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Residual Yield Strength Capacity of Reinforcing Steel Bar Exposed to Corrosive Media

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ABSTRACT: *The study investigated the use of extracts from extruded exudates /resins of natural inorganic eco-friendly materials from tree trunks. The tapped exudates /resin was directly applied by coating to reinforcing steel with varying thicknesses, embedded into concrete beams, and examined the potential use of exudates/resin as a corrosion inhibitor. Non-coated and coated samples were wholly immersed in corrosive media of 5% sodium chloride (NaCl) for 360 days, with 3 months interval of 90 days, 180 days, 270 days, and 360 days inspections and testing to ascertained surface changes and mechanical properties modifications and effects on both uncoated and exudates/resin coated specimens. From the flexural strength test, the maximum relative value was 26.540% compared to -19.953% and 26.550% for corroded and coated samples. Mean differential and percentile range checked (0.541kN and 1.374%), corroded (0.663kN and 1.027%), coated (0.520kN and 1.624%).The comparison results show that the maximum value obtained for the closed failure state in a controlled manner is -41.28% compared to 71.293% and -40.720% for corroded. The results show lower elongation loads in the case of controlled and coated samples with reduced values over corroded samples with higher elongation loads and increased values compared to the reference range (controlled) and coated samples. The calculated mean differential and percentile values were checked (0.063kN and 0.193%), corrosion values (0.030kN and 0.127%) and coating values (0.011kN and 0.204%). The results showed that the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in diameter also reduced the average and percentage recorded by the corroded samples, while the controlled and coated samples showed a preserved state, as the coating increased in diameter due to the different thicknesses of the exudates/resin layered to the rebar. The cross-sectional area of reinforcing steel gives different mean and percentile values for corroded values (0.074 mm and -0.956%) and coated values (0.066 mm and 3.139%). The calculation results of the maximum comparative value for both the yield point and the tensile strength of the controlled sample are 6.805% and 3.103% compared to the corroded and coated values of -6.290% and -3.301%, the coating values are 6.807% and 3.429% respectively. Corrosion of reinforcement does not have a major impact on the mechanical strength of the reinforcement, but corrosion products provide stresses to the concrete that cannot be supported by the limited tensile strength of the concrete, leading to the formation of cracks in the reinforcement.*

KEYWORDS: *Corrosion, Corrosion inhibitors, Flexural Strength, Concrete and Steel Reinforcement*

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I. INTRODUCTION

The degradation and deterioration of structures built in an aggressive environmental are often observed in many existing reinforced concrete structures such as in bridges, parking garages, and offshore structures. Deterioration can affect usability and ultimate load carrying capacity. Therefore, understand the true behavior of the wrecked structure and a realistic estimate of the remaining life is essential for competent authorities, stakeholders, engineers, and researchers. The corrosion rate of steel reinforcement in concrete is strongly influenced by a number of environmental parameters including oxygen and moisture, concrete permeability and gradients in the concrete cover, pH, High compressive strength allowed the permeability of the concrete (low water / cement ratio), which reduces the corrosion of steel by reducing the penetration of corrosion-induced materials. Major factors such as concrete pH, chloride ions, oxygen and water need to be considered in the control of corrosion resistance of reinforcement. The methods to control these factors include the use of epoxy coatings, inhibitors, buffers, electrochemical protection procedures and scavengers. It has been found that concrete samples with higher water / cement ratios have higher diffusion rates than models with lower water / cement ratios ([1], [2]), this may be due to the large size of the macrospores and unsegmented capillary pores in concrete with high water / cement ratios ([3], [4]), [5], [6]). Blend agents (slag, pozzolans and fillers) affect the permeability and hence the rate of penetration of chloride ions ([7], [8]). Combining cement with an explosive furnace slag has been found to reduce the rate of diffusion of chloride ions [9]. Reported that the use of silica fume in concrete reduces the permeability of the concrete, improves durability and reduces the rate of penetration of chloride ([10], [11]).

[12] Investigated effect on the flexural strength failure loads of members coated with dacryodes edulis, moringa oleifera lam, mangifera indica. Overall results showed that low load subjection was recorded in the coating members at failure loads, as was the case with high deflection and elongation. All results showed corrosion effect on the flexural strength of the reinforcement, which resulted in low load on the failure load and high midspan deflection on the bending load, and high midspan deflection on the failure load and low midspan deflection on the corroded and coated concrete beam members.

[13] Evaluates the effectiveness of the application of oligonum exudates / resins in reinforcing steel embedded in concrete, immersing in the corrosion environment and accelerating corrosion risk. The first cracks and manifestation stages are the embedded concrete members of the coating and non-coating. The Corroded members show lower flexural flexural loads on coated and uncoated samples, while midspan deflection rates are higher for corrugated and uncoated samples, and the ultimate tensile strength of corrugated members gives higher loads for corrugated and uncoated samples. The effect of corrosion on the mechanical properties of reinforcing steel is not related to the performance of depleted members. Coating members less; Flexural failure load, midspan deflection, strain ratio and ultimate tensile strength on corrugated members. It has standard mechanical properties that reinforce steel on corrugated members.

[14] Researched work aimed at reducing the corrosion of steel reinforcements in the saline area by introducing exudates/resins of reinforced steel of 150 µm, 300µm, and 450 µm thicknesses. Investigated the impact of corrosion on concrete beam and coating and non-coating members. Extensive test results have shown potential corrosion resistance with coating members on mechanical properties that strengthen the effects of weight loss, cracking, spelling and weight loss. Experimental results show signs of corrosion but not corrosion with corrosive properties that reduce the thickness of the metal surface, resulting in metal weight loss and cracking. These features lead to the failure of variable load and high retention capacity with low average usage, high levels of anxiety, extension, and midspan deviation.

[15] Investigated the performance of Garcinia cola as a protective layer to reinforcing steel embedded in the concrete. The members were immersed in a very corrosive environment and accelerated for 150 days with tests on changes in the mechanical properties of the steel. The reduced member ensemble results showed higher yield strength with lower applied load, higher midspan deflection, and extension. It has been shown that the properties of the corroded members are caused by corrosion that attacks the surface properties of reinforcing the steel and reducing the general mechanical properties of the steel. The results of exudates/resins coated members show less flexibility on corrugated members with shorter, less midspan deflection. Indications have shown that coating members have corrosion penetrating properties. Non-corroded member outcomes include higher values of flexural flexure load, lower midspan deflection and yield strength, strain ratio, and extension over wrinkled members.

[16] Investigated the effect of reinforcing steel with the introduction of milicia excelsa exudates/resins for surface modification and the deterioration of the mechanical properties of reinforcing steel in concrete structures. The corrosion acceleration process was 150 days and corrosion efficiency was determined. The corrosion properties of the spalling and cracks observed in the coated members showed that the entire test results showed signs of low flexural failure load; Midspan deviation, extension, and ultimate yield, high flexibility failure load is required and compared with corrugated members.

II. MATERIALS AND METHODS FOR EXPERINMENT

Aggregates

Aggregates of fine and coarse were purchased. Both met the requirements of BS882 [17]

Cement

Portland lime cement grade 42.5 is the most common type of cement in the Nigerian market. It was used for all concrete mixtures in this trial. Cement meets the requirements of BS EN 196-6 [18]

Water

The water samples were clean and free from contaminants. Freshwater used was obtained from the Department of Civil Engineering Laboratory, Kenule Beeson Polytechnic, Bori, Rivers State. Water met the requirements of BS 3148

Structural Steel Reinforcement

Reinforcements are obtained directly from the market at Port Harcourt. Confirmed to **B**S4449: 2005 + A3

Corrosion Inhibitors (Resins / Exudates) Treculia africana (African breadfruit)

The exuding sticky gummy cream was obtained from the tree bark through tapping process. It was obtained from a plantation farm in Odiokwu Town in Ahoada-West Local Government of Rivers State at *Coordinates*: 5°05′N 6°39′E / 5.083°N 6.650°E / 5.083; 6.650.

Methods

The study investigated the use of extracts from extruded exudates /resins of natural inorganic eco-friendly materials from tree trunks. The tapped exudate /resin was directly applied by coating to reinforcing steel with varying thicknesses, embedded into concrete beams, and examined the potential use of exudates/resin as a corrosion inhibitor. The study is aimed at using locally and abundantly available materials to mimic the negative impact of corrosion attack on reinforcing steel in the marine environment with a high level of salt concentration (sodium chloride). Samples of 175 mm x 175 mm 750 mm, thickness, width, and length, and embedded with four numbers of 16 mm diameter of reinforcing and immersed in sodium chloride (NaCl) for 360days after initial 28 days cured processed. The process of corrosion manifestation is a long-term process that takes years to occur in full stage, but the introduction of sodium chloride (NaCl) accelerates and simulates corrosion rate, and the process can be achieved within a short time. Further study is the determination of the contribution of resins against accelerated penetration and negative attack in the reinforcement by its adhesive capacity and the effective adhesion between the coated specimens and the concrete, its waterproofing and resistant nature (resistance), and its ability to resist surface modification of reinforcing steel due to coating application.

Sample Preparation and Casting of Concrete Beams

The standard method of concrete mix ratio was adopted, manual batching by the weight of the material. Concrete mixing ratio 1: 2: 4, water-cement ratio 0.65 by weight of concrete. Manual mixing was used on a clean concrete banker, and the mixing was inspected and water was added slowly to obtain a complete mixing design concrete. The standard uniform color and consistency were obtained by the addition of concrete cement, water, and aggregate. The test beams were cast in a steel mold of 175 mm x 175mm x 750 mm and compacted to diffused air, the fresh concrete mix for each batch was thoroughly compacted by tamping with rods, and 4 numbers of 16 mm diameter reinforcing steel were embedded and projection of 100 mm for possible measurement of half-cell potential.

Samples were de-molded after 72 hours and cured for 28-days standard practices and samples were cured at room temperature in the curing tanks for rapid corrosion testing process with sampling testing at 90 days, 180 days, 270 days, and 360 days, and observations were made on first crack appearance.

Flexure testing of beam specimens

The universal testing machine was used for flexural testing according to [19] and a total of 36 beam samples were tested. After 28 initial and standard curing, days of treatment, 12 controlled beams (non-corroded) were kept in a state of control to prevent corrosion-related reinforcement, while 24 beam samples of non-coated and exudate/ resin/ coated samples were wholly immersed in corrosive media of 5% sodium chloride (NaCl) for 360 days, with 3 months interval of 90 days, 180 days, 270 days and 360 days inspections and testing to ascertained surface changes and mechanical properties modifications and effects on both uncoated and exudate/resin coated specimens. The Flexural test was conducted on an Instron Universal Testing Machine with a capacity of 100KN. Samples were placed in the specification in the machine, flexural testing was taken at the third point on the two supports. The load was applied to the computerized system with the registration of digitally registered cracks and failure with corresponding values of flexural strength load, midspan deflection, and all corresponding investigations of measured rebar diameter before the test, rebar diameter- after corrosion, cross-sectional area reduction/increase, yield strength, ultimate tensile strength, strain ratio, elongation, rebar weights- before the test, rebar weights- after corrosion, and weight loss /gain of steel were all observed and recorded.

Table 3.1 : Flexural Strength of Beam Specimens (Controlled)

Samples	Samples A			Samples B			Samples C			Samples D		
Items	TA	TA1	TA2	TA3	TA4	TA5	TA6	TA7	TA8	TA9	TA10	TA11
Flexural Strength Load (KN)	85.32	84.51	84.03	86.25	84.45	82.47	85.27	84.59	85.52	85.46	83.47	84.56
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)	409.78	409.29	407.39	403.41	402.03	405.11	410.00	403.52	405.40	406.22	407.31	407.33
Ultimate Tensile Strength, fu (MPa)	579.53	574.48	566.16	571.94	575.47	565.89	565.69	566.49	565.09	577.64	570.14	579.00
Strain Ratio	1.41	1.40	1.39	1.42	1.43	1.40	1.38	1.40	1.39	1.42	1.40	1.42
Elongation (%)	17.17	17.24	17.37	16.57	18.37	18.71	16.17	16.74	15.67	18.27	17.21	16.50
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)

Items	TA1A	TA1B	TA1C	TA1D	TA1E	TA1F	TA1G	TA1H	TA1I	TA1J	TA1K	TA1L
Flexural Strength Load (KN)	68.26	67.60	66.97	66.95	67.39	66.50	68.21	67.53	68.46	65.41	65.91	69.19
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)	15.89	15.87	15.83	15.80	15.89	15.88	15.89	15.85	15.88	15.88	15.89	15.86
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.18	0.05	0.03	0.05	0.26	0.03	0.05	0.02	0.00	0.10	0.37	0.23
Yield Strength, fy (MPa)	384.06	383.57	381.67	377.69	376.31	379.39	384.28	377.80	379.68	380.50	381.59	381.61
Ultimate Tensile Strength, fu (MPa)	562.35	557.30	548.98	554.76	558.29	548.71	548.51	549.31	547.91	560.46	552.96	561.82
Strain Ratio	1.46	1.45	1.44	1.47	1.48	1.45	1.43	1.45	1.44	1.47	1.45	1.47
Elongation (%)	21.90	21.97	22.10	21.30	23.10	23.44	20.90	21.47	20.40	23.00	21.94	21.23
Rebar Weights- Before Test(Kg)	1.60	1.60	1.60	1.58	1.60	1.59	1.60	1.60	1.60	1.60	1.60	1.60
Rebar Weights- After Corrosion(Kg)	1.55	1.55	1.55	1.54	1.56	1.55	1.56	1.56	1.56	1.55	1.55	1.56
Weight Loss /Gain of Steel (Kg)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

Table 3.3: Flexural Strength of Treculia africana Exudate / Resin Coated Beam Specimens

Items	TA1A1	TA1B2	TA1C3	TA1D4	TA1E5	TA1F6	TA1G7	TA1H8	TA1I9	TA1J10	TA1K11	TA1L12
	150µm (Exudate/Resin) coated			300µm (Exudate/Resin) coated			450µm (Exudate/Resin) coated			600µm (Exudate/Resin) coated		
Flexural Strength Load (KN)	85.32	84.01	84.03	86.25	84.45	82.47	85.27	84.59	85.52	84.66	82.97	83.56
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)	409.78	409.29	407.39	403.41	402.03	405.11	410.00	403.52	405.40	406.22	407.31	407.33
Ultimate Tensile Strength, fu (MPa)	581.34	576.29	567.97	573.75	577.28	567.70	567.50	568.30	566.90	579.45	571.95	580.81
Strain Ratio	1.42	1.41	1.39	1.42	1.44	1.40	1.38	1.41	1.40	1.43	1.40	1.43
Elongation (%)	17.09	17.16	17.29	16.49	18.29	18.63	16.09	16.66	15.59	18.19	17.13	16.42
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 Treculia africana Exudate/Resin Coated Beam Specimens			
Flexural Strength Load (KN)	84.62	84.93	84.91	84.39	67.61	67.17	67.10	66.94	84.46	84.77	84.91	84.39
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	15.87	15.84	15.84	15.86	16.05	16.06	16.06	16.05
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-0.09	-0.02	-0.09	-0.10	0.23	0.19	0.26	0.24
Yield Strength, fy (MPa)	408.82	406.69	404.27	403.51	383.10	380.98	378.56	377.80	408.82	406.70	404.28	403.52
Ultimate Tensile Strength, fu (MPa)	573.39	570.86	571.19	571.10	556.21	553.68	554.01	553.92	575.20	572.67	573.00	572.91
Strain Ratio	1.40	1.40	1.41	1.42	1.45	1.45	1.46	1.47	1.41	1.41	1.42	1.42
Elongation (%)	17.26	17.06	17.43	17.88	21.99	21.79	22.17	22.61	17.18	16.98	17.36	17.80
Rebar Weights- Before Test(Kg)	1.61	1.61	1.61	1.61	1.60	1.59	1.59	1.59	1.56	1.56	1.56	1.56
Rebar Weights- After Corrosion(Kg)	1.61	1.61	1.61	1.61	1.55	1.55	1.55	1.55	1.63	1.63	1.63	1.63
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.04	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)	25.17	26.44	26.54	26.06	-19.95	-20.76	-20.98	-20.68	24.93	26.20	26.55	26.07
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)	0.398	0.378	0.384	0.378	0.370	0.389	0.358	0.386	0.385	0.389	0.385	0.387
Rebar Diameter- After Corrosion(mm)	0.66	0.64	0.67	0.63	-1.17	-1.36	-1.33	-1.16	1.18	1.38	1.35	1.17
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-13.16	-11.81	-13.82	-14.15	36.06	34.03	37.17	34.99
Yield Strength, fy (MPa)	6.71	6.75	6.79	6.81	-6.29	-6.32	-6.36	-6.37	6.71	6.75	6.79	6.81

Ultimate Tensile Strength, fu (MPa)	3.09	3.10	3.10	3.10	-3.30	-3.32	-3.31	-3.31	3.41	3.43	3.43	3.43
Strain Ratio	-3.39	-3.42	-3.46	-3.47	3.19	3.21	3.26	3.27	-3.09	-3.11	-3.15	-3.16
Elongation (%)	- 21.54	- 21.73	- 21.36	- 20.94	28.00	28.33	27.71	27.02	-21.87	-22.07	-21.70	-21.27
Rebar Weights-Before Test(Kg)	0.063	0.065	0.066	0.063	0.067	0.068	0.066	0.066	0.067	0.065	0.068	0.065
Rebar Weights- After Corrosion(Kg)	3.62	4.01	3.80	3.81	-4.57	-4.88	-4.75	-4.84	4.79	5.13	4.98	5.09
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	- 32.77	- 32.54	- 33.00	- 32.83	48.75	48.23	49.25	48.88

III. EXPERIMENTAL RESULTS AND DISCUSSION

Results and Discussion of Concrete Beam Members Flexural Strength Load and Midspan Deflection and Midspan Deflection

Corrosion of reinforced concrete or concrete has caused the sudden collapse of many structures in storms in coastal areas. The effect of corrosion on flexural forces has been studied by many researchers and is well understood. Many studies in this area are characterized by critical tests of their effectiveness in influencing the effects of corrosion on the flexibility of reinforced concrete beams. Due to the corrosive effect on high-salt reinforced concrete structures constructed in the coastal zone of the Niger Delta, Nigeria, the application of an exudates/resin extract from wood sources with environmental effects was applied directly to the reinforced concrete reinforcement and its effectiveness was evaluated as a corrosion protection agent.

The activity of hazardous compounds resulting from the reaction between the ions and the embedded reinforcing steel creates tensile stresses that lead to cracking and degrading into waste concrete. Although the passive layer of reinforcing steel protects the concrete from corrosion, reinforced concrete structures exposed to wet zones can corrode, especially in the presence of carbon dioxide and chloride ions ([20]). However, the formation and development of corrosion depend on many factors [21]. 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 calculated mean and minimum and maximum percentile values are the flexural strength of the Instron universal testing machine with a pressure of 100kN under pressure to a controlled sample failure state of 84.387kN and 84.929kN (25.166% and 26.540%), the corrosion values of the samples were 66.942 kN and 67.606 kN (-20.980% and -19.953%) and exudate/resin coated samples were 84.394 kN and 84.914 kN (24.926% and 26.550%). From the flexural strength test, the maximum relative value was 26.540% compared to -19.953% and 26.550% for corroded and coated samples. Mean differential and percentile range checked (0.541 kN and 1.374%), corroded (0.663 kN and 1.027%), coated (0.520 kN and 1.624%)

The results showed that the reference percentage of controlled samples according to BS 3148 was placed in fresh water 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 a 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 results and the percentage of of flexural strength and mid-span deflection failure loads recorded were 6.882 kN and 7.145 kN (-42.202% and -41.28%), corrosion samples were 11.907 kN and 12.171 kN (68.692% and 71.293% respectively), and coated samples were 6.951 kN and 7.215 kN (-41.621% and -40.720%). The comparison results show that the maximum value obtained for the closed failure state in a controlled manner is -41.28% compared to 71.293% and -40.720% for corrosion. The recorded mean and percentile difference values were examined (0.263 kN and 0.913%), corroded (0.263 kN and 2.602%) and coated (0.263 kN and 0.900%). The results show lower elongation loads in the case of controlled and coated samples with reduced values over corroded samples with higher elongation loads and increased values compared to the reference range (controlled) and coated samples. The results of the comparison of flexural strength and mid-span deflection failure loads of the corroded sample showed the effect of corrosion on the mechanical properties of reinforcing steel with detached ribs, high surface modification, which causes low load-bearing, failure capacity, and high deformation of reinforcing steel as found with works of ([13], [15], [15], [17]). From the results obtained, the exudate/resin of Treculia africana is proven to be a corrosion protection material in reinforced concrete structures exposed to corrosive environments, with high resistance and as a sealing membrane against the effects of corrosion.

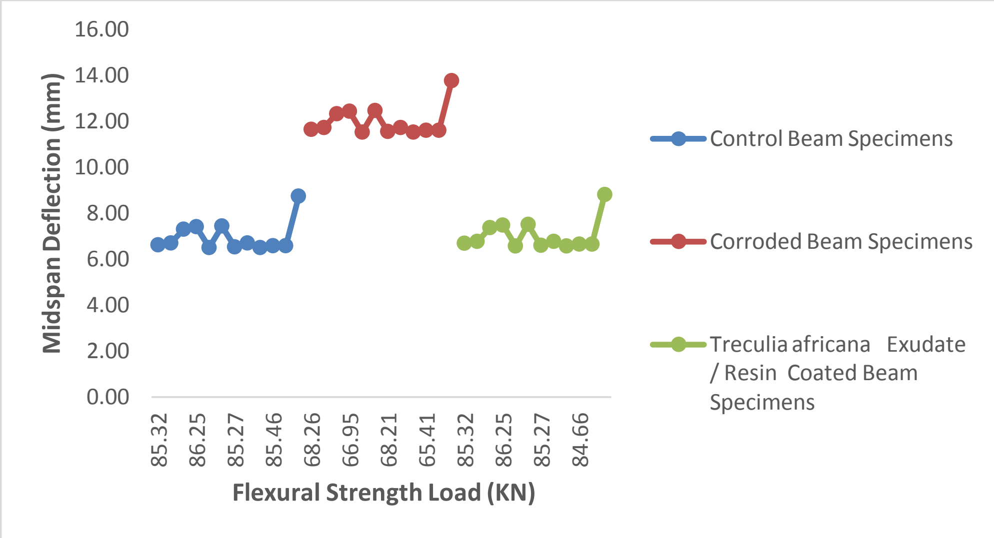


Figure 3.1: Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

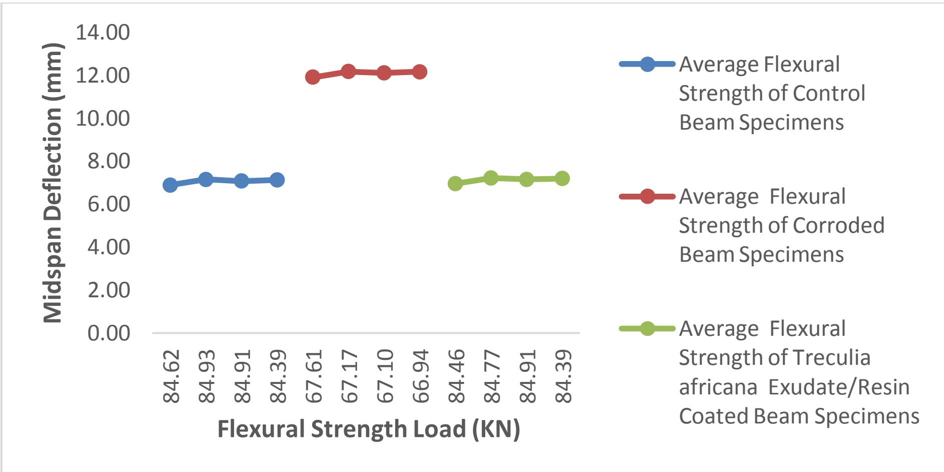


Figure 3.1A: Average Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

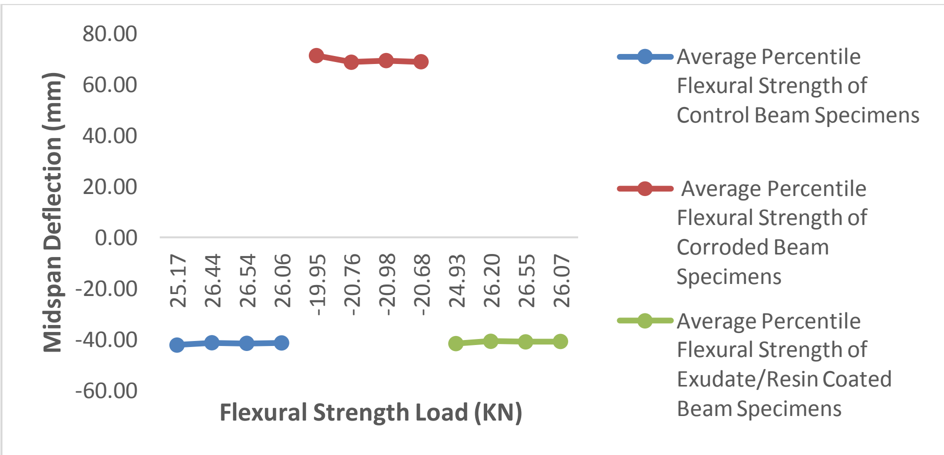


Figure 3.1B: Average Percentile Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

Results of Measured Rebar Diameter Before and After Corrosion Test

Overall corrosion, which occurs evenly along the length of the reinforcement, has two effects: First, it reduces the cross-sectional area of the steel and, secondly, localized cracks created in the steel surface. This effect reduces the tensile capacity of the steel in proportion to the loss of cross-sectional area. Thus, with increasing corrosion products, the cross-sectional area of the steel decreases, and with it, in addition to joint damage, the final torsional capacity of the structure also decreases and reduced until the area of the steel becomes so small that it can no longer withstand the load and thus causes the structure to collapse. Corrosion is an undeniable damage process. This becomes one of the main problems when evaluating the durability of reinforced concrete structures. The effect of calcium carbonate and chloride ions on the protective oxide layer of reinforcing steel in concrete has been identified as one of the main causes of corrosion ([22], [23]). The results obtained for the minimum and maximum mean and percentile for maximum of the nominal diameter of the valve is 16 mm (100%) for all common standards. The fitting diameters measured before testing for the controlled sample were 15.796mm and 15.859mm (0.292% and 0.312%), corroded were 15.751 mm and 15.814 mm (0.302% and 0.303%), and coating was 15.799mm and 15.862 mm (0.303% and 0.304%). 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 mean values and percentages of minimum and maximum rebar diameters of the controlled samples after corrosion test were 15.796 and 15.859 mm (1.137% and 1.330%), corroded sample values were 15.837 mm and 15.867 mm (-0.961% and -0.834%), the values of the coated samples were 16.047 mm and 16.058 mm (1.175% and 1.379%). The comparison results obtained during and after the corrosion test for the maximum value of the anchor diameter were controlled at 1.330% compared to the corroded and -0.834% and the coated sample was 1.379%. The calculated mean differential and percentile values were checked (0.063kN and 0.193%), corrosion values (0.030kN and 0.127%) and coating values (0.011kN and 0.204%). The results showed that the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in diameter also reduced the average and percentage recorded by the corroded samples, while the controlled and coated samples showed a preserved state, as the coating increased in diameter due to the different thicknesses of the exudates/resin layered to the rebar. 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 "decrease/increase in cross-sectional area (diameter)" of the controlled sample was 0.00mm, which indicates (100%) for all samples, the corroded samples were -0.09682mm and -0.02282mm (-14.154% and -11.806%) and coated samples were 0.193293mm and 0.259127mm (34.033% and 37.172%). The cross-sectional area of reinforcing steel gives different mean and percentile values for corroded values (0.074mm and -0.956%) and coated values (0.066 mm and 3.139%). 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. 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 (([13], [15], [15], [17]).

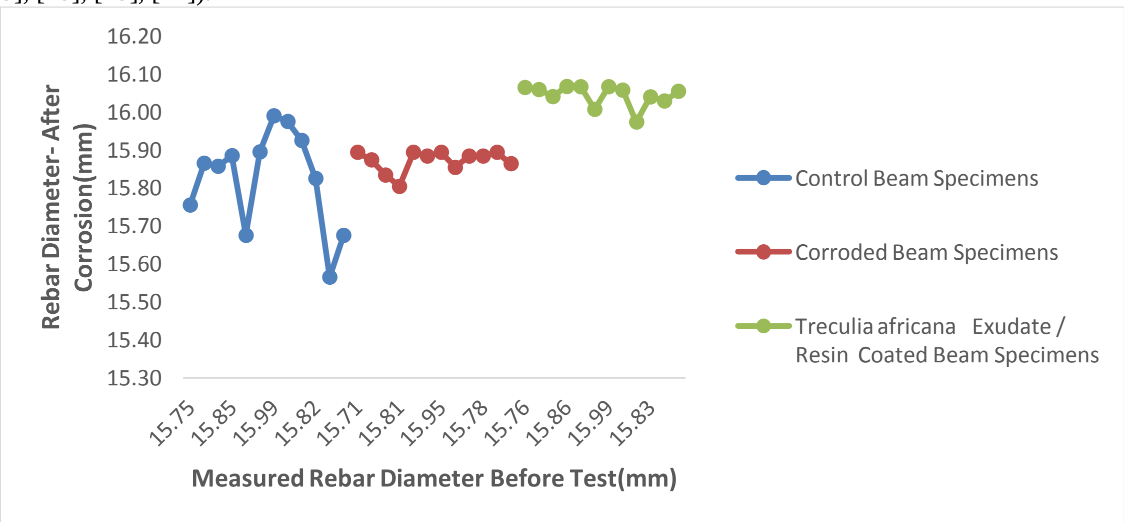


Figure 3.2: Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

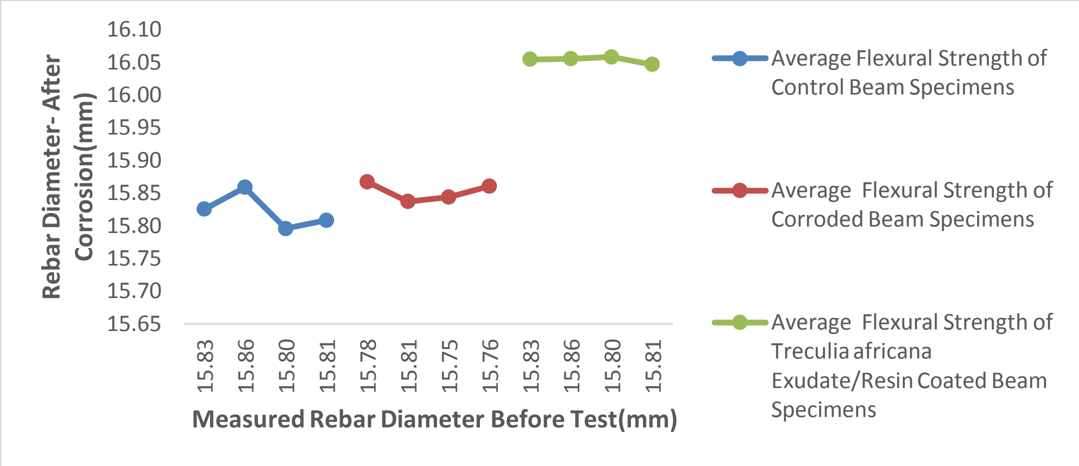


Figure 3.2A: Average Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

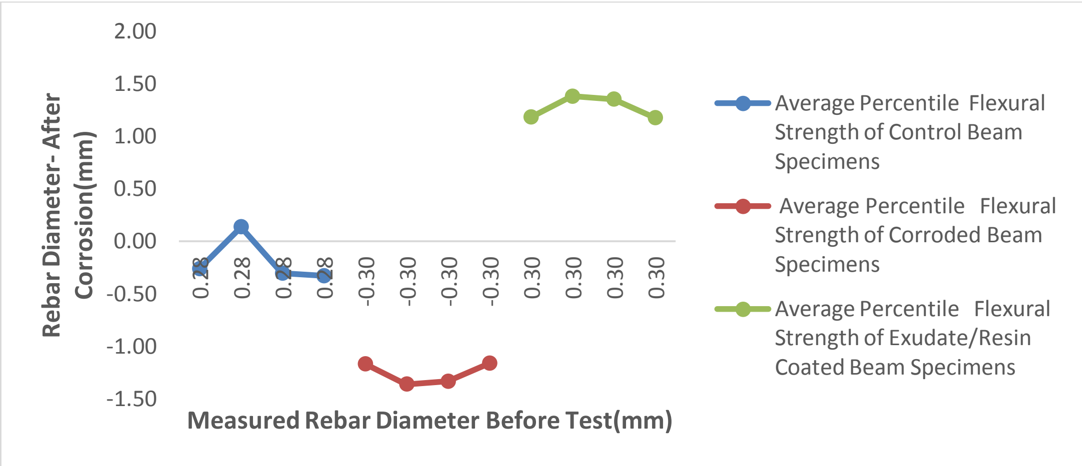


Figure 3.2B: Average Percentile Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

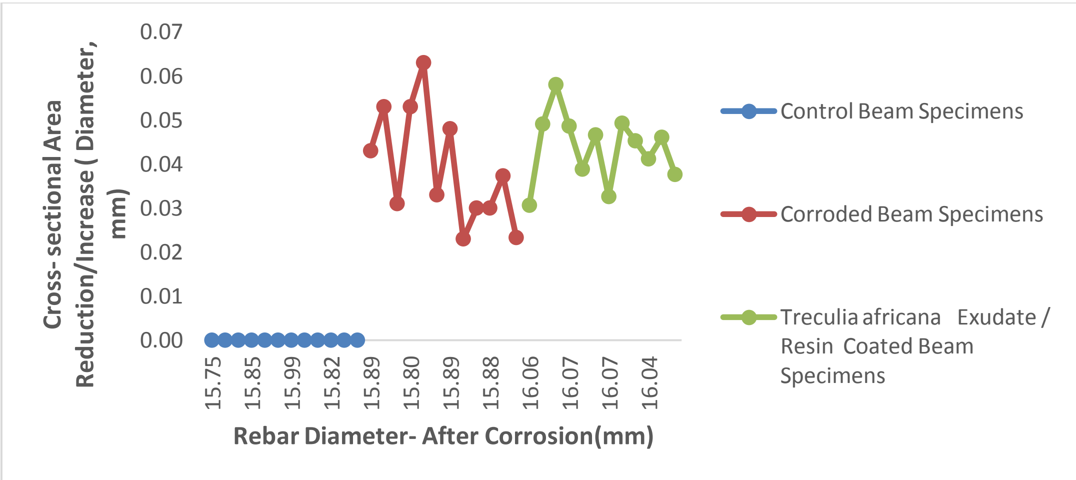


Figure 3.3: Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase (Diameter)

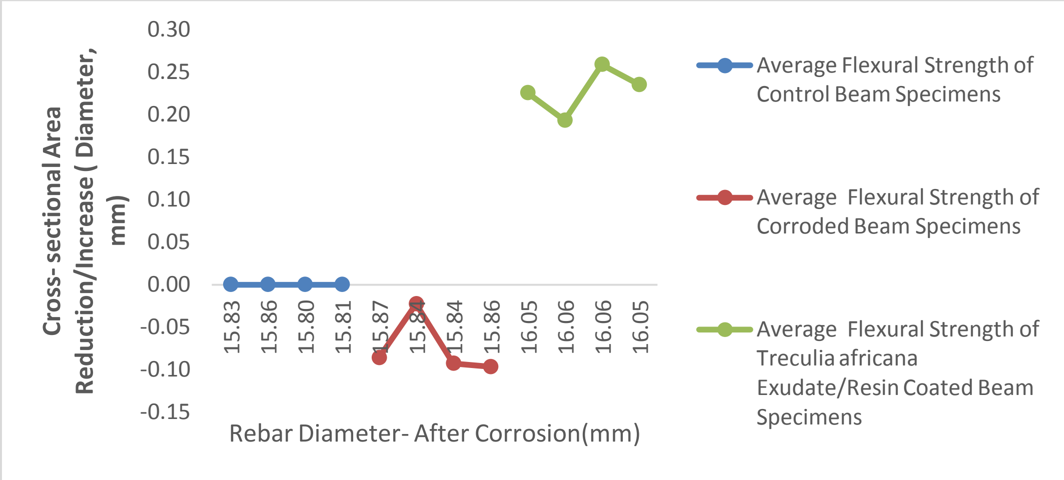


Figure 3.3A: Average Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase(Diameter)

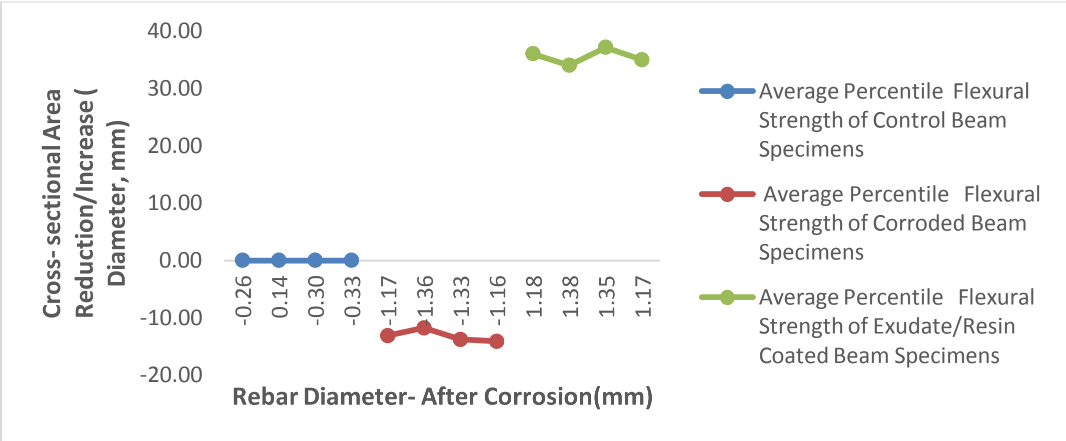


Figure 3.3B: Average Percentile Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase(Diameter)

Results of Ultimate Tensile Strength and Yield Strength

The tensional capacity of reinforced concrete beams mainly depends on the strength of the reinforcing steel. Therefore, the loss of reinforcement can be critical and requires special attention. Corrosion is one of the main causes of surface loss of steel. The results of the minimum and maximum mean and percentile values calculated in Tables 3.4 and 3.5 obtained from Tables 3.1 – 3.3 at the sample-controlled value result points are 403.512MPa and 408.8158MPa (6.711% and 6.805%), corroded samples were 377.799MPa and 383.103MPa (-6.373% and -6.290%), and coated samples were 403.516MPa and 408.8201MPa (6.712% and 6.807%).

The final tensile strength of the control sample was 570.861MPa and 573.39MPa (3.089% and 3.103%), the corroded sample was 553.678MPa and 556.208MPa (-3.315% and -3.301%), and the coated sample was 572.665MPa and 575.195MPa (3.4137 % and 3,429%). The calculation results of the maximum comparative value for both the yield point and the tensile strength of the controlled sample are 6.805% and 3.103% compared to the corroded and coated values of -6.290% and -3.301%, the coating values are 6.807% and 3.429%, respectively. Differently calculated mean and percentage values of yield point and maximum tensile strength (5.303MPa and 0.094%) and (2.530MPa and 0.014%) were examined, the corrosion values were (5.30MPa and 0.083%) and (2.530MPa and 0.015%), the values included are (5.303MPa and 0.094%) and (2.530MPa and 0.016%). Corrosion of reinforcement does not have a major impact on the mechanical strength of the reinforcement, but corrosion products provide stresses to the concrete that cannot be supported by the limited tensile strength of the concrete, leading to the formation of cracks in the reinforcement. From the data obtained and compared, the yield strength limit and tensile strength limit of the corroded sample take into account the average and percentile values for failure loads with low applications. The damage caused a corrosive effect on the mechanical properties of reinforcing steel through surface modifications affecting the ribs and fibers, whereas the coated samples from the reference area (controlled samples) showed an increase in the mean and percentage values with higher loads carrying capacity with respect to the works of ([13], [15], [15], [17]).

Exudates / resins have been proven to be effective and efficiency in protecting reinforced concrete structures exposed to corrosive media. The combined results of the controlled sample over the corroded sample showed that the controlled sample replaced the corroded sample properties with low flexural deformation, low deviation in the midspan deflection, normal yield strength, high ultimate strength, low deformation/ strain ratio. The results of the corroded samples showed high flexural strain loads, higher degree of deformation of the midspan. General experimental investigations have shown that the mechanical properties of reinforcing steel are impaired by corrosion. Coated samples exhibited low bending loads, moderate deformation, elongation ratio and maximum tensile strength. The general measured values of the tested samples clearly show that the exudates coated on reinforcing steel is a corrosion inhibitor.

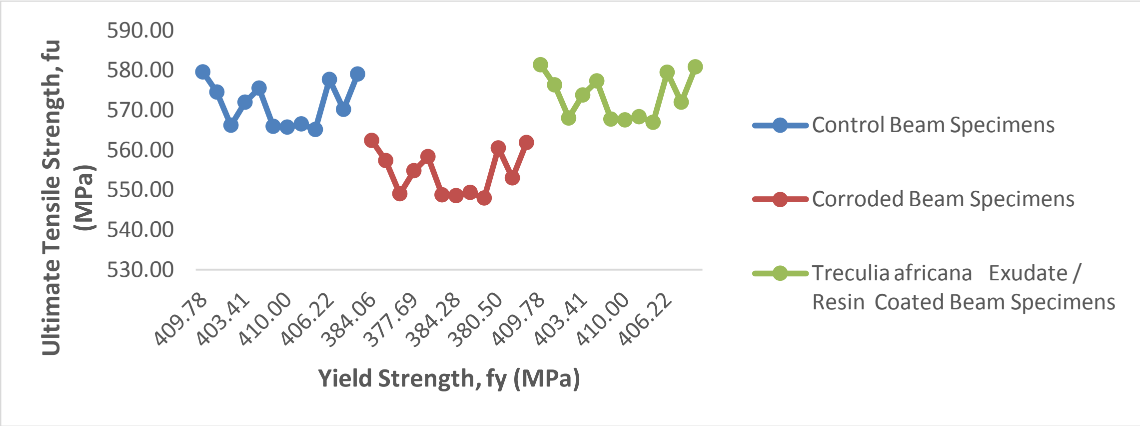


Figure 3.4: Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

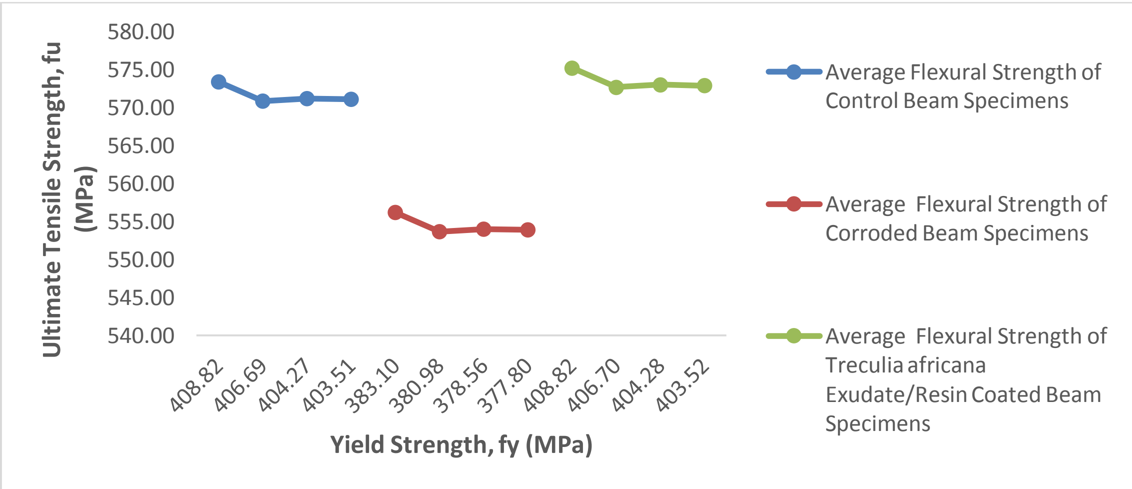


Figure 3.4A: Average Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

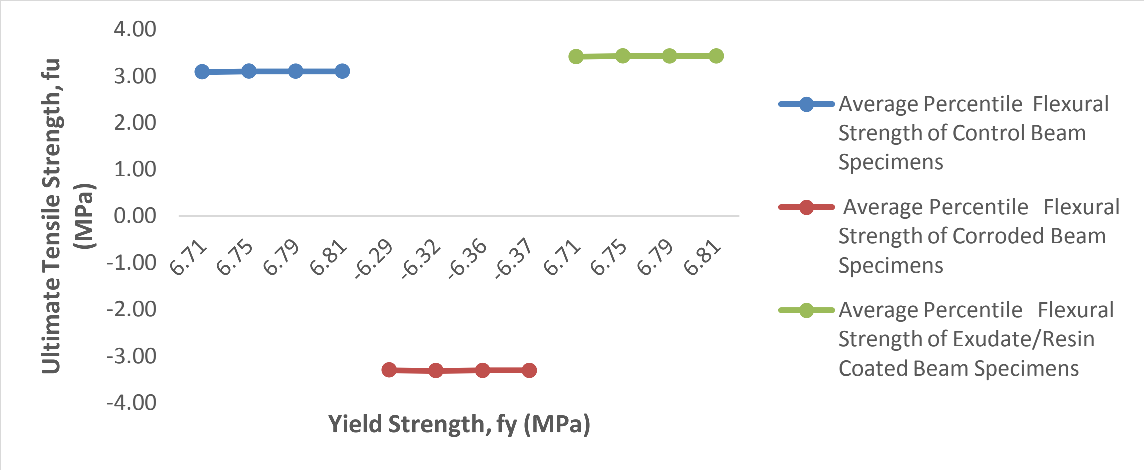


Figure 3.4B: Average percentile Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

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

However, not all reinforced concrete structures do well. There are many examples of durability problems due to corrosion of reinforcement in concrete structures, mainly due to poor quality concrete, inadequate coating of reinforcement, chlorides in concrete, or a combination thereof. This causes various forms of corrosion. Damage such as cracks and spills as well as a decrease in the load-bearing capacity of the structure. As the steel is gradually lost due to corrosion, its cross-section is reduced, which leads to a decrease in the flexural strength of the flexural elements. In addition, as corrosion progresses, the bond between the steel and the surrounding concrete weakens, which interferes with load transfer between the two materials. In order for reinforced concrete elements to conform to their dimensions, design, and service life, it is important to prevent or delay corrosion.

The results of the calculation of the average and minimum and maximum percentage values in Tables 3.4 and 3.5 obtained from Tables 3.1-3.3 the elongation ratio values of the controlled sample are 1.4025 and 1.415 (-3.4681% and -3.394 %), respectively. Corroded samples were reported to be 1.451 and 1.466 (3.190% and 3.267%), coated sample values were 1.406 and 1.419 (-3.164% and -3.091%). The comparison of the maximum calculated deformation ratio for the mean and percentile values for the controlled is -3.394% compared to the corroded and closed values of 3.267% and -3.091%, respectively. The mean differential and percentile values obtained for the control were (0.013 and 0.074%), corrosion values (0.014 and 0.078%), and closed values (0.013 and 0.073%). The results showed that the corroded samples had a higher elongation ratio due to lower damage loads and higher yields, whereas coatings had a higher percentage of load application with lower yields. Lower loads and higher yield and deformation strengths are the results 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 ([13], [15], [15], [17]). The results of the minimum and maximum elongation values (%) for controlled samples were 17.055% and 17.879% (-21.733% and -20.942%), corrosion values were 21.791% and 22.615% (27.017% and 28.327%).). %), the sample values with coverage were 16.981% and 17.804%, -22.074% and -21.27%). The maximum comparison value for the controlled sample was -20.942% compared to the corroded and coated sample of 28.327% and -21.27%, respectively. The mean differential and percentile values obtained for the controlled samples were (0.823% and 0.791%), corrosion values (0.823% and 1.31%), and masking values (0.823% and 0.804%). 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 application of exudates materials to rebar has reduced the scourge and tendency of corrosive attack to be exposed to reinforced concrete structures in heavy marine coastal areas in connection with works ([13], [15], [15], [17]).

The values of unit weight - the minimum and maximum mean and percentage values before the test, calculated in Tables 3.4 and 3.5 and obtained from Table 3.1 - 3.3 parameters per unit weight before and after corrosion testing, the controlled sample values are 1.608Kg and 1.611Kg (0 0.0676% and 0.066%), the corrosion values were 1.593Kg and 1.598Kg (0.0691% and 0.067%) and the included values were 1.562Kg and

1.564Kg (0.068% and 0.063.). %) and weight of reinforcement - the values obtained after corrosion (kg) of the average and percentile values of the minimum and maximum were checked 1.608 kg and 1.611 kg (3.618% and 4.005%), the corroded values were 1.549 kg and 1.554 kg (-4.883%) and -4.57%, the values included are 1.628 kg and 1.629 kg (4.789% and 5.133%). The difference values obtained for the mean and percentile of the controlled sample are (0.003 and 0.387%), corrosion values (0.005 kg and 0.313%), and coated values (0.001 kg and 0.344%).

The results of weight loss/weight gain of steel are the minimum and maximum values of the average and controlled percentage (100%) for the controlled sample, which leads to their combination in freshwater without any trace of corrosion attack, the values of which corroded samples were 0.044 kg and 0.044 kg (-33.05% and -32.54%, coated samples were 0.065 kg and 0.066 kg (48.235% and 49.254%).The calculated data for the maximum percentage of reinforcement beam weight before corrosion test for controlled, corroded, and coated values were 0.066%, 0.067%, and 0.063%. The maximum comparison values recorded after the corrosion test for the controlled sample remained the same, without any trace of the corrosive effect, because it was incorporated in freshwater, for the corroded and coated samples the values obtained were -4.57% and 5.133%, respectively.

The percentage of maximum weight loss/gain for corroded and coated samples was -32.54% and 49.254%, respectively. The calculated data showed a decrease in the value of the corroded sample as a result of the corrosion attack, which led to a decrease in the registered weight, whereas the coated sample showed an increase in weight compared to the reference value of the controlled sample due to the different coating thickness in the works (([13], [15], [15], [17]).

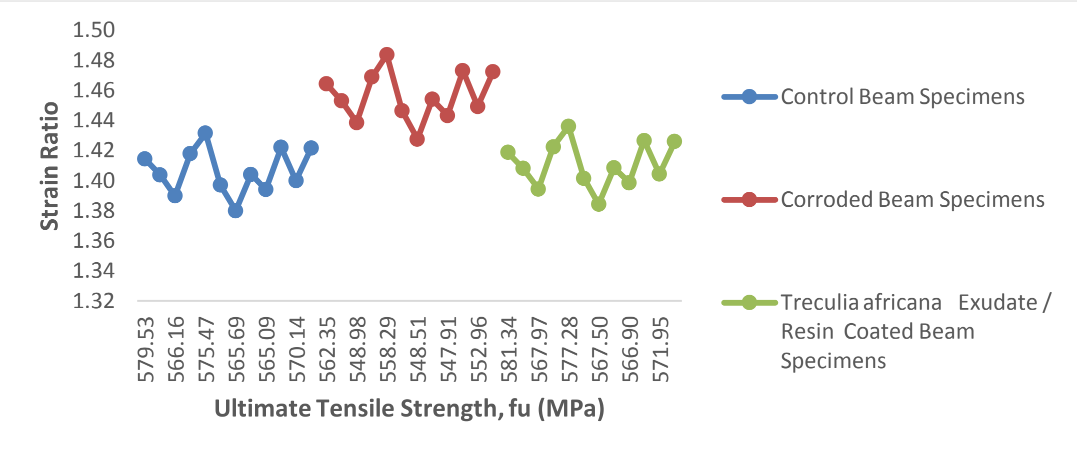


Figure 3.5: Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

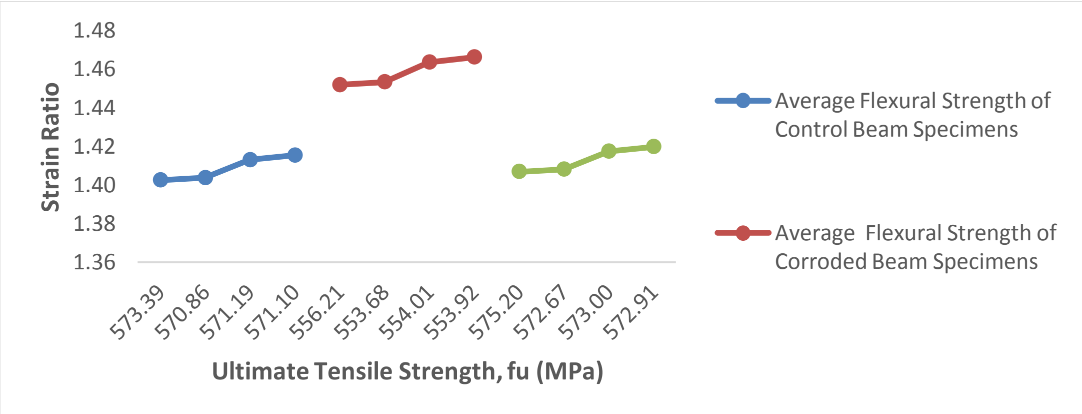


Figure 3.5A: Average Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

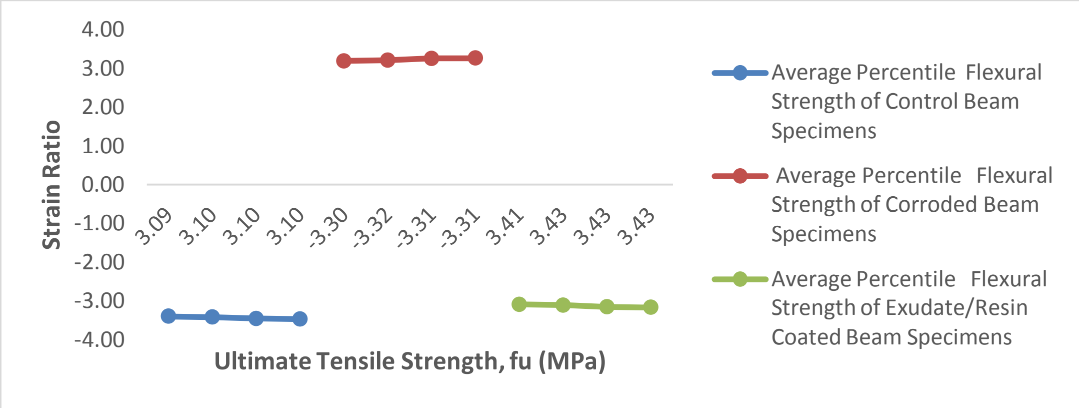


Figure 3.5B:Average Percentile Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

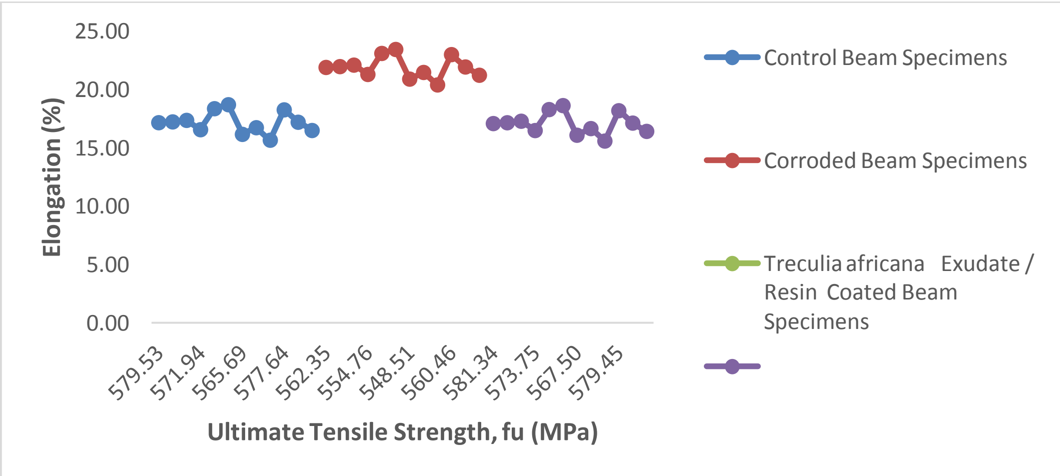


Figure 3.6: Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

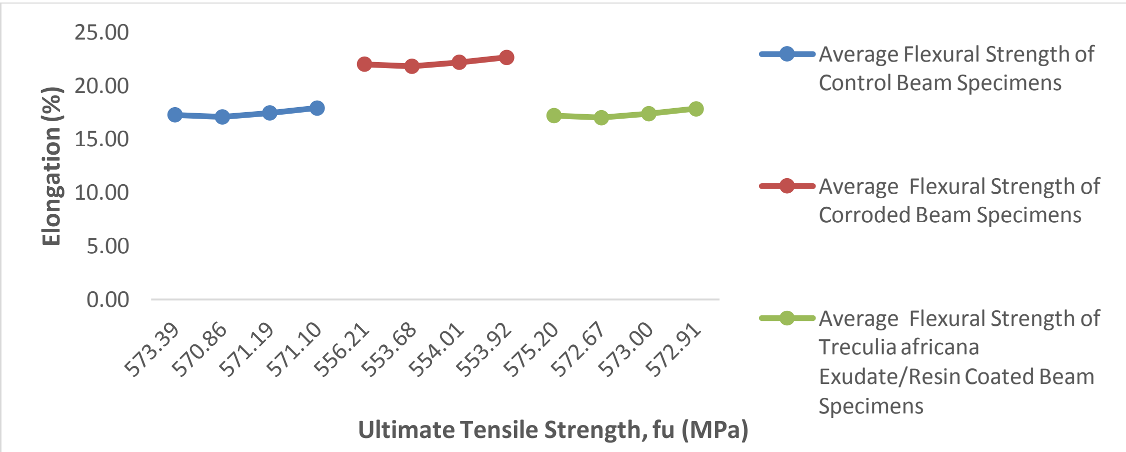


Figure 3.6A: Average Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

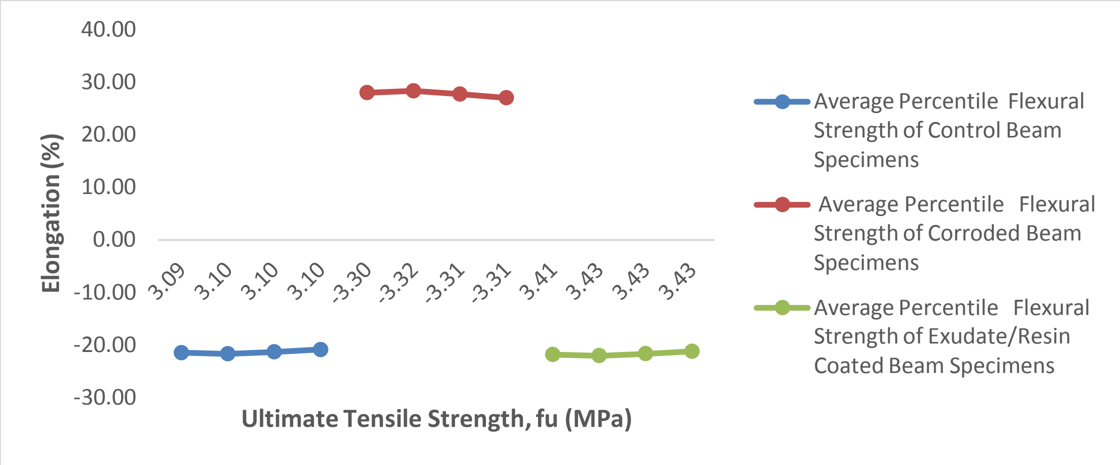
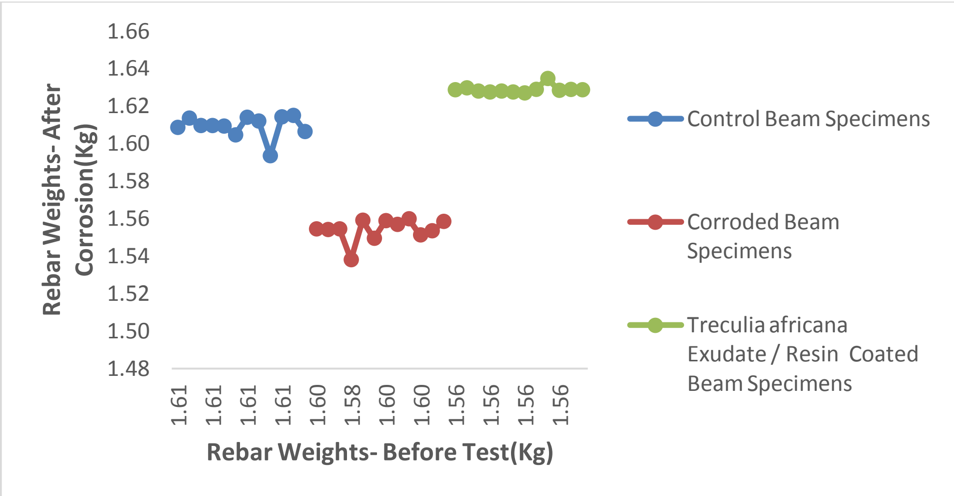


Figure 3.6B:Average Percentile Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens



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

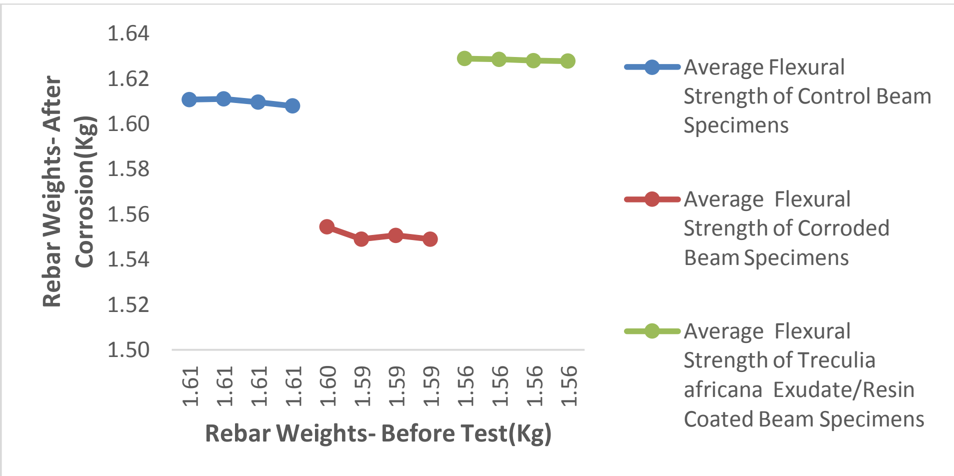


Figure 3.7A: Average Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

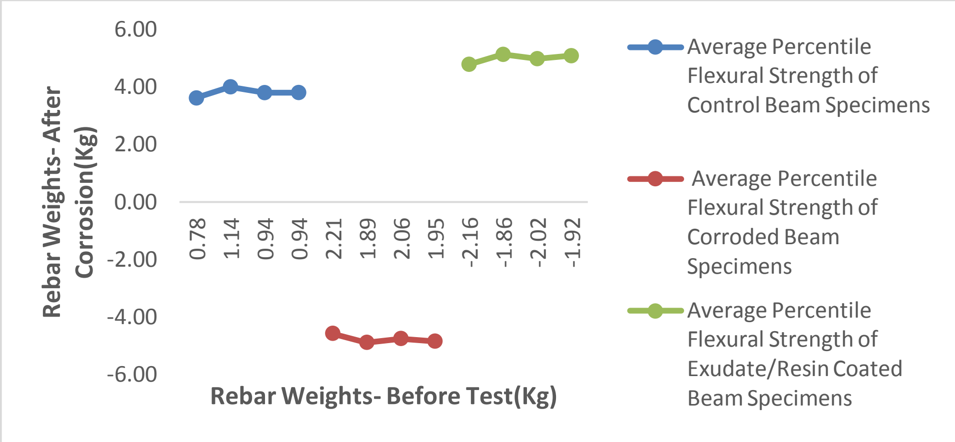


Figure 3.7B: Average Percentile Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

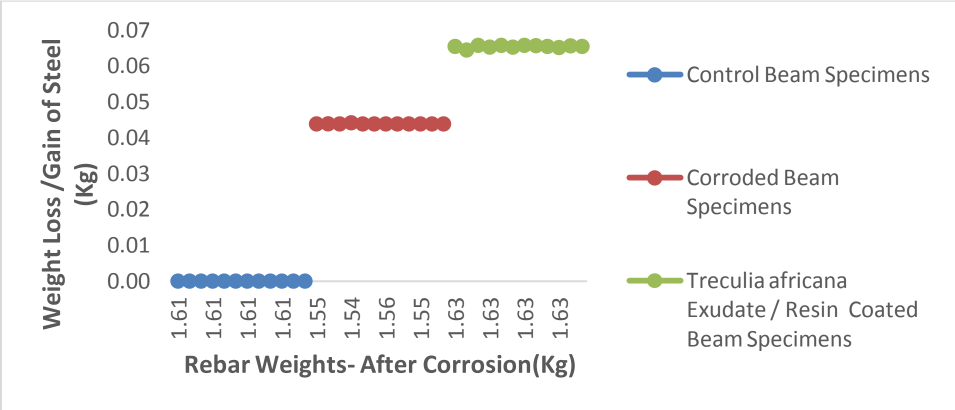


Figure 3.8: Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

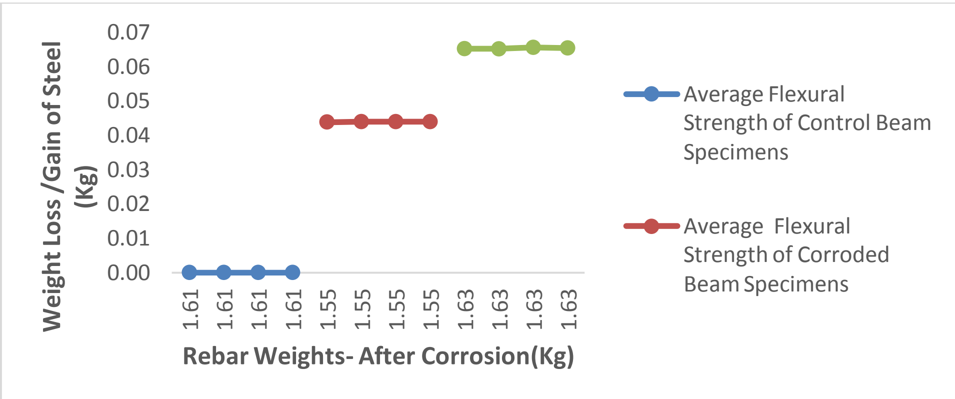


Figure 3.8A: Average Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

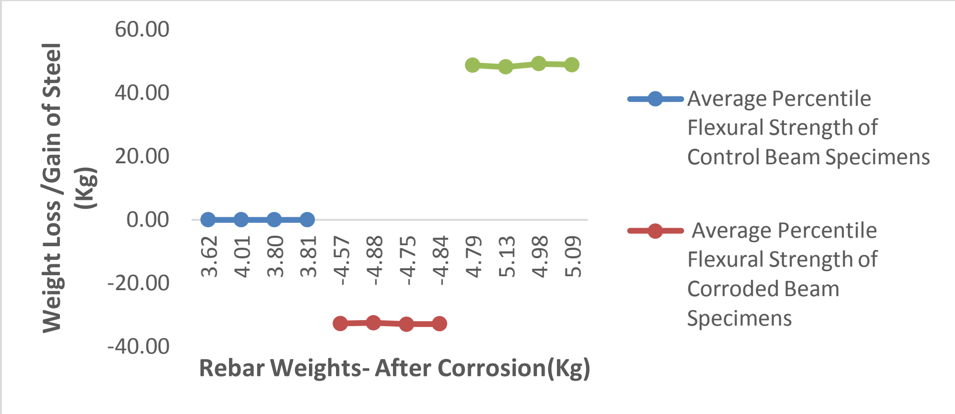


Figure 3.8B: Average Percentile Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

IV. CONCLUSION

The experimental results obtained from Table 3.1-3.5 and Figure 3.1-3.7B, the following conclusions are drawn:

1. The results showed lower elongation loads in the case of controlled and coated samples with reduced values over corroded samples with higher elongation loads and increased values compared to the reference range (controlled) and coated samples.
2. The results of the comparison of flexural strength and mid-span deflection failure loads of the corroded sample showed the effect of corrosion on the mechanical properties of reinforcing steel with scrapped ribs, high surface modification, which causes low load-bearing, failure capacity, and high deformation of reinforcing steel
3. From the results obtained, the exudate/resin of Treculia africana is proven to be a corrosion protection material in reinforced concrete structures exposed to corrosive environments, with high resistance and as a sealing membrane against the effects of corrosion.
4. 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.
5. 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
6. Exudates / resins have been proven to be effective and efficiency in protecting reinforced concrete structures exposed to corrosive media.
7. The combined results of the controlled sample over the corroded sample showed that the controlled sample replaced the corroded sample properties with low flexural deformation, low deviation in the midspan deflection, normal yield strength, high ultimate strength, low deformation/ strain ratio.
8. The results of the corroded samples showed high flexural strain loads, higher degree of deformation of the midspan.

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