ([16], [15],[8],[10]).

Figure 3.2: Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

Figure 3.2A: Average Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

Figure 3.2B: Average Percentile Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

Figure 3.3: Rebar Diameter- After Corrosion versus Cross- sectional Reduction/Increase (Diameter

Figure 3.3A: Average Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase (Diameter)

Figure 3.3B: Average Percentile Rebar Diameter- After Corrosion versus Cross-sectional Area Reduction/Increase (Diameter)

3.4 Results of Ultimate Tensile Strength and Yield Strength

The tensile capacity of steel decreases in proportion to the loss of the steel surface. In addition, the loss of the steel surface leads to the loss of the connection between the steel and the enclosed concrete. All these actions contribute to the loss of the hardness and plasticity of the beam and thereby reduce the final strength of the beam. It should be emphasized that reinforcing steel is provided in reinforced concrete to resist tensile forces and to produce controlled crack formation in these areas. However, corrosion not only affects the steel bars and their function in transmitting tensile stresses, but also affects the concrete by spalling and cracking. The results of the calculation of the minimum and maximum mean and percentage values in Tables 3.4 and 3.5 are obtained from Tables 3.1-3.3 at the point of the sample-controlled value results are 407.56MPa and 408.56MPa (6.34% and 7.93%), the corroded samples were 381.65MPa and 381.57MPa (-9.43% and -8.07%) and the coated samples were 407.56MPa and 408.57MPa (6.34% and 7.93%) respectively.

The ultimate tensile strength values of controlled samples were 571.36MPa and 573.89MPa (2.39% and 2.4%), corroded samples were 551.88MPa and 554.41MPa (-4.83% and -4.81%) and coated samples of 573.17MPa and 575.7MPa (2.71% and 2.73%). The results of the calculation of the maximum comparison value both tensile strength and tensile strength for the controlled sample are 7.93% and 2.4% compared to the corroded and coated values of -8.07% and -4.81%, the coverage values are respectively are 7.93% and 2.73%.

Differentially calculated mean and percentage values of yield point and maximum tensile strength (1.0MPa and 1.59%) and (2.55MPa and 0.01%) were checked, the corrosion value was (5.5MPa and 0.09%) and (2.57MPa and 0.02%), the values coated are (1.04MPa and 1.6%) and (2.53MPa and 0.02%). From the data obtained and compared, the limit values and tensile strength of the corroded samples showed a decrease in the average and percentage values for load damage with few applications. The damage caused causes a corrosive effect on the mechanical properties of reinforcing steel due to surface modifications affecting the ribs and fibers, while the coated samples at higher loads increase the mean values and percentages of the reference range (control samples) listed. load bearing capacity with respect to the studies of ([16], [15], [8], [10]). Exudates / resins have been proven to be effective and effective in protecting reinforced concrete structures exposed to corrosive media

Figure 3.4: Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Figure 3.4A: Average Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Figure 3.4B: Average percentile Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

3.5 Results of Strain Ratio, Elongation, Rebar Weights- Before and After Corrosion and Weight Loss /Gain of Steel

Reinforced concrete is used as the main material in the main structural system of various structures in several countries. Reinforced concrete is considered durable and can withstand a wide range of environmental conditions. However, premature corrosion of steel reinforcement causes structural damage. Corrosion of reinforcement in reinforced concrete worsens the strength of such structures. With reinforced concrete elements, the effect of corrosion is even more pronounced, since almost all of the tensile force is exerted on the steel reinforcement. Corrosion of steel reinforcement in reinforced concrete beams reduces the cross-section of the steel surface and causes localized cracks in the steel surface. The results of the calculation of the minimum and maximum mean and percentage in Tables 3.4 and 3.5 obtained from Tables 3.1 to 3.3 the elongation ratio values obtained from the controlled sample are 1.40 and 1.41 (-5 , 45% and - 5.38%). Corroded samples were recorded as 1.43 and 1.45 (5.18% and 5.27%), coated sample values were 1.41 and 1.41 (-5.15% and -5.05%). It was found that the ratio of the maximum calculated deformation ratio for the mean and percentile values for the controlled was -5.38% compared to the corroded and overlaid values of 5.27% and -5.08%, respectively. The mean differential and percentile values obtained for the control were (0.01 and 0.07%), corrosion values (0.44 and 0.09%) and closed values (0.01 and 0.07%).

The results showed that the corroded sample had a higher deformation ratio due to lower breakdown stress and higher yield strength, whereas the coating had a higher percentage of stress at lower elongation. Lower loads and higher yield and deformation strengths are the result of the effect of corrosion on the mechanical properties of reinforcing steel, which affects the interface, surface modification, fiber reduction and rib removal. The above factors have reduced the load bearing capacity of work-related reinforced concrete structures with respect to the studies of ([16], [15],[8],[10]).

The results of the minimum and maximum strain values (%) for the controlled sample were 9.43% and 10.26% (-51.18% and -49.09%), corrosion values were 19.32% and 20.15% (57.85% and 66.46%).) coated sample values were 9.36% and 10.18% (-51.56% and -49.46%). The maximum comparison value for the controlled sample was -49.09% compared to the corroded and coated sample of 66.46% and -49.46%, respectively. The mean differential and percentile values obtained for the controlled samples were (0.86% and 2.09%), corrosion values (0.85% and 8.61%), and coated values (0.85% and 2.1%).

In comparison, the corroded samples showed higher stress values and higher elongation rates, whereas the damaged state of coated samples was lower load and reduced elongation. The effect of corrosion impairs the mechanical properties of reinforcing steel, leading to higher fracture rates at low loads; coated samples show a range of values closer to the reference (controlled sample). The use of exudates materials for rebar has reduced the scourge and tendency of corrosive attack to which reinforced concrete structures in marine coastal areas are heavily exposed in connection with respect to the studies of ([16], [15],[8],[10]).

The unit weight of rebar mean and percentage values of the minimum and maximum before the test, calculated in Tables 3.4 and 3.5 and obtained from Tables 3.1 - 3.3 parameters per unit weight before and after the corrosion test, the controlled sample values are 1.55 kg and 1.56Kg (0.066% and 0.07%), the corroded values are 1.55Kg and 1.56Kg (0.064% and 0.07%), and the coated values are 1.56Kg and 1.56Kg (0.067% and 0.071%).

The rebar weight - after corrosion (Kg) the average and minimum and maximum percentile values were 1.55kg and 1.56kg (2.71% and 3.11%) were checked, the corrosion value was 1.5Kg and 1.51Kg (-7.02% and -6.63%), the values covered are 1.62Kg and 1.62Kg (5.1% and 5.55%). The difference values obtained for the mean and percentile of the controlled samples were (0.01 and 0.15%), corrosion values (0.01kg and 0.39%) and coated values (0.002kg and 0.45%).

The result of weight loss/gain of average minimum and maximum steel and controlled percentage values (100%) for controlled samples, which leads to their combination in fresh water without any trace of corrosion attack, corroded sample values of 0.05 kg and 0.05 kg (- 27.08% and -27.08%, coated samples were 0.06 kg and 0.06 kg (37.13% and 37.13%). The calculated data for the maximum percentage for the weight of the reinforcing beam before the corrosion test for the controlled, corroded and coated values were 0.05%, 0.04% and 0.06%.

The maximum comparison values recorded after the corrosion test for the controlled samples remained the same, with no trace of a corrosive effect, because they were incorporated in fresh water; values of -6.63% and 5.55% were achieved for corrosive and coated samples. Percentages of maximum weight loss/gain for corroded and coated samples were -27.08% and 37.13%, respectively. The calculated data showed a decrease in the values of the samples corroded due to corrosion attack, which led to a decrease in the recorded weight, whereas the coated samples showed an increase in weight due to the different coating thickness compared to the reference values of the controlled samples with respect to the studies of ([16], [15], [8], [10]).

Figure 3.5: Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Figure 3.5A: Average Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Figure 3.5B: Average Percentile Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Figure 3.6: Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Figure 3.6A: Average Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Figure 3.6B: Average Percentile Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Figure 3.8: Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg)
(Non-Corroded, Corrode and Resin Coated Specimens)

Figure 3.8A: Average Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg)
(Non-Corroded, Corrode and Resin Coated Specimens)

Figure 3.8B: Average Percentile Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens)

4.0 Conclusion

The experimental results obtained are summarized as follows:

- I. The results showed that exudate/resin is a corrosion-resistant material in reinforced concrete structures exposed to a corrosive environment, with high resistance and as a waterproof membrane against the effects of corrosion.
- II. The results of the comparison of flexural strength and elongation load in the center of the corroded sample show the effect of corrosion on the mechanical properties of reinforcing steel with curved reinforcement, high surface modification, low load carrying capacity, tensile strength and high deformation of reinforcing steel.
- III. Reduced cross-sectional area due to corrosive effects on reinforced concrete structures built in marine coastal environments and work-related increase in exudates/resin
- IV. Exudates / resins have been proven to be effective and efficient in protecting reinforced concrete structures exposed to corrosive environments.
- V. The results obtained showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in the diameter of the reinforcement in the corroded sample, while the coated sample showed an increase due to the thickness of the exudate paste layer.
- VI. The results show lower elongation loads for controlled and coated samples with lower values than for corroded samples with higher elongation loads and increased values compared to the reference range (controlled) and coated samples.
- VII. The combined results of the controlled sample on the corroded sample show that the controlled sample replaces the corroded sample with low flexural elongation, low deviation in the average elongation range, normal limits, high tensile strength, low elongation / elongation ratio.
- VIII. Corrosion test results show high flexural stresses; stretch rate is higher than the average range.

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