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Induced Corrosion Influence on Mechanical Properties of Reinforcing Steel Embedded in Reinforced Concrete Beam

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Abstract

The study aims to determine the role of exudates/resins in detrimental attacks on reinforcement through water tightness and durability (resistance) as well as repair of steel reinforcement surface due to coating. The coated reinforcing steel is embedded in the concrete beam after layers of different thicknesses was applied directly to the steel reinforcement. Its utility is assessed as corrosion-resistant reinforced concrete structures that are exposed to the harsh territorial marine environment. The obtained flexural strength test results of the maximum value of controlled was 23.34% compared to the corroded and coated sample values of -17.61% and 23.12%, respectively. The computed differential average and percentile values are controlled (0.06kN and 0.02%), corroded values are (0.06kN and 0.08%) and coated values are (0.06kN and 0.08%). Results showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in diameter also decrease in both average and percentile values recorded by the corroded samples while controlled and coated samples showed a maintained status with the coated having an increase in diameter resulting from varying coating thicknesses with

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exudates/resin. The differential computed average and percentile value of the yield strength and ultimate tensile strength are controlled (5.42MPa and 0.11%) and (2.53MPa and 0.03%), the corroded values are (5.5MPa and 0.08%) and (2.53MPa and 0.02%), the coated values are (5.3MPa and 0.09%) and (2.53MPa and 0.01%). An attributed failure resulted in the corrosion effect on the mechanical properties of reinforcing steel through surface modifications that affected the ribs and fibre, whereas, coated samples recorded increasing average and percentile values from the reference range (controlled samples) with higher load-carrying capacity. The comparative strain ratio obtained of the maximum computed values for the average and percentile values for the controlled is -3.42% against corroded and coated values of 3.29% and -3.11%. Obtained differential average and percentile values for the controlled are (0.02 and 0.07%), corroded values are (0.02 and 0.08%) and coated values are (0.01 and 0.08%). Obtained differential average and percentile values for controlled samples are (0.82% and 0.63%), corroded values are (0.83% and 0.99%), and coated values are (0.83% and 0.65%). The maximum recorded comparative values after corrosion test for controlled sample remained the same, with no traces of corrosion effect because it was pooled in freshwater, for the corroded and coated samples, the obtained values are -6.24% and 6.75%. The computed data showed a decreased value from corroded sample resulting from corrosion attack that has led to weight loss recorded whereas, coated samples has weight increase resulting from varying coating thicknesses.

Keywords: Corrosion, Corrosion inhibitors, Flexural Strength, Concrete and Steel Reinforcement

INTRODUCTION

Reinforced concrete beam load depends on the carrying capacity and its moment of inertia or the strength of the steel bar. Corrosion is the cause of loss or loss of strength of steel reinforcement and its products usually occupy a much larger volume, about 6 to 10 times that of the base metal. The increase in volume exerts considerable tear stress on the surrounding concrete, which leads to the formation of cracks.

Cracks in the hairline on the concrete surface that are directly above and parallel to the reinforcement are a positive sign that the reinforcement is corroding. These cracks indicate that widespread rust has grown enough to crack the concrete. At this stage too, the reinforcement appears to be rust-free if the concrete breaks.

Ting and Nowak (1991) formulated the effect of reinforcing the steel area loss calculations caused by the mechanical damage caused by corrosion loss on the beam loading capacity of the corrosion presence.

They formulate a finite difference method of numerical processing, considering a variety of concrete members, including solid slab, vacuum slab, rectangular beam, T-beam and box beam. This approach assesses and demonstrates the impact loss of reinforcing the steel area of a typical reinforced concrete bridge girder. Their formulation and mechanism, reinforcing the loss of steel area is a linear function of material loss.

Umoto and Mishra (1988), by contrast, have established a different approach, which is indirectly correlated with structural degradation resulting from reinforcement corrosion, loss of bar strength caused by cross-sectional area reduction, and crack strength in concrete, leading to loss of bond strength.

Huang and Yang (1997) experimented with corroded reinforced concrete beams with dimension of 150 mm x 150 mm × 500 mm in 30 beams, strengthening the steel bar to study the flexibility effect and behavior of the beams. Two of the 4 bars are flexural reinforcement and there are no provisions for shear reinforcement. The load bearing capacity of the beam is reduced due to the current application which impressed the beams which accelerated the corrosion rate. The load-carrying capacity of the RC beams decreased as corrosion production increased. The loss of load carrying capacity was computed to determine the percentage reduction of the steel bar diameter resulting from corrosion. Experimental results showed that the loading efficiency was reduced by 10%.

Yoon et al. (2000) investigated 100mm × 150 mm × 1170 mm lightweight concrete beams, reinforced with a standard Grade 60 steel reinforcement measure. The epoxy (coated) was applied to the reinforcing steel bar to reduce or reduce the strength of the rust and the effect of the metal corrosion was evaluated using water cement of

0.5 with standard concrete strength to investigate the dynamic loading strength of the concrete figures. Four-point loading adjustments used the distance between two reinforced concrete type end supports as 1050 mm, while a clean flexural moment was performed within the 230 mm center of the center of the beams. It was found that, as the beams have a weight reduction of ≥3% weight, the residual load of the joints decreased as the weight decrease of the reinforcing steel increased indicating that the loss of load strength could be primarily due to the loss of the steel in the steel.

Torres-Acosta et al. (2007) investigated the loss of flexibility with loss of steel cross section due to normal corrosion of embedded steel with a cross section of 100 mm × 150 mm and a concrete beam of 1500 mm long with chloride. The sample was tested in flexure under a three-point load. They concluded that the most important parameter affecting the reduction in flexural stress is a reduction of 60% at a ratio of only 10%, because corrosion corrosion significantly reduces the cross-sectional area of steel and shifts the steel from its elastic behavior to brittle.

Ell-Maadawy et al. (2005) investigated the combined effect of corrosion and a linear function of static loads on corrugated reinforced concrete beams. The presence of permanent loads and associated cracks during corrosion loading reduces the corrosion crack formation time significantly and slightly increases the width of the corrosion crack. They found that crack width increased 22% faster under load conditions, with weight loss of 8.9% and 22.2%, while the strength loss was 6.4% and 20.0%, respectively.

Ballim and Reid (2003) tested and tested a 160 x 100 x 1500 mm beam reinforced by pre-corrosion carbonization with a single 16 mm diameter and a pair of 8 mm diameter reinforcing steel, and this was achieved by filling the bars with CO2. The chamber is pressurized (maintained at 80 kPa) and carries a current of 400 A/cm2. The rods are simultaneously discharged with 23% and 34% of the final load (pu).

John et al. (2019) investigated the effectiveness of applying olibanum exudates/resin to steel reinforcement embedded in concrete and immersed in a corrosive environment against possible corrosion by an accelerated process. Embedded concrete elements of coated and uncoated elements were observed for cracks and spalling. Corrosive elements exhibit lower flexural loads application with higher yielding, midspan deflection, elongation and strain ratio over controlled and coated samples. The effect of corrosion created surface modification and reduction in cross-sectional area and weight loss.

Rodriguez et al. (1997) investigated different degrees of corrosion in concrete images. Vaccine test is 200mm by 150mm with a gap of 2000mm. The beam consists of rigid, compressive and accelerated shear reinforcement by placing the model in a 3% by weight solution of calcium chloride in aqueous solution for a period of 101-190 days at a constant current and a maximum of 100 A/cm2. The results show that rust increases the deflection and crack width at the load of the material, reduces the breaking strength and causes a larger gap and wider break width as a result of bond failure.

Eyre and Nokhasteh (1992) investigated reinforcing behavior that was only expressed through behavioral symptom support. In the experiment it was assumed that the concrete-steel interface had zero beams of different concrete lengths and it was observed that the volume of the beams decreased with the maximum beam length. They concluded that even if the length was unattached, the rope on the concrete breaker would fail, no matter how much metal it was. The results show that the beam can be very strong, even if the connection is completely broken in some parts of the room, as long as the pipe remains immobile.

Nwaobakata et al. (2019) investigated a natural inorganic product made from garcinia cola extract (exudates/resin) as a protective layer on steel reinforcement embedded in concrete. The samples were immersed in a highly corrosive environment and accelerated for 150 days by testing for changes in the mechanical properties of the steel. The results obtained on corroded elements show higher tensile strengths with lower loads, larger deviations in the midspan and elongation zones. The data show that the properties of the corrosive samples are the result of the corrosion of steel by reducing the surface properties of the steel reinforcement and the general mechanical properties of the steel. The results of uncoated elements have high elastic destructive load values, deformation in the center of the spring and tensile strength, deformation and elongation rates, especially corroded samples.

Charles et al. (2019) investigated the surface changes, diameter reduction and weight loss of reinforcing steel from uncoated and exudates/resin-coated elements built into concrete and incorporated in an aggressive environment for 150 days. Uncoated (corroded) elements exhibit a decrease in the mechanical properties of reinforcing steel due to corrosion attack, leading to larger deviations at average span and higher yielding to load application, whereas coated elements retain higher structural integrity. Coated elements exhibit greater flexibility before failure due to higher yields and lower elongation stresses.

Kanee et al (2019) aimed at reinforcing steel with the introduction of milicia excelsa exudates/resin for surface modification and degradation of mechanical properties that reinforce steel in concrete structures. The accelerated corrosion process lasted for 150 days and the corrosion potential was determined. Corrosion properties of spalling and fractures in uncoated elements show that the overall experimental results show low fracture stresses with flexibility, midspan deformation and elongation. Coated members show less average deflection, elongation and ultimate yield strength compared to the corroded members.

Daso et al. (2019) examined the use of environmentally friendly inorganic exudates/resin products from Artocarpus altilis to prevent corrosion attacks on reinforcing steel embedded in concrete. The results of corroded samples on the mechanical properties of reinforcing steel embedded in concrete and exposed to corrosive environment showed decreased in cross-section area and diameter reduction of reinforcing steel, weight loss, low flexural load application to high yield and high midspan deflection. Exudates/resin exhibited waterproofing surface to corrosion attacks.

MATERIALS AND METHODS FOR EXPERINMENT

Aggregates

Fine and coarse are purchased. Both meet BS882 requirements

Cement

Class 42.5 limestone cement is the most common type of cement in the Nigerian market. It is used for all the concrete mixtures in this test. The cement complies with the BS6 196-6 requirements

Water

Clean and contamination-free water samples. The clean water used is obtained from the construction laboratory of Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State. Water meets BS 3148 requirements.

Structural steel reinforcement

Reinforcements are sourced directly from the Port Harcourt market. Confirmed as of BS4449: 2005 + A3

Corrosion Inhibitors (Resins / Exudates) Gongronema latifolium

The exudates were obtained from the stem and yield milky gummy exudates. They are abundantly seen in the Southern part of Nigeria. They are obtained from Chokocho Town in Etche Local Government of Rivers State.

Methods

This study evaluates the application of exudates/resins from natural extruded plants that have environmentally friendly properties from non-hazardous materials derived from tree trunks. The coated reinforcing steel is embedded in the concrete beam after layers of different thicknesses was applied directly to the steel reinforcement. Its utility is assessed as corrosion-resistant reinforced concrete structures that are exposed to the harsh territorial marine environment.

This study aimed to use a locally available sourced material to prevent the negative effects of corrosion attack on steel reinforcement at the highest salt concentration (sodium chloride) in the marine environment. A beam measuring 175mm x 175mm, 750mm, thick, wide, and long with four (4) 16mm diameter figures is implanted in the beam and completely immersed in sodium chloride (NaCl) for 360 days after the first 28 days of cure. Corrosion is a natural, long-term process that lasts for years. However, the introduction of artificial sodium chloride (NaCl) accelerates and stimulates the corrosion rate, that is, the salt concentration in the coastal area, and this process will take the shortest possible time. Besides, this study aims to determine the role of exudates/resins in detrimental attacks on reinforcement through water tightness and durability (resistance) as well as repair of steel reinforcement surface due to coating.

Sample Preparation and Full Beam Casting

Standard methods for concrete mixing ratio and manual manipulation of material weights are followed. The ratio of the concrete mixture is 1: 2: 4, the water-cement ratio is 0.65. Manual mixing is used to clean the concrete pavement and the mixing is checked and water is added slowly to give a complete concrete mix design. By adding cement, water, and gravel, consistent color and consistency are achieved. The test beam is poured into a steel mold measuring 175 mm x 175 mm x 750 mm and supplied with suction air, and reinforcing steel with a diameter of 16 mm is installed. Samples were deformed after 72 hours and preserved for 28 days using standard procedures and at room temperature in the aggregation tank for a 360-days rapid corrosion acceleration test with a test-days interval of 3 months of 90 days, 270 days, and 360 days observations on first crack appearance and pitting.

Flexural Beam Test

According to BS EN 12390-2, a Universal Testing Machine is used for flexural tests and a total of 36 beam models are tested. After 28 pretreatments and standards, 12 (controlled) remained under control to prevent corrosion-related reinforcement, while 24 uncoated and exudate/resin coated samples were completely immersed in 5% sodium chloride (surface) NaCl for 360 days with regular tests after 90 days, 180 days, 270 days, and 360 days and investigations of the effect of changes in mechanical properties on uncoated (rusted) and coated samples. The flexural test was carried out on the Intron Universal testing machine with a capacity of 100 kN. The sample is placed in the machine according to specifications and a flexural test is carried out. Crack and flexural strength through digitally recorded and computerized system, average span deformation and all relevant tests of the measured reinforcement diameter before testing, the reinforcement diameter - after corrosion, reduction/increase in cross-sectional area, tensile strength deformation ratio, elongation, the weight of reinforcement - 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	GL	GL1	GL2	GL3	GL4	GL5	GL6	GL7	GL8	GL9	GL10	GL11
Flexural Strength Load (KN)	90.60	89.79	89.30	85.47	89.72	87.74	90.54	89.86	90.79	90.73	88.74	89.83
Midspan Deflection (mm)	6.63	6.71	7.31	7.42	6.51	7.45	6.54	6.71	6.51	6.59	6.59	8.75
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)	15.75	15.86	15.86	15.85	15.67	15.89	15.99	15.97	15.92	15.82	15.56	15.67
Rebar Diamete at 28 days(mm)	15.75	15.86	15.86	15.85	15.67	15.89	15.99	15.97	15.92	15.82	15.56	15.67
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)	407.71	407.22	405.32	401.34	399.96	403.04	407.93	401.45	403.33	404.15	405.24	405.26
Ultimate Tensile Strength, fu (MPa)	577.46	572.41	564.09	569.87	573.40	563.82	563.62	564.42	563.02	575.57	568.07	576.93
Strain Ratio	1.42	1.41	1.39	1.42	1.43	1.40	1.38	1.41	1.40	1.42	1.40	1.42
Elongation (%)	19.75	19.82	19.95	19.15	20.95	21.29	18.75	19.32	18.25	20.85	19.79	19.08
Rebar Weights- Before Test	1.61	1.61	1.61	1.61	1.61	1.60	1.61	1.61	1.59	1.61	1.61	1.61
Rebar Weights- After at 28 days (Kg)	1.61	1.61	1.61	1.61	1.61	1.60	1.61	1.61	1.59	1.61	1.61	1.61
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)

	GL1A	GL1B	GL1C	GL1D	GL1E	GL1F	GL1G	GL1H	GL1I	GL1J	GL1K	GL1L
Flexural Strength Load (KN)	73.53	72.87	72.24	72.22	72.66	71.77	73.48	72.80	73.73	70.68	71.18	68.41
Midspan Deflection (mm)	11.65	11.73	12.33	12.44	11.53	12.47	11.56	11.73	11.53	11.61	11.61	13.77
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)	15.71	15.82	15.81	15.81	15.63	15.85	15.95	15.93	15.88	15.78	15.52	15.63
Rebar Diameter- After Corrosion(mm)	1.51	1.51	1.52	1.51	1.51	1.51	1.51	1.51	1.49	1.51	1.51	1.51
Cross- sectional Area Reduction/Increase (Diameter, mm)	14.20	14.31	14.30	14.30	14.12	14.35	14.43	14.42	14.39	14.27	14.01	14.12
Yield Strength, fy (MPa)	381.99	381.50	379.60	375.62	374.24	377.32	382.21	375.73	377.61	378.43	379.52	379.54
Ultimate Tensile Strength, fu (MPa)	560.28	555.23	546.91	552.69	556.22	546.64	546.44	547.24	545.84	558.39	550.89	559.75
Strain Ratio	1.47	1.46	1.44	1.47	1.49	1.45	1.43	1.46	1.45	1.48	1.45	1.47
Elongation (%)	24.48	24.55	24.68	23.88	25.68	26.02	23.48	24.05	22.98	25.58	24.52	23.81
Rebar Weights- Before Test(Kg)	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.57	1.58
Rebar Weights- After Corrosion(Kg)	1.53	1.53	1.53	1.53	1.53	1.53	1.52	1.53	1.53	1.53	1.53	1.52
Weight Loss /Gain of Steel (Kg)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05

Table 3.3 : Flexural Strength of Gongronema latifolium Exudate / Resin Coated Beam Specimens

	GL1A1	GL1B2	GL1C3	GL1D4	GL1E5	GL1F6	GL1G7	GL1H8	GL1I9	GL1J10	GL1K11	GL1L12
	150µm	(Exudate/Resin)	coated	300µm	(Exudate/Resin)	coated	450µm	(Exudate/Resin)	coated	600µm	(Exudate/Resin)	coated
Flexural Strength Load (KN)	90.60	89.29	89.31	85.47	89.73	87.75	90.55	89.87	90.80	89.94	88.25	88.84
Midspan Deflection (mm)	6.70	6.78	7.38	7.49	6.58	7.52	6.61	6.78	6.58	6.66	6.66	8.82
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)	15.76	15.87	15.86	15.86	15.68	15.90	15.99	15.98	15.93	15.83	15.57	15.68
Rebar Diameter- After Corrosion(mm)	16.06	16.06	16.04	16.07	16.07	16.01	16.07	16.06	15.97	16.04	16.03	16.05
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.31	0.19	0.18	0.21	0.39	0.11	0.07	0.08	0.05	0.21	0.46	0.38
Yield Strength, fy (MPa)	407.71	407.22	405.32	401.34	399.96	403.04	407.93	401.45	403.33	404.15	405.24	405.26
Ultimate Tensile Strength, fu (MPa)	579.27	574.22	565.90	571.68	575.21	565.63	565.43	566.23	564.83	577.38	569.88	578.74
Strain Ratio	1.42	1.41	1.40	1.42	1.44	1.40	1.39	1.41	1.40	1.43	1.41	1.43
Elongation (%)	19.67	19.74	19.87	19.07	20.87	21.21	18.67	19.24	18.17	20.77	19.71	19.00
Rebar Weights- Before Test(Kg)	1.56	1.57	1.56	1.56	1.56	1.56	1.56	1.56	1.57	1.56	1.56	1.56
Rebar Weights- After Corrosion(Kg)	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63
Weight Loss /Gain of Steel (Kg)	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07

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 Specimens**			
Flexural Strength Load (KN)	89.89	88.19	88.16	87.64	72.88	72.44	72.37	72.22	89.73	88.02	88.17	87.65
Midspan Deflection (mm)	6.88	7.15	7.08	7.13	11.91	12.17	12.10	12.15	6.95	7.21	7.15	7.19
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)	15.83	15.86	15.80	15.81	15.78	15.81	15.75	15.76	15.83	15.86	15.80	15.81
Rebar Diameter- After Corrosion(mm)	15.83	15.86	15.80	15.81	1.51	1.51	1.51	1.51	16.05	16.06	16.06	16.05
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	14.27	14.30	14.24	14.25	0.23	0.19	0.26	0.24
Yield Strength, fy (MPa)	406.75	404.62	402.20	401.44	381.03	378.91	376.49	375.73	406.75	404.63	402.21	401.45
Ultimate Tensile Strength, fu (MPa)	571.32	568.79	569.12	569.03	554.14	551.61	551.94	551.85	573.13	570.60	570.93	570.84
Strain Ratio	1.40	1.41	1.42	1.42	1.45	1.46	1.47	1.47	1.41	1.41	1.42	1.42
Elongation (%)	19.84	19.64	20.01	20.46	24.57	24.37	24.75	25.20	19.76	19.56	19.94	20.39
Rebar Weights- Before Test(Kg)	1.61	1.61	1.61	1.61	1.58	1.58	1.58	1.58	1.56	1.56	1.56	1.56
Rebar Weights- After Corrosion(Kg)	1.61	1.61	1.61	1.61	1.53	1.53	1.53	1.53	1.63	1.63	1.63	1.63
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.07	0.07	0.07	0.07

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)	23.34	21.73	21.82	21.36	-18.78	-17.70	-17.92	-17.61	23.12	21.51	21.83	21.37
Midspan Deflection (mm)	-42.20	-41.29	-41.52	-41.36	71.29	68.69	69.33	68.88	-41.62	-40.72	-40.94	-40.79
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)	0.38	0.36	0.38	0.38	0.38	0.34	0.30	0.37	0.30	0.36	0.38	0.38
Rebar Diameter-After Corrosion(mm)	0.63	0.65	0.67	0.68	-1.21	-1.18	-1.17	-1.19	0.98	1.01	1.02	1.04
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-10.26	-12.33	-12.68	-14.42	11.35	13.43	16.15	18.42
Yield Strength, fy (MPa)	6.75	6.79	6.83	6.84	-6.32	-6.36	-6.39	-6.41	6.75	6.79	6.83	6.84
Ultimate Tensile Strength, fu (MPa)	3.09	3.12	3.11	3.11	-3.31	-3.33	-3.33	-3.33	3.43	3.44	3.44	3.44
Strain Ratio	-3.42	-3.44	-3.48	-3.49	3.21	3.23	3.28	3.29	-3.11	-3.13	-3.17	-3.19
Elongation (%)	-19.27	-19.43	-19.14	-18.80	24.34	24.59	24.12	23.60	-19.57	-19.74	-19.44	-19.09
Rebar Weights-Before Test(Kg)	0.078	0.081	0.082	0.079	0.076	0.081	0.081	0.082	0.082	0.082	0.079	0.083
Rebar Weights- After Corrosion(Kg)	5.56	5.56	5.46	5.38	-6.32	-6.28	-6.24	-6.26	6.75	6.70	6.66	6.68
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	-22.06	-22.39	-24.07	-23.77	28.31	28.84	31.70	31.19

RESULTS AND DISCUSSION

Results of Concrete Beam Members Flexural Strength Load and Midspan Deflection

Corrosion of reinforced concrete or concrete has caused the sudden collapse of many structures in coastal areas by storm. The effect of corrosion on flexural strength has been studied by a many researchers and is well understood. Many studies that have been carried out in this area have been characterized by critical tests of their effectiveness in influencing the effect of corrosion on the flexibility of reinforced concrete beams. Considering the corrosive effect on reinforced concrete structures built in the high salinity coastal region of the Niger Delta, Nigeria, the application of exudates extract of “Gongronema latifolium” from plant sources with eco-friendly effect was coated to reinforcing steel and embedded into reinforced concrete beams and was evaluated on its effectiveness as a corrosion inhibitor.

The phenomenon of pitting corrosion affects a certain part of the rod with an uneven stress distribution due to a shift in the center of gravity in the cross-section and stress concentrations due to the gap effect (Fernandez et al., 2015; Tahershamsi et al., 2017). Apostolopoulos, (2007), test results for corroded steel rods, which also showed a decrease in ductility, elongation, and energy density with sample exposure time.

The experimental data for flexural tests on concrete beam samples are shown in Tables 3.1, 3.2, and 3.3, was averagely computed into table 3.4 and the percentile values are summarized in table 3.5, and the results are shown graphically in Figures 3.1 - 3.7b. The computed average, minimum and maximum percentile values of the flexural strength failure condition for the controlled sample were 87.64kN and 89.89kN (21.36% and 23.34 %), the corroded values of the samples were 72.22kN and 72.88 kN (-18.78% and -17.61%), and the samples coated with exudate/resin were 87.65kN and 89.73kN (21.37% and 23.12%). From the flexural strength test, the maximum value of controlled was 23.34% compared to the corroded and coated sample values of -17.61% and 23.12%, respectively. The average differential and percentile range are, controlled (2.25kN and 1.98%), corroded (0.66kN and 1.17%), coated (2.08kN and 1.75%).

The results showed that the reference percentage of the controlled sample was placed in freshwater according to BS 3148 and no corrosion effect was observed and was therefore used as a reference value for uncoated and coated in a corrosive environment as described in the test program. Corroded specimens failed with a lower load, whereas coated specimens have a higher load failure occurs. The results further confirm that the flexural rupture load of the controlled and coated specimen maintains a closed range of values over the corroded specimen at moderate, reduced, and lower loads.

The minimum and maximum yields and the percentage of midspan deflection reported on controlled were 6.88 kN and 7.15 kN (-42.2% and -41.29%), corroded samples were 11.91 kN and 12.17 kN (68.692% and coated were71.293%) 6.951 kN and 7.215 kN (-41.621% and -40.720%). The comparative of midspan deflection results shows that the maximum value obtained for the failure state of the controlled sample is -41.28% against 71.293% and -40.720% of the corroded and the coated samples. The recorded average and percentile difference values were recorded as controlled (0.263 kN and 0.913%), corroded (0.263 kN and 2.602%) and coated (0.263 kN and 0.900%) and related to Zhuet al., (2017) with an observed 1% reduction in the cross-sectional area of tensile steel resulted in a 1% loss of flexibility and a maximum load loss of 0.84%. The results showed a lower elongation load in the case of controlled and coated samples with a reduction value above the corrosion samples with higher elongation loads and increased values compared to the reference range (controlled) and coated samples. The comparative results obtained for the flexural strength and midspan deflection of the corroded sample shows the effect of corrosion on the mechanical properties of reinforcing steel with shredded ribs, high surface modification, which causes low load-bearing capacity and high midspan deflection. areas with works (Nwaobakata et al., (2019); Charles et al., (2019); Kanee et al., (2019); Daso et al., (2019). From the results obtained, the exudate/resin of ficus plane trees is proven as an anti-corrosion material in reinforced concrete structures exposed to corrosive environments, with high resistance and as a waterproofing membrane against the effects of corrosion.

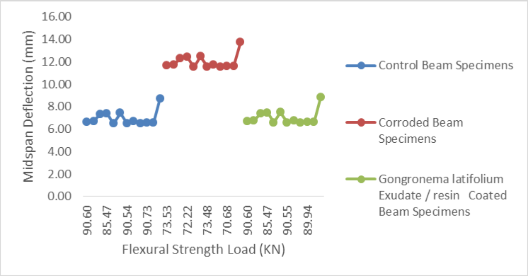

Figure 3.1: Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

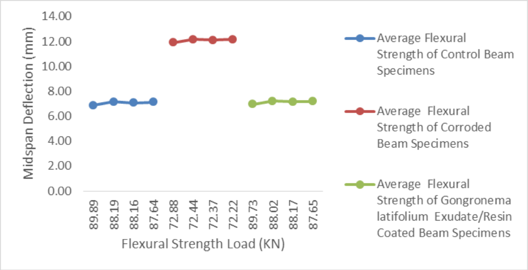

Figure 3.1A: Average Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

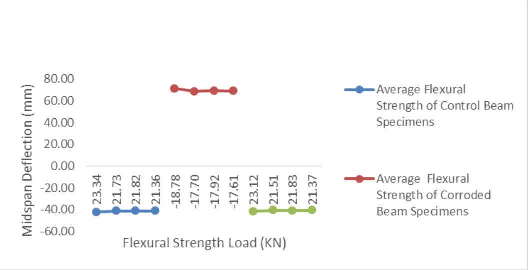

Figure 3.1B: Average Percentile Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

Results of Measured Rebar Diameter before and after Corrosion Test

The results obtained of minimum, maximum average and percentile values for the nominal rebar diameter are 16mm (100%) for all standard references. The measured rebar diameter before test for controlled samples are 15.8mm and 15.86mm (0.36% and 0.38%), the corroded are 15.75mm and 15.81mm (0.3% and 0.38%) and the coated are 15.8mm and 15.86mm (0.3% and 0.38%). Obtained results showed the diameter of reinforcing steel varies in minute range due to rebar production from different companies, the production mold used led to the averages and percentile difference, though are negligible. The minimum and maximum average and percentile values of the rebar diameter- after corrosion test of controlled are 15.8mm and 15.86mm (0.63% and 0.68%), the corroded sample values are 1.51mm and 1.51mm (-1.21% and -1.17%), the coated sample values are16.05mm and 16.06mm (0.98% and 1.04%).

Comparative results obtained during and after corrosion test on the rebar diameter maximum values are controlled 0.68% against the corroded -1.17% and coated sample 1.04%. The computed differential average and percentile values are controlled (0.06kN and 0.02%), corroded values are (0.06kN and 0.08%) and coated values are (0.06kN and 0.08%). Results showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in diameter also decrease in both average and percentile values recorded by the corroded samples while controlled and coated samples showed a maintained status with the coated having an increase in diameter resulting from varying coating thicknesses with exudates/resin. The use of exudates/resin protected the reinforcing steel from the severe damages of corrosion. The average and percentile values obtained after and before correction test has an adverse effect on the reinforcing steel diameter resulting to decreased and increased in the cross-sectional area.

The minimum and maximum obtained "cross-sectional area reduction/increase (diameter)" are of the controlled samples are 0.00mm indicating (100%) for all samples, the corroded samples are 0.055mm and 0.056mm (-14.42% and -10.26%) and the coated samples are 0.19mm and 0.26mm (11.35% and 18.42%). The cross-sectional areas of the reinforcing steel recorded differential average and percentile computed values of corroded (0.06mm and -4.16%) and coated values are (0.07mm and 7.07%). The obtained results showed the effect of corrosion on the mechanical properties of reinforcing steel with decrease in rebar diameter of corroded samples while coated samples showed an increase resulting from the coating thicknesses from exudates paste. The reduction in cross-sectional area is been attributed to the effect of corrosion on reinforced concrete structures built within the coastal marine environment and the increase from the protective coating offered by exudates/resin as related to the works of ((Nwaobakata et al., (2019); Charles et al., (2019); Kanee et al., (2019); Daso et al,. (2019).

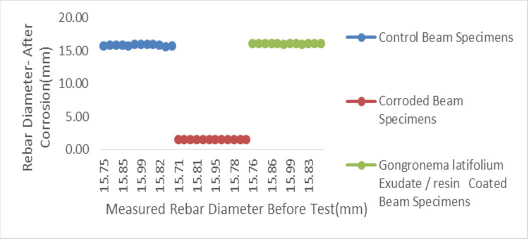

Figure 3.2: Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

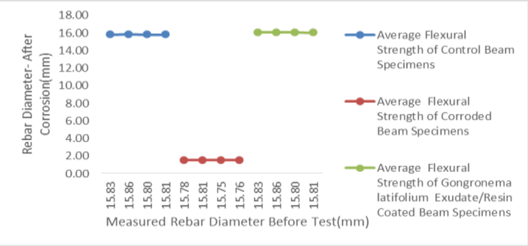

Figure 3.2A: Average Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

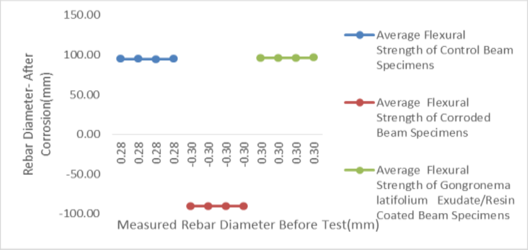

Figure 3.2B: Average Percentile Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

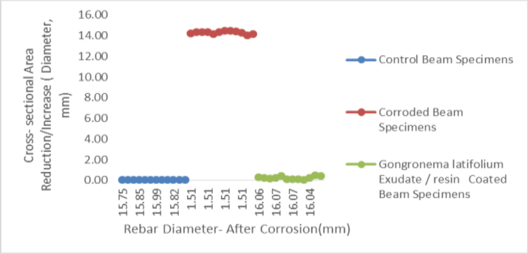

Figure 3.3: Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase (Diameter)

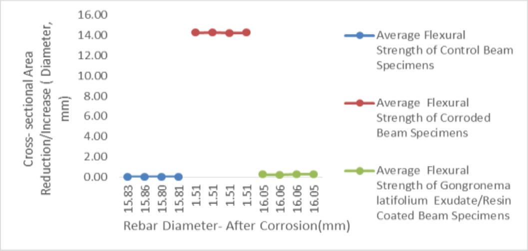

Figure 3.3A: Average Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase(Diameter)

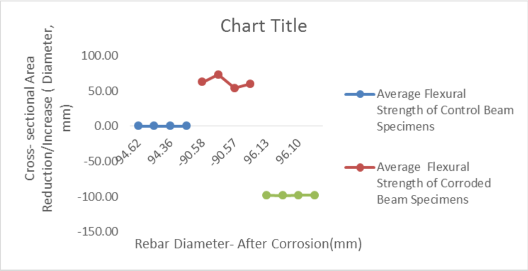

Figure 3.3B: Average Percentile Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase (Diameter)

Results of Ultimate Tensile Strength and Yield Strength

The results of the minimum and maximum average and percentile computed values in tables 3.4 and 3.5 obtained from tables 3.1 - 3.3 of yield strength of the controlled sample values are 401.44MPa and 406.75MPa (6.75% and 6.84%), the corroded samples are 375.73MPa and 381.03MPa (-6.41% and -6.32%), and the coated samples are 401.45Mpa and 406.75MPa (6.75% and 6.84%). The ultimate tensile strength values of the controlled samples are 568.79MPa and 571.32MPa (3.09% and 3.12%), the corroded samples are 551.61MPa and 554.14MPa (-3.33% and -3.31%), and the coated samples are 570.6MPa and 573.13MPa (3.43% and 3.44%). The results of computed maximum comparative values for both the yield strength and ultimate tensile strength for the controlled samples are 6.84% and 3.12% against the corroded values of -6.32% and -3.31%, as well as the coated values of 6.84% and 3.44% respectively.

The differential computed average and percentile value of the yield strength and ultimate tensile strength are controlled (5.42MPa and 0.11%) and (2.53MPa and 0.03%), the corroded values are (5.5MPa and 0.08%) and (2.53MPa and 0.02%), the coated values are (5.3MPa and 0.09%) and (2.53MPa and 0.01%). From the data obtained and compared, the yield strength and ultimate tensile strength values of corroded samples recorded decrease average and percentile values with load failure at low application. An attributed failure resulted in the corrosion effect on the mechanical properties of reinforcing steel through surface modifications that affected the ribs and fibre, whereas, coated samples recorded increasing average and percentile values from the reference range (controlled samples) with higher load-carrying capacity as related to the works of (Nwaobakata et al., (2019); Charles et al., (2019); Kanee et al., (2019); Daso et al,. (2019). The exudates/resin showed effectiveness and potency in the protection of reinforced concrete structures exposed to corrosive media

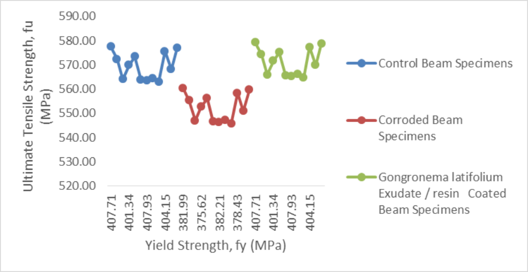

Figure 3.4: Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

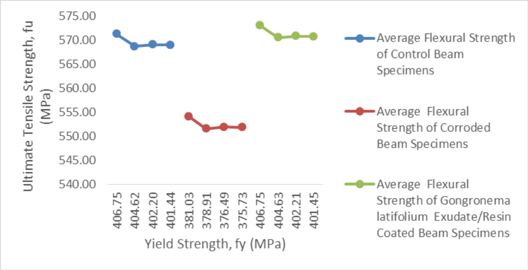

Figure 3.4A: Average Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

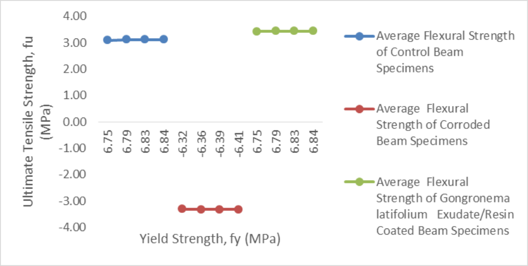

Figure 3.4B: Average percentile Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

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

The results of the minimum and maximum average and percentile computed values in tables 3.4 and 3.5 obtained from tables 3.1 - 3.3 of strain ratio values computed of controlled samples are 1.4 and1.42(-3.49% and -3.42%), the corroded samples recorded 1.45 and 1.47(3.21% and 3.29%), the coated samples values are 1.41 and 1.42(-

3.19% and -3.11%). The comparative strain ratio obtained of the maximum computed values for the average and percentile values for the controlled is -3.42% against corroded and coated values of 3.29% and -3.11%. Obtained differential average and percentile values for the controlled are (0.02 and 0.07%), corroded values are (0.02 and 0.08%) and coated values are (0.01 and 0.08%). Results revealed that the corroded sample recorded a higher percentile strain ratio resulting from lower failure load and higher-yielding whereas, the coated recorded higher failure load application with lower yield. The lower load application and higher yields and straining resulted from the effects of corrosion on the mechanical properties of reinforcing steel that has affected the interface, surface modifications, fiber reduction, and rib peeled off. The above factors have reduced the load carry capacity of reinforced concrete structures as related to the works of ((Nwaobakata et al., (2019); Charles et al., (2019); Kanee et al., (2019); Daso et al,. (2019)

The results of the elongation (%) minimum and maximum average and percentile values for controlled samples are 19.64% and 20.46% (-19.43% and -18.8%), the corroded values are 24.37% and 25.2% (23.6% and 24.59%), the coated samples values are 19.56% and 20.39% (-19.74% and -19.09%).

The maximum comparative values for the controlled sample are -18.8% against the corroded and coated samples of 24.59% and 19.09%. Obtained differential average and percentile values for controlled samples are (0.82% and 0.63%), corroded values are (0.83% and 0.99%), and coated values are (0.83% and 0.65%). In comparative, the corroded sample recorded a higher value of load application and also a higher elongation percentage whereas, the coated sample failure status is lower load application and decreased elongation. The effect of corrosion adversely affected the mechanical properties of reinforcing steel that has resulted in a low load to a higher failure state; the coated samples exhibited a closer value range to the reference (controlled samples). The application of exudates material to reinforcing steel has reduced the scourge and trend of corrosion attacks encountered by reinforced concrete structures built within the severe marine coastal areas as related to the works of (Nwaobakata et al., (2019); Charles et al., (2019); Kanee et al., (2019); Daso et al,. (2019)

The rebar weights- before test minimum and maximum average and percentile values computed in tables 3.4 and 3.5 and obtained from tables 3.1 - 3.3 of unit weight parameters of before and after corrosion test values of controlled samples are 1.61Kg and 1.61Kg (0.078% and 0.082%), the corroded values are 1.58Kg and 1.58Kg (0.076% and 0.082%), and the coated values are 1.56Kg and 1.56Kg (0.079% and 0.083%) and the rebar weights- after corrosion(Kg) obtained values of minimum and maximum average and percentile values are controlled 1.61Kg and 1.63Kg (5.38% and 5.56%), corroded values are 1.53Kg and 1.53Kg (-6.32% and -6.24%), coated values are 1.63Kg and 1.63Kg (6.66% and 6.75%). The differential values obtained for the average and percentile of the controlled samples is (0.02kg and 0.17%), corroded values are (0.003Kg and 0.08%) and coated values are (0.001Kg and 0.09%)

The results of weight loss/gain of steel minimum and maximum average and percentile values are controlled (100%) for controlled samples resulting in its pooling in freshwater with no traces of corrosion attacks, the corroded sample values are 0.05kg and 0.05kg (-24.07% and -22.06%), the coated samples are 0.07kg and 0.07kg (28.31% and 31.70%).

The computed data of maximum percentile values for rebar unit weights before corrosion test for controlled, corroded, and coated values are 0.5%, 0.5%, and 0.07%. The maximum recorded comparative values after corrosion test for controlled sample remained the same, with no traces of corrosion effect because it was pooled in freshwater, for the corroded and coated samples, the obtained values are -6.24% and 6.75%. The maximum percentile values of weight loss/gain for corroded and coated samples are -23.1% and 31.82%. The computed data showed a decreased value from corroded sample resulting from corrosion attack that has led to weight loss recorded whereas, coated samples has weight increase resulting from varying coating thicknesses in comparative to the reference range values obtained from controlled samples as related to the works of (Nwaobakata et al., (2019); Charles et al., (2019); Kanee et al., (2019); Daso et al,. (2019).

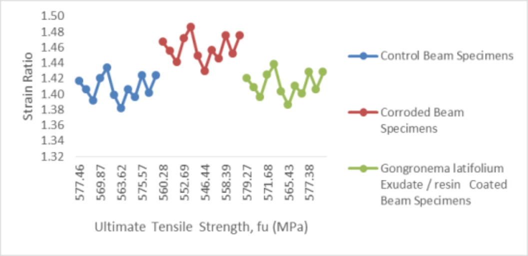

Figure 3.5: Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

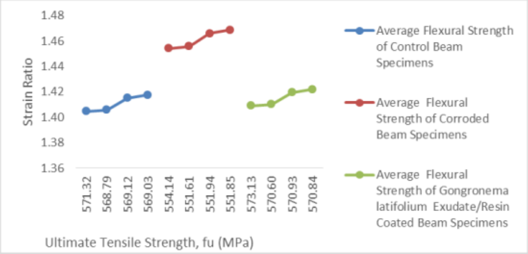

Figure 3.5A: Average Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

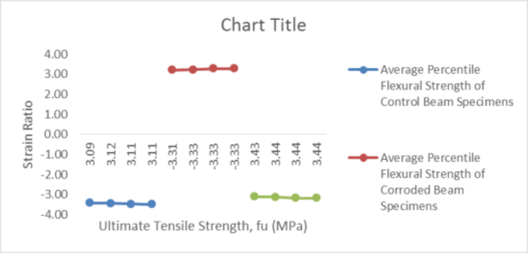

Figure 3.5B:Average Percentile Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

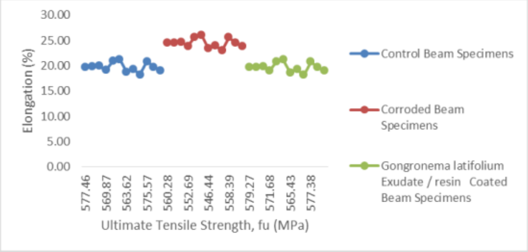

Figure 3.6: Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

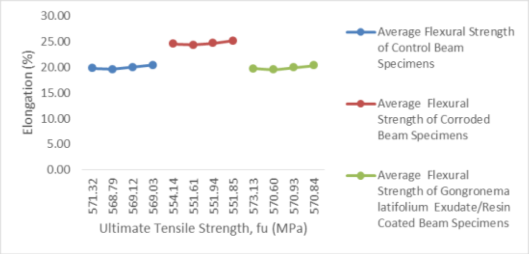

Figure 3.6A: Average Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

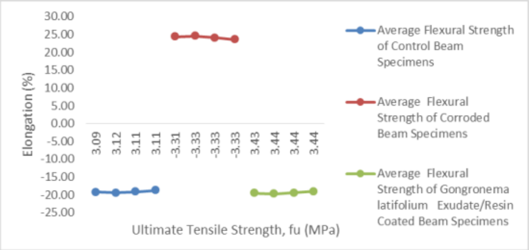

Figure 3.6B:Average Percentile Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

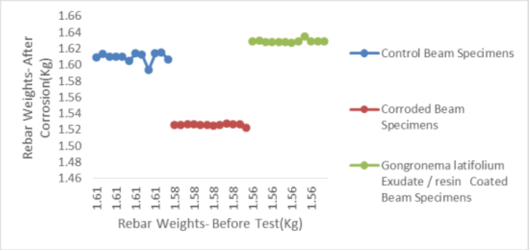

Figure 3.7: Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

Figure 3.7A: Average Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

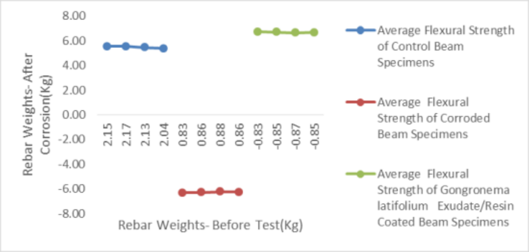

Figure 3.7B: Average Percentile Rebar Weights- Before Test versus Rebar Weights-After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

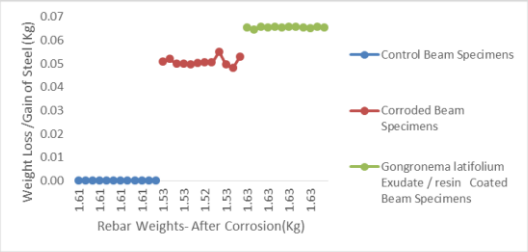

Figure 3.8: Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

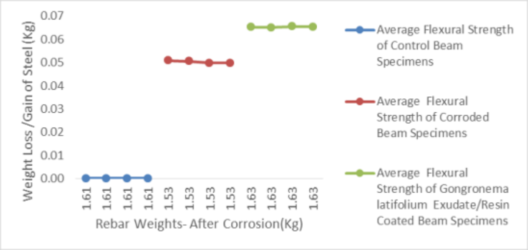

Figure 3.8A: Average Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

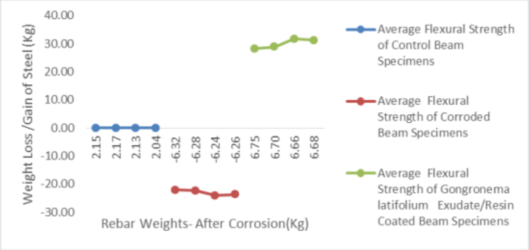

Figure 3.8B: Average Percentile Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

CONCLUSION

The experimental results obtained are summarized as follows:

1. The results showed that exudates/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.
2. 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 layer.
3. Reduced cross-sectional area due to corrosive effects on reinforced concrete structures built in marine coastal environments and work-related increase in exudates/resins
4. Exudates / resins have been proven to be effective and efficient in protecting reinforced concrete structures exposed to corrosive environments.
5. The results show lower strain loads for the controlled and coated samples with lower values than the corroded samples with higher strain loads and increased values compared to the reference range (controlled) and coated samples.
6. The results of the comparative of flexural strength and elongation load in the center of the corroded sample show the effect of corrosion on the mechanical properties of reinforced steel with curved reinforcement, high surface modification, low load carrying capacity, tensile strength and high deformation of reinforcing steel.
7. 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.
8. Corrosion test results show high flexural stresses; stretching speed is faster than the average range.

REFERENCES

1. Apostolopoulos, C. A. (2007). Mechanical behavior of corroded reinforcing steel bars S500s tempcore under low cycle fatigue. *Construction and Building Materials*, 21(7), .1447–1456.
2. Ballim, Y. & J. C. Reid. (2003). Reinforcement Corrosion and the Deflection of RC Beams, An Experimental Critique of Current Test Methods. Cement and Concrete Composites, 25 (6), 625-632.
3. BS. 882; 1992- Specification for Aggregates from Natural Sources for Concrete. British Standards Institute. London, United Kingdom.
4. BS EN 196-6; 2010- Methods of Testing Cement. Determination of fineness, British Standards Institute. London, United Kingdom, 2010.
5. BS 3148; 1980 – Methods of test for Water for Making Concrete. British Standards Institute. London, United Kingdom.
6. BS 4449:2005+A3; 2010 – Steel for Reinforcement of Concrete. British Standards Institute. London, United Kingdom.
7. BS EN 12390-2; 2005 – Testing Hardened Concrete: Flexural Strength Test of Specimens, *British Standards Institute. London, United Kingdom*,
8. Charles, K., Letam, L. P., Nzidee, L. F. (2019). Flexural Strength of Non-coated and Coated Reinforcement Embedded in Concrete Beam and pooled in Corrosive Solution. Journal of Multidisciplinary Engineering Science and Technology, 6 (9), 10736 – 10746.
9. Daso, D., Kanee, S., Charles, K. (2019). Mechanical Properties Behavior of Corroded and Coated Reinforced Concrete structures in Coastal Marine Environment. International Journal of Scientific and Engineering Research, 10 (9), 1154 – 1168.
10. Ell-Maaddawy, T. E., Soudki, K., and Topper, T. (2005). Analytical Model to Predict Nonlinear Flexural Behavior of Corroded Reinforced Concrete Beams. *ACI Structural Journal, 102 (4),550-559.*
11. Eyre, J. R. and Nokhasteh, M. A. (1992). Strength Assessment of Corrosion Damaged Reinforced Concrete Slabs and Beams. Proceedings Institution of Civil Engineers, Structures and Buildings, 94, 197-203.
12. Fernandez, I., Bairán, J. M. and Marí, A. R. (2015). Corrosion effects on the mechanical properties of reinforcing steel bars. Fatigue and σ- ε behavior. *Construction and Building Materials*. Elsevier Ltd, 101, 772–783.
13. Huang, R. & Yang, C. C. (1997). Condition Assessment of Reinforced Concrete Beams Relative to Reinforcement Corrosion, *Cement and Concrete Composites*, *19, 131-137*
14. Kanee, S., Petaba, L. D., Charles, K. (2019). Inhibitory Action of Exudates / Resins Extracts on the Corrosion of Steel Bar Yield Strength in Corrosive Media Embedded in Concrete, "European Academic Research, 7 (7), 3381 – 3398.
15. Nwaobakata, C., Charles, K., Sule, S. (2019). Residual Strength Capacity of Corroded and Coated Reinforcing Bars Corrosion Performance on the Flexural Strength of Reinforced Concrete Members, "International Journal of Civil and Structural Engineering Research, 7 (2), 13-23.

16. Tahershamsi, M. *et al.* (2017) ‘Investigating correlations between crack width, corrosion level and anchorage capacity. *Structure and Infrastructure Engineering*.
17. Ting, S.C. and Nowak, A. S. (1991). Effect of Reinforcing Steel Area Loss on Flexural Behavior of Reinforced Concrete Beams,” *ACI Structural Journal*, 4, 309-314
18. Torres-Acost, A. A., Navarro-Gutierrez, S. & Terán-Guillén, J. (2007). Residual flexure capacity of corroded reinforced concrete beams. Engineering Structures, 29(6), 1142-1152
19. TrustGod, J. A., Kennedy, C., and Gilbert, D. R. (2019). Flexural Residual Capacity and Ultimate Yield Strength of Corroded and Inhibitive Reinforced Concrete Beams in Corrosive Environment. International Journal of Science and Engineering Investigations, 8 (92), 121 – 129.
20. Uomoto, T., and Misra, S. (1988). Behavior of concrete beams and columns in marine environment when corrosion of reinforcing bars take place, *ACISpecial Publication SP 109-6, 127-145.*
21. XuGang, Zhangunderstand, Liu Defu, 2012 Study on mechanical properties of corroded steel bars in concrete under chloride environment [J].Journal of Hydraulic Engineering, 43(4):452-459
22. Yoon, S., Wang, K., Weiss W. J., and Shah, S. P. (2000). Interaction between Loading, Corrosion, and Serviceability of Reinforced Concrete, *ACI Materials Journal*, *97(6), 637- 644.*
23. Zhu, W., François, R. and Liu, Y. (2017). Propagation of corrosion and corrosion patterns of bars embedded in RC beams stored in chloride environment for various periods’, *Construction and Building Materials*. Elsevier Ltd, 145, 147–156..