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Residual Structural Ductility of Corrosion Induced Reinforcing Steel Mechanical Properties

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ABSTRACT

This study determines the role of exudates/resin against adverse attack on reinforced concrete structures exposed to severe environments due to its waterproofing nature to steel reinforcement, and resistance to surface change of coating application. The viscous exudates/resin is introduced into the concrete base after applying layers of various thicknesses directly to the steel reinforcement and assessing its usefulness as a corrosion-resistant structure exposed to the harsh and harsh environment of the territorial sea. From the flexural strength test, the maximum value was 24.42% compared to the corroded and coated sample values of -18.3% and 24.19%, respectively. 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 calculated mean differential and percentile values were checked (0.02kN and 0.06%), corrosion values (0.01kN and 0.19%) and closed values (0.01kN and 0.2%). The results showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in diameter as well as a decrease in the average value and the percentile recorded from the corroded samples, while the controlled and coated samples showed a preserved state by coating at one increase in diameter resulted in different thicknesses of the exudates/resin layer. The cross-sectional area of reinforcing steel gives different mean and percentile values for corroded values (0.15 mm and -5.21%) and coated values (0.016 mm and 7.12%). The results of the calculation of the maximum comparison value for both yield strength and ultimate tensile strength for the controlled sample are 7.34% and 3.48% of the corroded and coated values of -6.75% and -3.62% are coverage of 7 .35% and 3.8%. The strain ratio obtained of the maximum calculated value for the mean and percentile values for the controlled is -3.55% compared to the corroded and overlaid values of 3.45% and -3.25%, respectively. The mean differential and percentile values obtained for the control were (0.02 and 0.08%), corrosion values (0.02 and 0.09%) and closed values (0.02 and 0.08%). The mean differential and percentile values obtained for the controlled samples were (0.68% and 0.73%), corrosion values (0.68% and 1.41%), and closed values (0.68% and 0.72%). 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 computed data for maximum percentile values for rebar unit weights before corrosion test for controlled, corroded, and coated values are 0.5%, 0.5%, and 0.47%. 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 -6.61% and 7.15%.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.

Index Terms: Corrosion, Corrosion inhibitors, Flexural Strength, Concrete and Steel Reinforcement

1.0 INTRODUCTION

Corrosion of steel reinforcement can damage or reduce the serviceability of concrete structures in many ways. Steel reinforcement in corrosive concrete creates tensile stress in the surroundings, resulting in initial cracking. The pressure due to this volume expansion induces cracks in the surrounding concrete, which aggravates further corrosion of steel and results in total loss of interaction between steel and concrete. A solution to minimize such corrosion problems is to apply protective coating on reinforcing steel. The most popular one is the fusion bonded epoxy coating. The epoxy coating reduces the bond between the reinforcement and concrete. Bond in reinforced concrete is described by three components viz., chemical adhesion, friction and mechanical interaction between the bar ribs and the surrounding concrete. Cracks reduce the overall strength and rigidity of the concrete structure and accelerate the entry of aggressive ions, which can lead to other types of concrete degradation and result in more fractures (Mehta and Gerwick, [1]. Furthermore, corrosion products are highly porous, weak, and form around reinforcing steel, thereby reducing the strength between reinforcement and concrete (Wang and Montero, [2]. In addition, a cross sectional - area reduction of steel reinforcement has been identified, which reduces the ductility of the structure, especially when corrosion pitting occurs. Concrete produced with a low water / cement ratio has low permeability, which reduces the impeller-corrosion penetrating factors to the steel surface, such as moisture, chloride and carbon dioxide (Ahmed, [3]).

Torres-Acosta et al., [4] Investigated the loss of flexibility capacity due to the normal strength of steel cross-sectional loss Corrosion of embedded steel using 100 mm × 150 mm cross section and concrete beam designs Samples were tested in flexion under three-point loading. They The flexural loading capacity is reduced by 60% with the 10% ratio being the most important parameter Flexural loading affects the reduction, as corrosion greatly reduces the cross-sectional area Convert steel and steel from elastic to brittle behavior in a given location.

Ell-Maaddawy [5] Investigated the linear function of the combined effect of corrosion and continuous load. The test results showed the presence of continuous load Associated flexural fractures during corrosion exposure significantly reduce the time to corrosion fractures and the width of the corrosion crack is slightly increased. They found that the crack width propagates 22% faster loaded conditions, with 8.9% and 22.2% mass loss, 6.4% and 20.0% strength losses

Charles et al. [6] Investigated the effect on three different flexural residual yield strength efficiency from exudates of dacryodes eudulis, moringa oleifera lam, mangifera indica paste coated resins / exudates. The results showed corrosion potential on controlled members. Overall results showed that low load subjection was recorded in the coating members against corroded members that yielded highly on low load application with high deflection and elongation.

Yu et al. [7] Conducted a similar experiment by Zhu and Francois ([8], [9]), with the same dimensions, loading conditions and coating thickness as samples. Control beam damaged by compressed concrete crack, accompanied by a fracture of both fittings near the center of the beam. This occurs after the formation of four cracks, starting from the tension zone to the stress zone. On the other hand, the corroded reinforced concrete beam also cracked from the tension zone to the compression zone, its width increased rapidly, whereas the beam failed due to fracture of the single drawbar 75mm from the centre, which confirmed that corrosion changed the failure mode.

Al-Saidy et al. [10] Conducted a series of experimental tests on reinforced concrete beams that corroded on Flexural with and without shear reinforcement. They reported that corroded beams without shear reinforcement were very brittle, with maximum deflection reduced by about 60%. This is due to the premature dissolution of the longitudinal reinforcement joints. Corroded beams with shear reinforcement have a certain decrease in flexural strength, but are more prone to plastic failure. They reported that corroded beams with masses of 5% and 7.5% had maximum deviation reductions of about 1% and 25%, respectively.

El Maaddawy et al. [11] Performed a series of experimental tests on virgin and corroded RC carriers. Specimens are corroded using an accelerated corrosion process and constant loading to indicate the working load of the structure. The constant load on the beam causes flexural cracking, which in turn causes accelerated corrosion-related material degradation. They reported that the corrosion rate caused by cracking of the concrete surface in the loaded beams has increased by about 22% compared to the unloaded beams. They found that there was a linear relationship between the loss of cross-sectional area of the tensile reinforcement and the residual flexural strength of the corroded reinforced concrete beam. However, corrosion has a greater impact on ductility corrosion-damaged reinforced concrete beams with mass loss coefficients greater than 15%, where deep depressions are formed in corroded reinforcement.

Charles et al. [12] Experimented on the effects of corrosion and inhibitors (inorganic source) extract Resins / exudates from tree bark on residual flexibility strength of submerged concrete beam members Corrosion accelerated the media for 90 days to ensure possible changes in the surface conditions of the probe Samples. Flexural failure load and ultimate tensile strength and midspan deflection have been suggested to decrease of corroded samples over the controlled and coated samples with higher load application to failure, low percentile midspan deflection and elongation.

Castel et al. [13] Conducted experimental tests on a 14-year-old corroded RC carrier flexible load. They found that about 20% corrosion resulted in a decrease in flexural stiffness of about 35% and approximately 70% reduction in ductility of corroded reinforced concrete beams. They found that the residual flexural strength was corroded.Reinforced concrete beams are primarily a function of the mass loss of tensile reinforcement and are not significantly affected by losses on the strength of the connection.

Branly et al., [14] Researched work was aimed at preventing the formation of surface films covering the reinforcing steel and the surface. The direct use of exudates / resins extract of inorganic of eco-friendly coated to reinforcing steel with varying thicknesses, embedded into concrete member and pooled into destructive media for rapid corrosion process and assess the mechanical properties of the steel reinforcement for a period of 150 days. The results of corroded members showed high yield characteristics with low flexural failure load, high elongation and midspan deflection. The general results of corroded members showed a reduction in the diameter cross section and weight loss mechanical properties of reinforcing steel.

Gilbert et al**.** [15] Researched work aimed at reducing the corrosion reduction of steel reinforcements in the brine area by introducing exudates/resins of coated Invincia gabonensis to reinforceing steel. Investigated the effect of corrosion on the concrete beam and the coated and non-coated members. Detailed test results have shown potential corrosion resistance with coated members on mechanical properties that strengthen the effects of weight loss, cracking, spalling and weight loss. These features led to failure of variable load and high retention capacity with low average load, high levels of stresses, extension, and midspan deflection on the corroded beams. Nwaobakata et al., [16] Investigated the performance of natural products from the Garcinia kola extracts (exudates/resins) as protective membrane to strengthen reinforcing steel embedded in concrete members that are exposed to corrosive harsh environment for 150days and assessed mechanical modification of steel properties. Obtained results for the corroded members showed high yield strength with low load, high mid-span deflection, and elongation. Indicators have shown that coated members have signs of corrosion resistance.

Kanee et al. [17] Investigate the effect of reinforcing steel with the introduction of milicia excelsa exudates/resins for surface modifications and mechanical properties degradation of steel in concrete structures. The corrosion acceleration process was 150 days and the corrosion potential determined. The overall experimental results have shown that the corrosion properties of the spalling and fractures in coated members indicate a lower flexibility failure load; Midspan deflection, extension, and ultimate yield, high flexibility failure load required, and compared to corroded members.

2.1 Materials

2.1.1 Aggregates

The fine and coarse collection was purchased. Both meet the requirements of BS882 [18]

2.1.2 Cement

Limestone Cement Grade 42.5 is the most common type of cement in the Nigerian market. It was used for all concrete mixes in this test. Cement meets the requirements of BS6 196-6 [19]

2.1.3 Water

The water samples were clean and free of impurities. The freshwater used was obtained from the Department of Civil Engineering Laboratory, Kenpoly, Bori, Rivers State. Water meets the requirements of BS 3148[20]

2.1.4 Structural steel reinforcement

Reinforcements are obtained directly from the market at Port Harcourt. Confirmed on BS4449: 2005 + A3 [21]

2.1.5 Corrosion Inhibitors (Resins / Exudates) Chrysophyllum albidum

The grayish-brown and whitish gummy exudates were obtained from the tree bark. They are abundantly seen in the bushes of Ekpeye land in Ahoada West / Ahoada East Local Government of Rivers State

2.2 Methods

This study examines the use of exudates/resins extracts from tree trunks. The viscous exudate/resin was applied directly to the steel reinforcement by a coating of different thicknesses and embedded in the concrete beam, and its application as corrosion resistant.

The available and abundantly local materials were studies to mimic the control of the negatively impactive corrosion attacks on steel reinforcement embedded in concrete structures in marine environments with high salinity (sodium chloride). Samples of concrete beams of 175 mm x 175 mm x 750 mm, thickness, width, and length were embedded with 4 numbers of reinforcing steel of 16mm diameter and cured for 28 days for initial setting and final setting, transported to pooling tank for corrosion acceleration stimulation process of 5% sodium chloride (NaCl) to water for 360 days. The process of corrosion exposure is naturally a long-term process and takes many years to fully manifest, but the introduction of sodium chloride (NaCl) accelerates and stimulates the corrosion rate achievement within shorter-term and this represents the harsh and severe coastal marine region. This study determines the role of exudate/resin against adverse attack on reinforced concrete structures exposed to severe environments due to its waterproofing nature to steel reinforcement, and resistance to surface change of coating application.

2.2.1 Preparation and Casting of Model Concrete Beams

The standard method of concrete mixing ratio was followed, which was set manually by material weight. The mix ratio of concrete is 1: 2: 4, the water-cement ratio is 0.65. Manual mixing was applied to the edges of the clean concrete, and the mixing was inspected and the complete mixing design was gradually added with water to obtain the standard designed concrete beam achieved by adding concrete cement, water, and aggregate. The test beam was cast in a 175 mm x 175 mm x 750 mm steel mold, compressed in air, and 4 numbers of 16 mm diameter bar embedded. Samples were de-molded after 72 hours and treated under the standard procedure for 28 days and samples were cured at room temperature for 90 days, 180 days, 270 days, and 360 days for rapid corrosion testing process, and observations were recorded to correspond 3 months interval testings for first crack appearance and behavior status.

2.2.2 Flexure Testing of Beam Specimens

According to BS EN 12390-2 [22], the Universal Testing Machine was deplored for flexibility testing and a total of 36 beam models were tested. After initial 28 days of treatment, 12 beams (non-coated) were controlled to prevent corrosion-related reinforcement, while 24 beam samples of non-coated and exudate/resin coated samples contained in 5% sodium chloride (NaCl) for 360days. Surface changes and mechanical properties were investigated on non-coated and coated samples at 3-month intervals of 90 days, 180 days, 270 days, and 360 days, respectively. Flexibility was tested on an Intron Universal testing machine with a capacity of 100KN and samples were subjected to failure based on laid down specifications. The obtained test results of all samples were computerized and digitally recorded with all values related to cracking and flexural strength load, midspan deflection, and pre-test measured rebar diameter, re-diameter-after-cross section reduction/increase, yield strength, final tensile strength. Strength, strain rate, elongation, re-usable weights - before testing, re-weights- after corrosion, and weight loss/steel increase were all observed and recorded.

Table 3.1 : Flexural Strength of Beam Specimens (Controlled

Samples	Samples A			Samples B			Samples C			Samples D		
Items	CA	CA1	CA2	CA3	CA4	CA5	CA6	CA7	CA8	CA9	CA10	CA11
Flexural Strength Load (KN)	88.66	87.85	87.37	83.53	87.79	85.81	88.61	87.93	88.86	88.80	86.81	87.90
Midspan Deflection (mm)	7.39	7.47	8.07	8.18	7.27	8.21	7.30	7.47	7.27	7.35	7.35	9.51

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)	16.00	15.99	15.97	16.00	15.99	15.94	16.00	15.98	15.90	15.97	15.96	15.98
Rebar Diamete at 28 days(mm)	16.00	15.99	15.97	16.00	15.99	15.94	16.00	15.98	15.90	15.97	15.96	15.98
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)	407.70	407.21	405.31	401.33	399.95	403.03	407.92	401.44	403.32	404.14	405.23	405.25
Ultimate Tensile Strength, fu (MPa)	581.35	576.30	567.98	573.76	577.29	567.71	567.51	568.31	566.91	579.46	571.96	580.82
Strain Ratio	1.43	1.42	1.40	1.43	1.44	1.41	1.39	1.42	1.41	1.43	1.41	1.43
Elongation (%)	18.48	18.55	18.68	17.88	19.68	20.02	17.48	18.05	16.98	19.58	18.52	17.81
Rebar Weights- Before Test	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.58	1.60	1.61	1.60
Rebar Weights- After at 28 days (Kg)	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.58	1.60	1.61	1.60
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)

	CA1A	CA1B	CA1C	CA1D	CA1E	CA1F	CA1G	CA1H	CA1I	CA1J	CA1K	CA1L
Flexural Strength Load (KN)	71.35	70.69	70.06	70.04	70.48	69.59	71.30	70.62	71.55	68.50	69.00	66.22
Midspan Deflection (mm)	11.70	11.78	12.38	12.49	11.58	12.52	11.61	11.78	11.58	11.66	11.66	13.82
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)	1.56	1.56	1.56	1.56	1.56	1.55	1.56	1.55	1.54	1.56	1.56	1.55
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)	380.23	379.74	377.84	373.86	372.48	375.56	380.45	373.97	375.85	376.67	377.76	377.78
Ultimate Tensile Strength, fu (MPa)	562.27	557.22	548.90	554.68	558.21	548.63	548.43	549.23	547.83	560.38	552.88	561.74
Strain Ratio	1.48	1.47	1.45	1.48	1.50	1.46	1.44	1.47	1.46	1.49	1.46	1.49
Elongation (%)	25.76	25.83	25.96	25.16	26.96	27.30	24.76	25.33	24.26	26.86	25.80	25.09
Rebar Weights- Before Test(Kg)	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.58	1.57	1.57	1.57
Rebar Weights- After Corrosion(Kg)	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	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 Chrysophyllum albidum Exudate / resin Coated Beam Specimens

	CA1A1	CA1B2	CA1C3	CA1D4	CA1E5	CA1F6	CA1G7	CA1H8	CA1I9	CA1J10	CA1K11	CA1L12
	150μm (Exudate/Resin) coated			300μm (Exudate/Resin) coated			450μm (Exudate/Resin) coated			600μm (Exudate/Resin) coated		
Flexural Strength Load (KN)	88.66	87.35	87.37	83.54	87.79	85.81	88.61	87.93	88.86	88.00	86.31	86.90
Midspan Deflection (mm)	7.45	7.53	8.13	8.24	7.33	8.27	7.36	7.53	7.33	7.41	7.41	9.57

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)	16.00	15.99	15.97	16.00	15.99	15.94	16.00	15.98	15.90	15.97	15.96	15.98
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)	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Yield Strength, fy (MPa)	407.70	407.21	405.31	401.33	399.95	403.03	407.92	401.44	403.32	404.14	405.23	405.25
Ultimate Tensile Strength, fu (MPa)	583.15	578.10	569.78	575.56	579.09	569.51	569.31	570.11	568.71	581.26	573.76	582.62
Strain Ratio	1.43	1.42	1.41	1.43	1.45	1.41	1.40	1.42	1.41	1.44	1.42	1.44
Elongation (%)	18.41	18.48	18.61	17.81	19.61	19.95	17.41	17.98	16.91	19.51	18.45	17.74
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 Exudates/Resin Coated (specimens)

	Average Flexural Strength of Control Beam Specimens				Average Flexural Strength of Corroded Beam Specimens				Average Flexural Strength of Exudate/Resin Coated Beam			
Flexural Strength Load (KN)	87.96	85.71	87.40	87.45	70.70	70.03	70.45	70.50	87.80	85.72	87.41	87.45
Midspan Deflection (mm)	7.64	7.88	7.59	7.66	11.95	12.20	11.90	11.97	7.71	7.95	7.66	7.72
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)	15.99	15.97	15.97	15.97	15.83	15.81	15.85	15.95	15.99	15.97	15.97	15.97
Rebar Diameter- After Corrosion(mm)	15.99	15.97	15.97	15.97	1.56	1.56	1.56	1.55	16.05	16.05	16.05	16.04
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	14.27	14.25	14.30	14.40	0.07	0.07	0.07	0.07
Yield Strength, fy (MPa)	406.74	401.43	403.63	404.13	379.27	373.97	376.16	376.66	406.74	401.44	403.63	404.13
Ultimate Tensile Strength, fu (MPa)	575.21	572.92	570.83	567.84	556.13	553.84	551.76	548.77	577.01	574.72	572.64	569.64
Strain Ratio	1.41	1.43	1.41	1.41	1.47	1.48	1.47	1.46	1.42	1.43	1.42	1.41
Elongation (%)	18.57	19.20	19.06	18.52	25.85	26.47	26.34	25.79	18.50	19.12	18.99	18.44
Rebar Weights- Before Test(Kg)	1.60	1.60	1.60	1.60	1.57	1.57	1.57	1.57	1.56	1.56	1.56	1.56
Rebar Weights- After Corrosion(Kg)	1.62	1.61	1.61	1.60	1.52	1.52	1.52	1.52	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)	24.42	22.39	24.06	24.04	-19.48	-18.30	-19.40	-19.39	24.19	22.40	24.07	24.05
Midspan Deflection (mm)	-36.09	-35.37	-36.24	-36.04	55.06	53.38	55.43	54.95	-35.51	-34.80	-35.66	-35.46

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)	0.399	0.379	0.385	0.379	0.371	0.390	0.359	0.387	0.386	0.390	0.386	0.388
Rebar Diameter- After Corrosion(mm	0.68	0.66	0.62	0.65	-0.92	-1.11	-1.08	-0.92	0.91	1.10	1.07	0.90
Cross- sectional Area Reduction/Increase (Diameter, mm)	0	0	0	0	-11.84	-14.63	-14.7	-17.05	13.24	16.94	17.04	20.36
Yield Strength, fy (MPa)	7.24	7.34	7.30	7.29	-6.75	-6.84	-6.81	-6.80	7.24	7.35	7.30	7.29
Ultimate Tensile Strength, fu (MPa)	3.43	3.44	3.46	3.48	-3.62	-3.63	-3.65	-3.67	3.75	3.77	3.78	3.80
Strain Ratio	-3.55	-3.63	-3.58	-3.56	3.36	3.45	3.39	3.36	-3.25	-3.33	-3.28	-3.25
Elongation (%)	-28.15	-27.48	-27.62	-28.21	39.73	38.44	38.71	39.85	-28.43	-27.77	-27.91	-28.49
Rebar Weights- Before Test(Kg)	1.91	1.80	1.92	1.95	0.47	0.50	0.50	0.50	-0.47	-0.49	-0.49	-0.49
Rebar Weights- After Corrosion(Kg)	5.33	5.15	5.28	5.33	-6.67	-6.61	-6.63	-6.65	7.15	7.08	7.10	7.12
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	-24.14	-23.65	-23.54	-23.10	31.82	30.98	30.80	30.04

3.1 Results and Discussion 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 forces has been studied by a large number of 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 with high salinity in the coastal area of the Niger Delta, Nigeria, the application of Chrysophyllum albidum exudates extract/resin from wood sources with environmentally friendly effects was applied directly to the embedded arthropods and evaluated as effective as a corrosion inhibitor.

The formation of corrosion products on the surface of the bars can affect the fracture behavior and the failure strength of flexural elements for two reasons: on the one hand, due to reduce bar retention due to opening longitudinal cracks in the reinforcement and, on the other hand, due to significant changes in the boundary between steel and concrete due to changes in the surface quality of reinforcing steel. Changes in surface structure caused by corrosion are initially characterized by changes in surface roughness, then by the formation of an intermediate layer of corrosion products between the concrete and steel which is less firmly adherent, and finally by localized surface damage to the reinforcing bar profile.

The experimental data for flexural tests on concrete beam samples are shown in Tables 3.1, 3.2, and 3.3, at 3.4 the mean and percentile values are summarized in 3.5, and the results are shown graphically in Figures 3.1 - 3.7b. The average values of the minimum and maximum percentile calculated are controlled sample of 85.7kN and 87.96kN (22.39% and 24.42 %), the corroded values of the samples were 70.03kN and 70.7kN (-19.48% and -18.3%), and the samples coated with exudates/resin were 85.724kN and 87.8kN (22.4 % and 24.19%). From the flexural strength test, the maximum value was 24.42% compared to the corroded and coated sample values of -18.3% and 24.19%, respectively. The average differential and percentile range checked are (2.25kN and 2.03%), corroded (0.67kN and 1.18%), coated (2.08kN and 1.79%).

The results show that the reference percentile of the controlled sample was placed in freshwater according to BS 3148 [20] and no corrosion effect was observed and was therefore used as a reference value for controlled and coated in a corrosive environment as described in the test program. Corroded specimens fail with a lower load, whereas coated specimens have a higher load failure. 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 yields and the percentile values of midspan deflection loads recorded on the controlled material were 7.59kN and 7.88kN (-36.24% and -35.37%), corroded samples were 11.9kN and 12.2kN (53.38% and 55.43%) and coated samples are 7.66kN and 7.95kN (-35.66% and -34.8%). The comparison results show that the maximum value obtained for the failed state is -35.37% compared to 55.43% controlled corrosion and -34.8% closed. The recorded mean and percentile difference values were monitored (0.29kN and 0.87%), corroded (0.3kN and 2.05%) and coated (0.29kN and 0.86%). 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 comparison results obtained for the flexural strength and deformation load in the center of the corroded sample show the effect of corrosion on the mechanical properties of reinforcing steel with detached ribs, high surface modification, which causes low load-bearing capacity and high midspan deflection, see (Charles et al.[12]; Nwabakata et al. [16]; Kanee et al.,[17]; Gilbert et al. [15]). From the results obtained, Chrysophyllum albidum exudates/resin proved to be a corrosion protective material in reinforced concrete structures exposed to corrosive environments, with high resistance and waterproof membranes against the effects of corrosion.

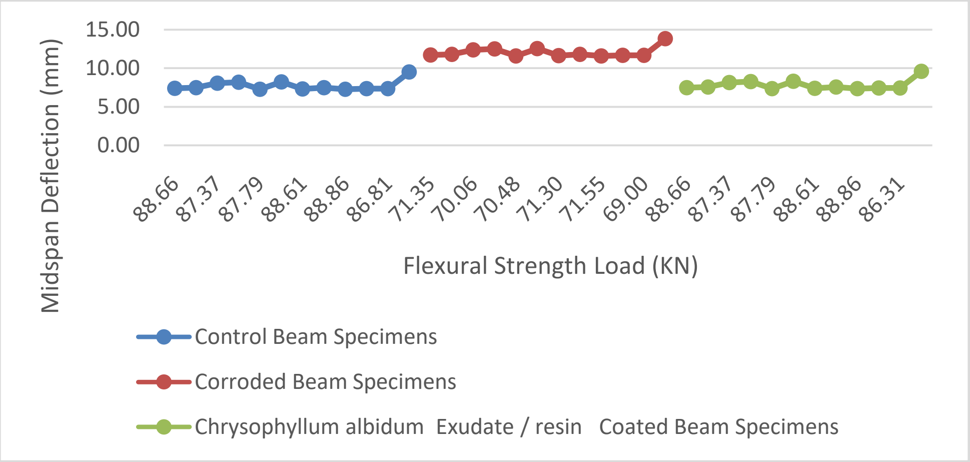


Figure 3.1: Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

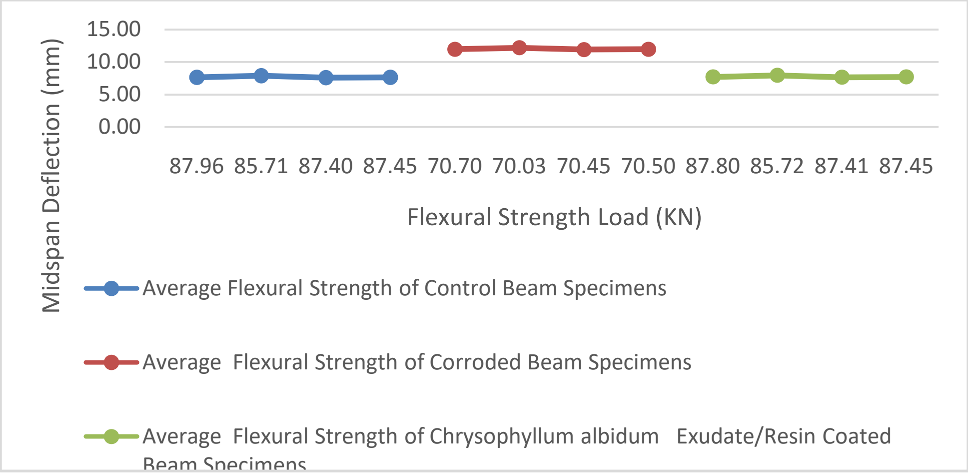


Figure 3.1A: Average Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

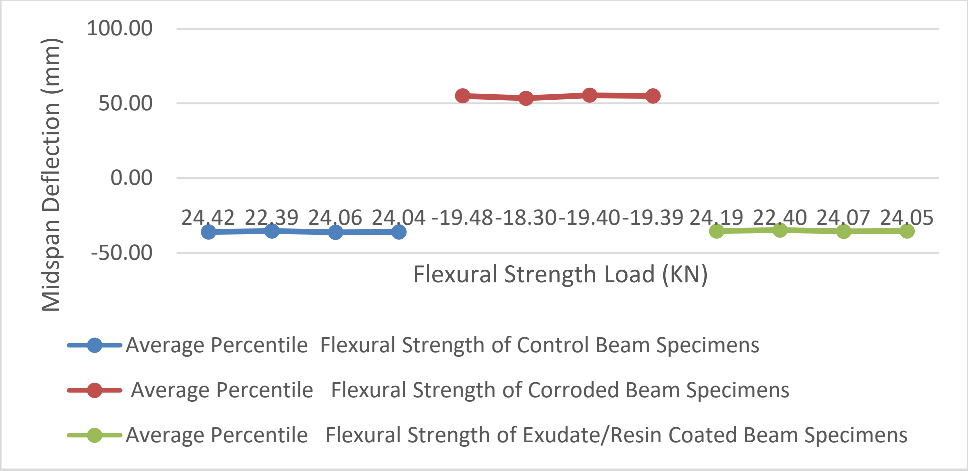


Figure 3.1B: Average Percentile Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

3.3 Results of Measured Rebar Diameter Before and After Corrosion Test

Corrosion of steel in concrete can cause premature damage and defects in reinforced concrete structures. It can also lead to a significant reduction in the safety and efficiency of concrete structures. Corrosion of reinforcement can have serious consequences on the mechanical properties of reinforced concrete (Palsson and Mirza, [23], including loss of load-bearing capacity due to reduced cross-sectional area of reinforcing steel and loss of load-bearing capacity resulting due to the destruction of the concrete-steel interface.

The results of the minimum and maximum mean and percentile values for the nominal diameter of the value are 16 mm (100%) for all common standards. The fitting diameters measured before testing for the controlled sample were 15.97 mm and 15.99 mm (0.379% and 0.399%), which corroded were 15.81 mm and 15.95 mm (0.359% and 0.39%), and the coated were 15.97 mm and 15.99 mm (0.386% and 0.39%). The results obtained indicate that the diameter of the reinforcing steel varies in the range of minutes due to the production of reinforcement by different companies, the production mold used produces an average value and the percentile difference is not significant.

The average values and the minimum and maximum percentiles of the rebar diameter - after the controlled corrosion test were 15.97 mm and 15.99 mm (0.62% and 0.68%), the corroded sample values were 1.55 mm and 1.56 mm (-1.11% and -0.92%), coated sample values were 16.04 mm and 16.05 mm (0.9% and 1.1%). The comparison results obtained during and after the corrosion test the maximum value of the anchor diameter was controlled by 0.68% in relation to being corroded and -0.92% and the sample with a coating of 1.1%. The calculated mean differential and percentile values were checked (0.02kN and 0.06%), corrosion values (0.01kN and 0.19%) and closed values (0.01kN and 0.2%). The results showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in diameter as well as a decrease in the average value and the percentile recorded from the corroded samples, while the controlled and coated samples showed a preserved state by coating at one increase in diameter resulted in different thicknesses of the exudates/resin layer. The use of exudates/resin protects the reinforcing steel from severe corrosion damage. The mean and percentile values determined after and before the correction test 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 loss of ductility due to uneven distribution of cross-sectional area along with the reinforcement and stress concentration due to sudden changes in geometry.

The minimum and maximum "decrease/increase in cross-sectional area (diameter)" of the controlled sample was 0.00 mm, which indicates for all samples (100%) that the corroded samples were -0.089 mm and -0.072 mm 05% and -11.84%) and the coated samples were 0.07 mm and 0.07 mm (13.24% and 20.36%). The cross-sectional area of reinforcing steel gives different mean and percentile values for corroded values (0.15 mm and -5.21%) and coated values (0.016 mm and 7.12%).

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, see (Charles et al.[12]; Nwabakata et al. [16]; Kanee et al.,[17]; Gilbert et al. [15]).

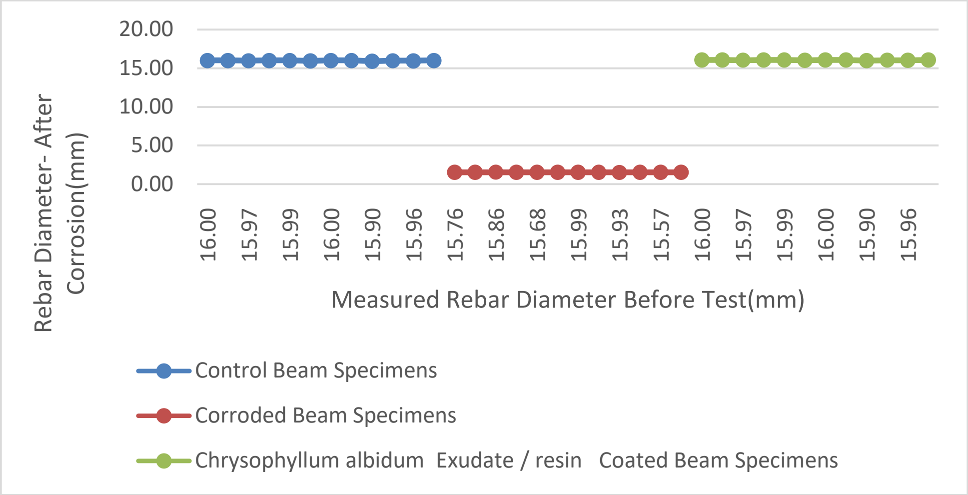


Figure 3.2: Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

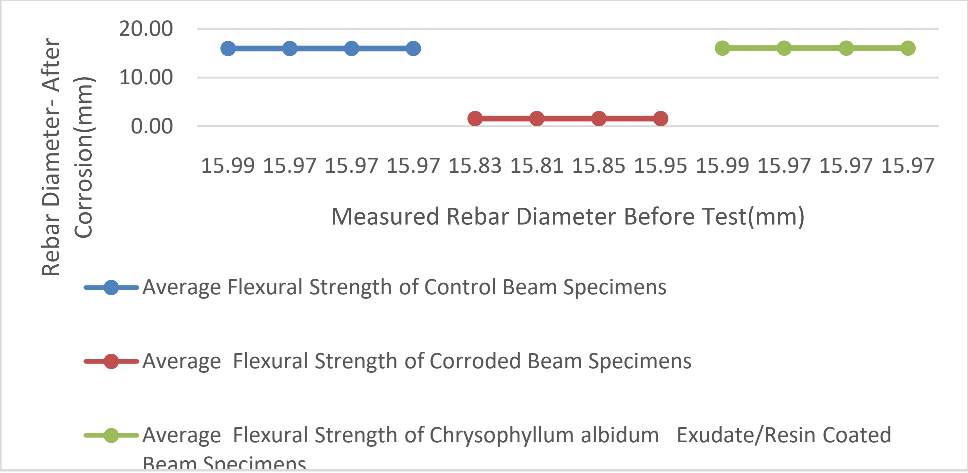


Figure 3.2A: Average Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

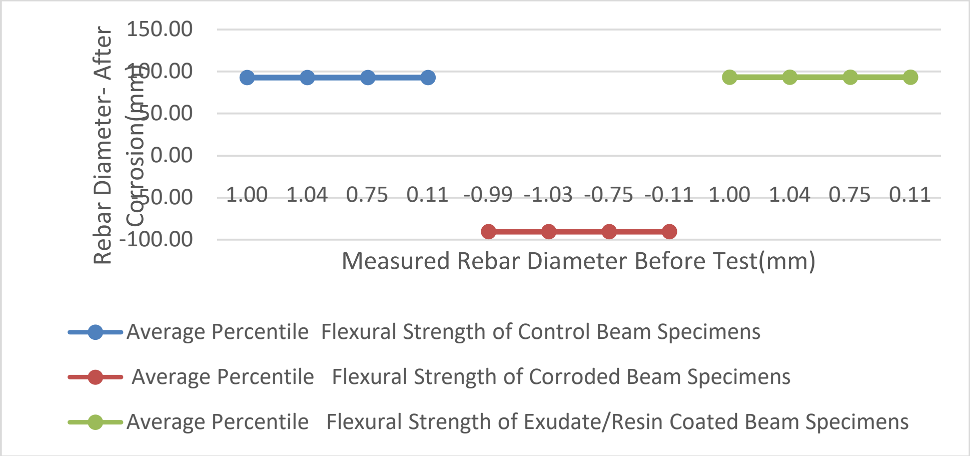


Figure 3.2B: Average Percentile Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

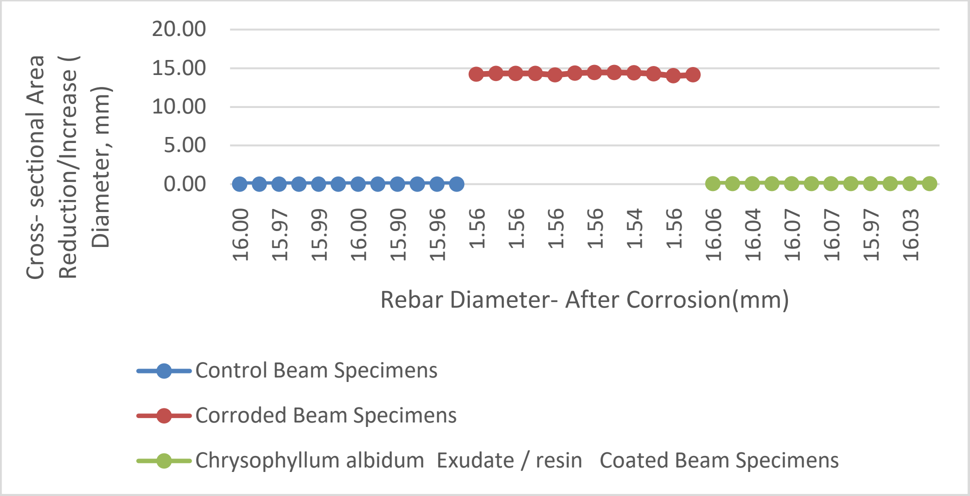


Figure 3.3: Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase (Diameter)

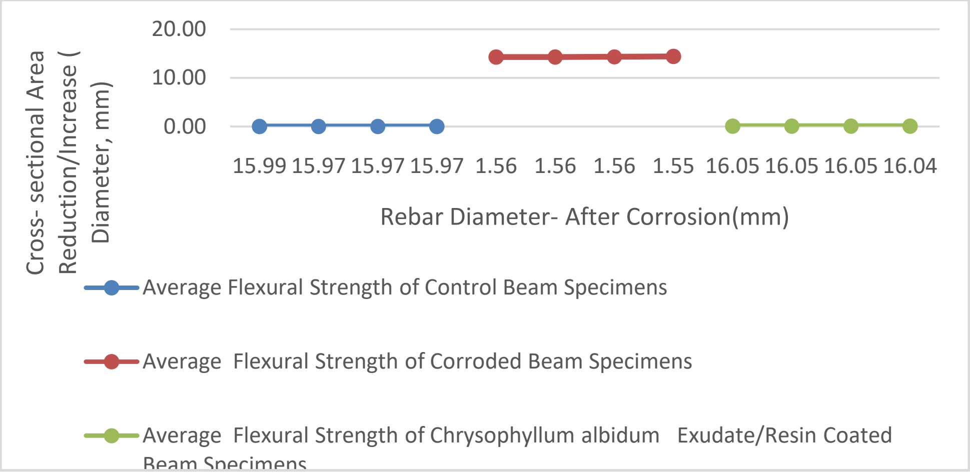


Figure 3.3A: Average Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase(Diameter)

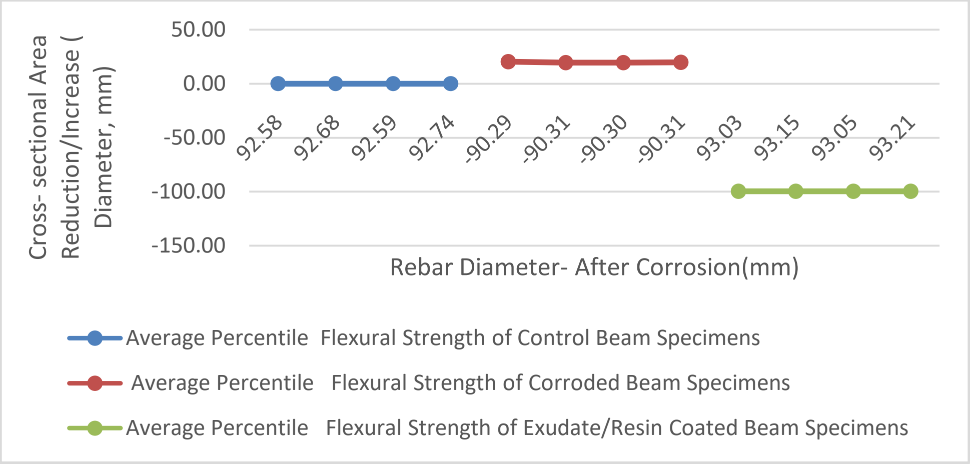


Figure 3.3B: Average Percentile Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase(Diameter)

3.4 Results of Ultimate Tensile Strength and Yield Strength

Chloride ions in the environment and in the concrete raw materials penetrate around the steel and destroy the passive film, causing corrosion of the steel bar and the effective cross-section of the steel bar. This damage causes changes in the macro-productivity and microstructure of the steel.

Weakening of the strength of steel bars and cracking during expansion after corrosion leads to a decrease in the bonding properties between steel and concrete bars that reduced the load-bearing capacity of the structural mechanical properties of steel bars which corrode after high-temperature exhibit different damping laws at increasing temperature.

The results of the calculation of the average and minimum and maximum percentile values in Tables 3.4 and 3.5 are obtained from Tables 3.1-3.3 on the yield strength of the controlled sample is 401.43MPa and 406.74MPa (7.24% and 7.34%), the corroded sample had 373.97MPa and 379.27MPa (-6.84% and -6.75%), and the coated sample was 401.44MPa and 406.74MPa (7.24% and 7.35% respectively).

The ultimate tensile strength values of controlled samples were 567.84MPa and 575.21MPa (3.43% and 3.48%), corroded samples were 548.77MPa and 556.13MPa (-3.67% and -3.62 respectively). %) and coated samples were 569.64MPa and 577.01MPa (3.75% and 3.8%).

The results of the calculation of the maximum comparison value for both yield strength and ultimate tensile strength for the controlled sample are 7.34% and 3.48% of the corroded and coated values of -6.75% and -3.62% are coverage of 7 .35% and 3.8%. Differently calculated mean and percentile values of yield point and maximum tensile strength (5.31MPa and 0.1%) and (7.37MPa and 0.05%) were examined, the corrosion value was (5.3MPa and 0.09%) and (7.36MPa and 0.05%), the values included are (5.3MPa and 0.11%) and (7.37MPa and 0.05%). The Effect of different degrees of corrosion on nominal yield strength, nominal ultimate strength, equivalent tensile strength, equivalent failure strength, elongation, and tensile gradient reinforcing force resulting from environmental effects of chloride salts (Xu Gang, [24]). 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 due to surface modifications affecting the ribs and fibers, whereas the coated samples recorded an increase in the mean values and percentiles of the reference range (controlled samples) under higher loads. Product Carrying Capacity see (Charles et al.[12]; Nwabakata et al. [16]; Kanee et al.,[17]; Gilbert et al. [15]). Exudates/resins have been proven to be effective and effective in protecting reinforced concrete structures exposed to corrosive media.

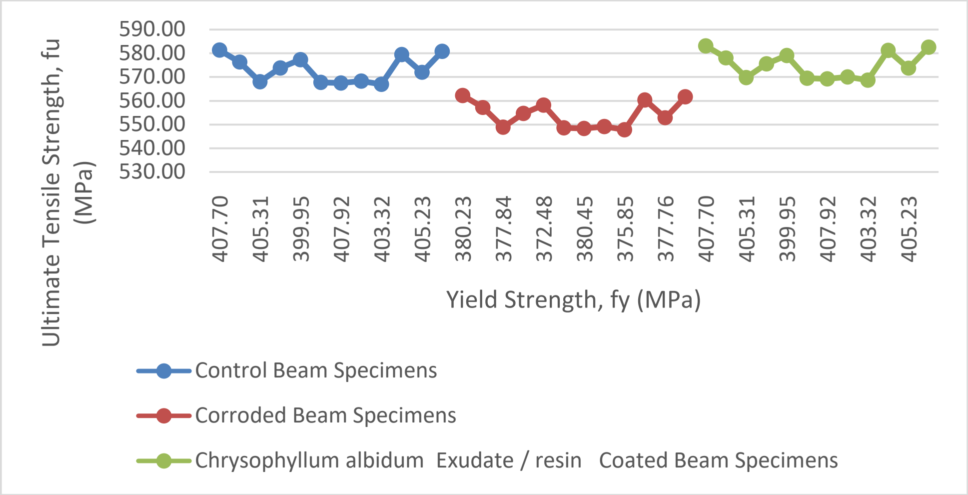


Figure 3.4: Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

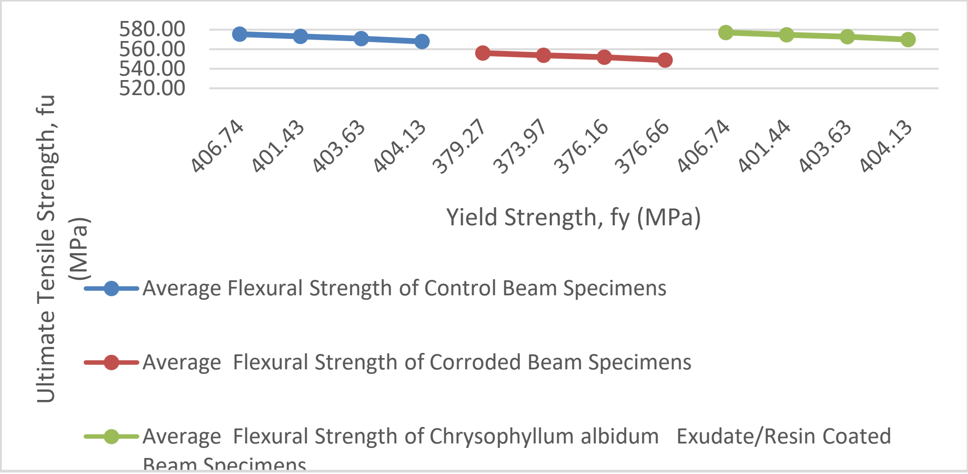


Figure 3.4A: Average Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

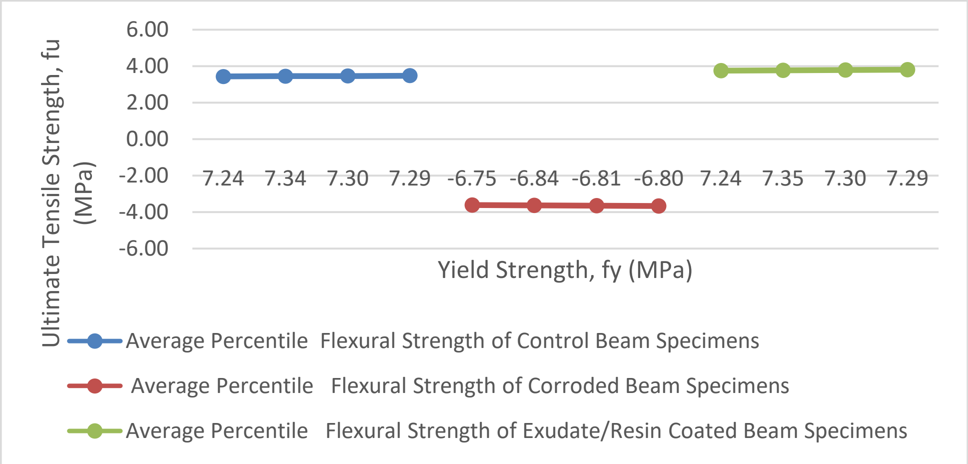


Figure 3.4B: Average percentile Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

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

Non-coated reinforcing steel eventually corrodes when exposed to natural elements due to various chemical, electrochemical and physical reactions (Burström, [25]). This results in a loss of cross-sectional area due to the formation of highly developed corrosive products. Concrete offers several corrosion protection systems for reinforcing steel. The concrete layer creates a physical barrier by acting as a buffer zone with a relatively impermeable and dense structure between the aggressive environment and the reinforcement (U, [26]; Lau and Lasa, [27]).

The results of the calculation of the minimum and maximum mean and percentile values in Tables 3.4 and 3.5 obtained from Tables 3.1 to 3.3 of the elongation values obtained from the controlled sample are 1.41 and 1.43 (-3.63% and -3.55%), the samples that corroded were 1.46 and 1.48 (3.46% and 3.45%), the values of the coated samples were 1.41 and 1.43 (-3.33%) and -3.25%).

The strain ratio obtained of the maximum calculated value for the mean and percentile values for the controlled is -3.55% compared to the corroded and overlaid values of 3.45% and -3.25%, respectively. The mean differential and percentile values obtained for the control were (0.02 and 0.08%), corrosion values (0.02 and 0.09%) and closed values (0.02 and 0.08%). The results showed that the corroded samples had a higher percentile of elongation deformation as a result of lower breakage loads and higher yields, whereas the coatings had higher load application rates with lower yields. Lower loads and higher yield and deformation strengths are a result of the effect of corrosion on the mechanical properties of reinforcing steel, which has effects on the interface, surface modification, fiber reduction and rib removal. The above factors have reduced the load bearing capacity of work-related reinforced concrete structures, see (Charles et al.[12]; Nwabakata et al. [16]; Kanee et al.,[17]; Gilbert et al. [15]).

The results of the minimum and maximum elongation values (%) for the controlled sample were 18.52% and 19.2% (-28.21% and -27.48%), corrosion values were 25.79% and 26.47% (38.44% and 39.85%), the values of the coated samples were 18.44% and 19.12% (-28.49% and -27.77%). The maximum comparison value for the controlled sample was -27.48% compared to the corroded and coated sample of 39.85% and -27.77%, respectively. The mean differential and percentile values obtained for the controlled samples were (0.68% and 0.73%), corrosion values (0.68% and 1.41%), and closed values (0.68% and 0.72%). 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 a higher fracture state when the load is low; coated samples show a range of values closer to the reference (controlled sample). The use of exudates materials for rebar has reduced the scourge and tendency of corrosive attack to which reinforced concrete structures in marine coastal areas are heavily exposed, see (Charles et al.[12]; Nwabakata et al. [16]; Kanee et al.,[17]; Gilbert et al. [15]).

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 1.60Kg and 1.60Kg (1.8% and 1.95%), the corroded values are 1.57Kg and 1.57Kg (0.47% and 0.5%), and the coated values are 1.56Kg and 1.56Kg (0.49% and 0.47%) and the rebar weights- after corrosion(Kg) obtained values of minimum and maximum average and percentile values are, controlled 1.60Kg and 1.62Kg (5.15% and 5.33%), corroded values are 1.52Kg and 1.52Kg (-6.67% and -6.61%), coated values are 1.63Kg and 1.63Kg (7.08% and 7.15%). The differential values obtained for the average and percentile of the controlled samples is (0.02and 0.18%), corroded values are (0.002Kg and 0.06%) and coated values are (0.001Kg and 0.07%).

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 (-24.14% and -23.1%), the coated samples are 0.07and 0.07kg (30.04% and 31.82%).

The computed data for maximum percentile values for rebar unit weights before corrosion test for controlled, corroded, and coated values are 0.5%, 0.5%, and 0.47%. 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 -6.61% and 7.15%.

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 comparison to the reference range values obtained from controlled samples, see (Charles et al.[12]; Nwabakata et al. [16]; Kanee et al.,[17]; Gilbert et al. [15]).

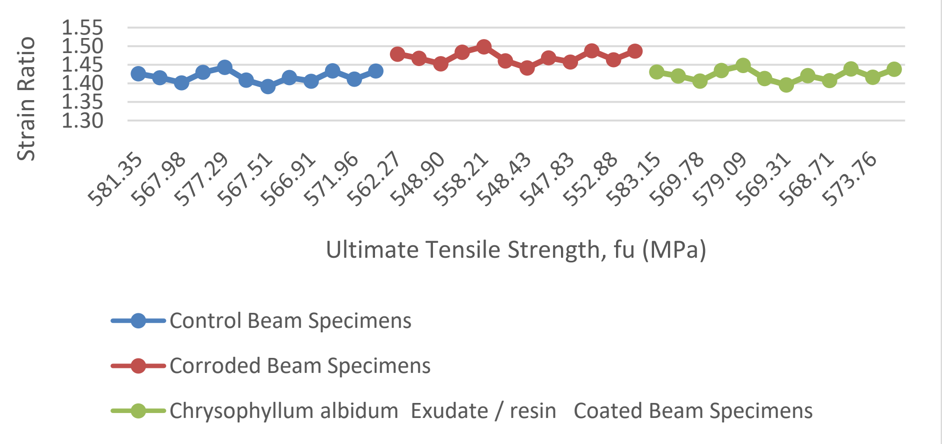


Figure 3.5: Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

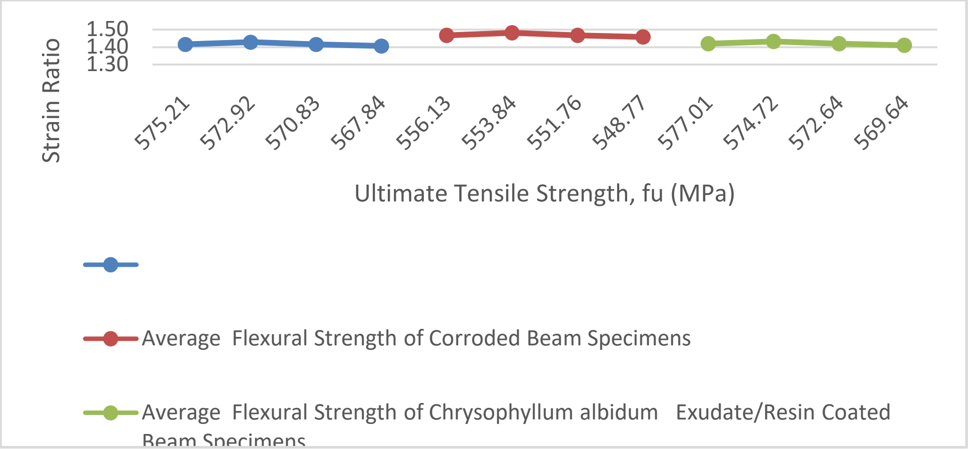


Figure 3.5A: Average Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

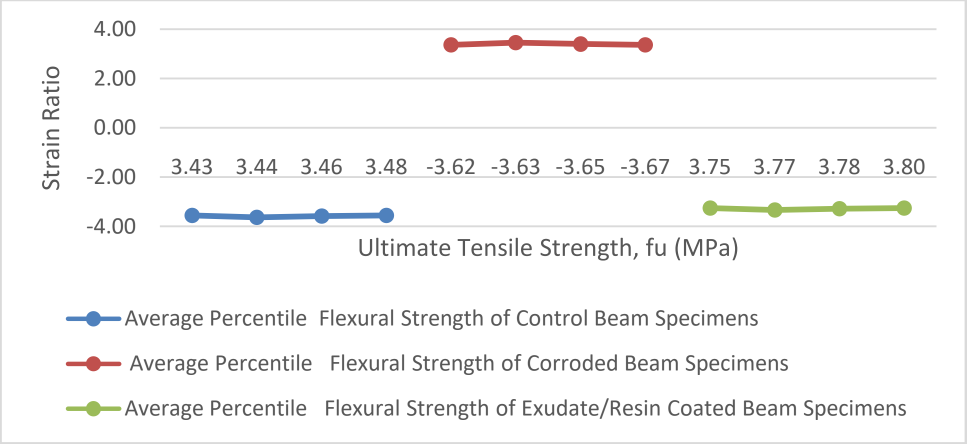


Figure 3.5B:Average Percentile Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

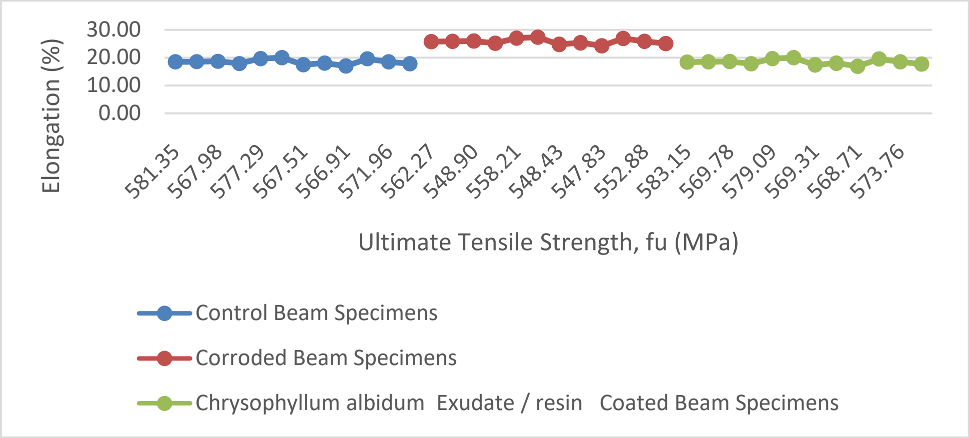


Figure 3.6: Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

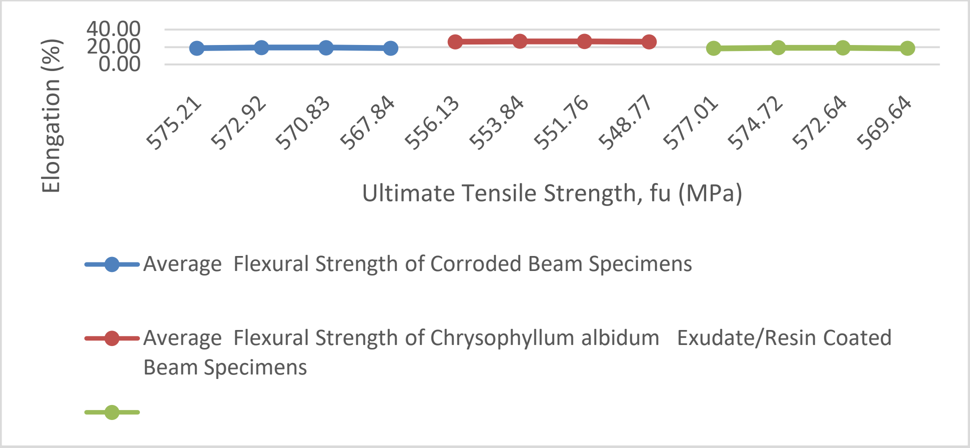


Figure 3.6A: Average Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

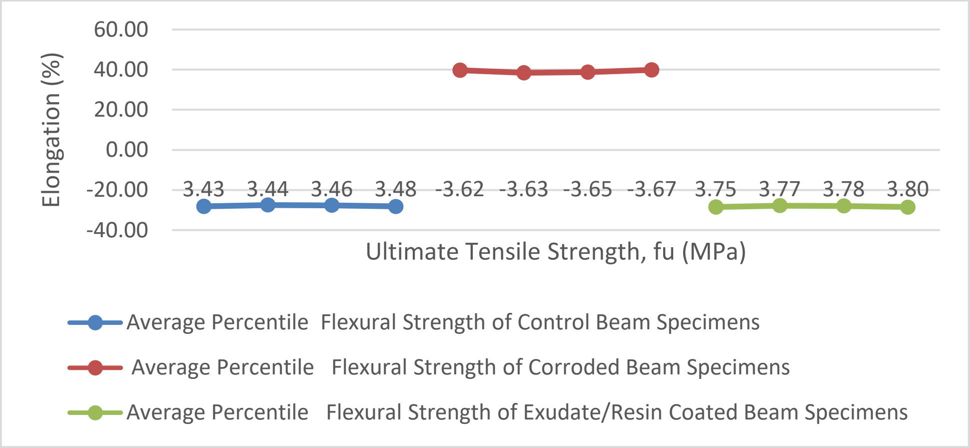
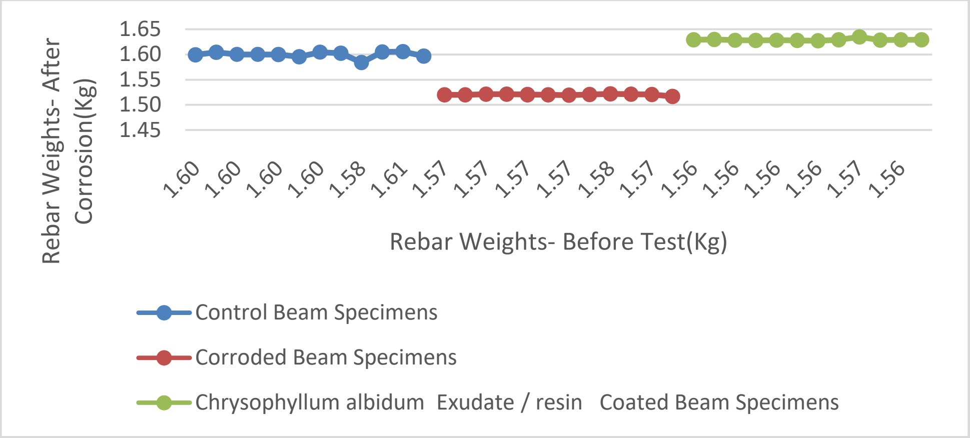


Figure 3.6B:Average Percentile Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens



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

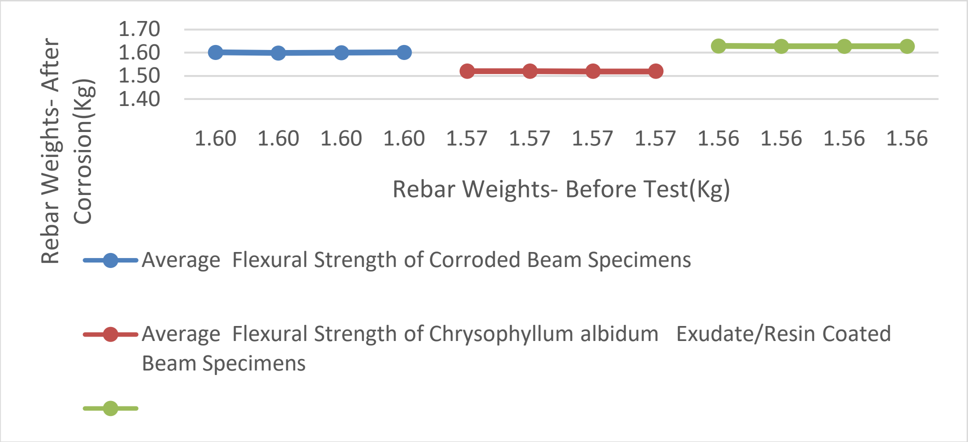


Figure 3.7A: Average Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

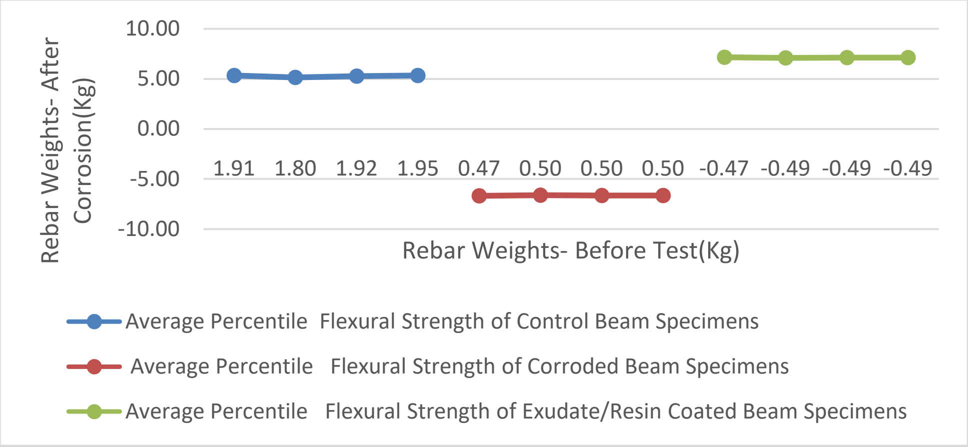


Figure 3.7B: Average Percentile Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

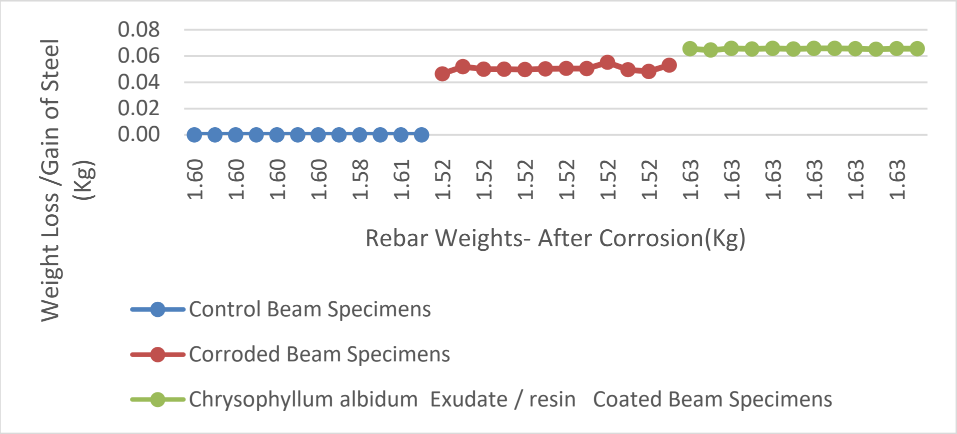


Figure 3.8: Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

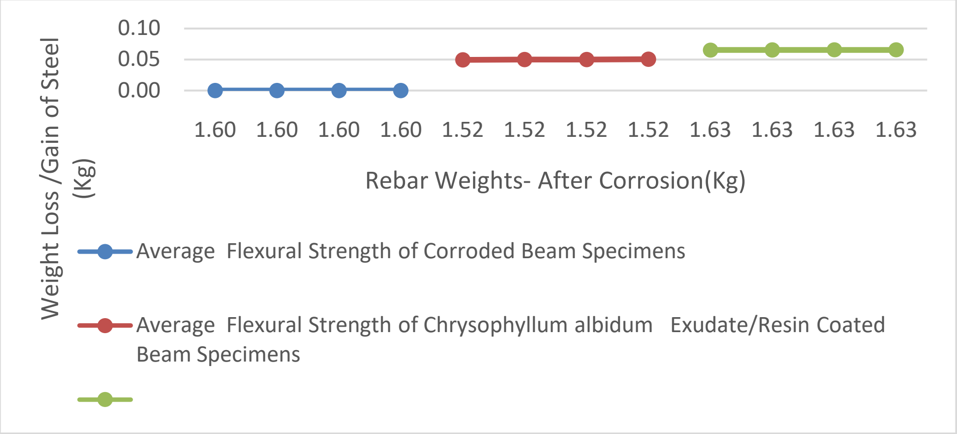


Figure 3.8A: Average Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

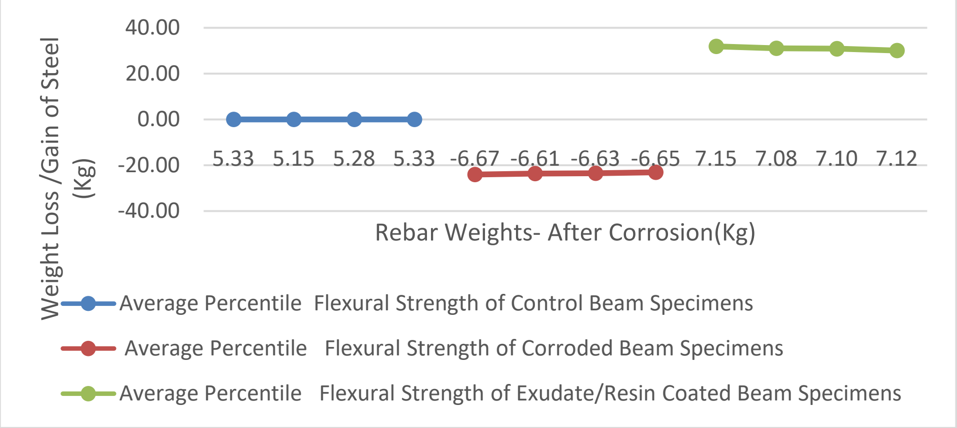


Figure 3.8B: Average Percentile Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin C7 Specimens

4.0 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 elongation loads for controlled and coated samples with lower values than for corroded samples with higher elongation loads and increased values compared to the reference range (controlled) and coated samples.

6. The results of the comparison of flexural strength and elongation load in the center of the corroded sample show the effect of corrosion on the mechanical properties of reinforcing steel with curved reinforcement, high surface modification, low load carrying capacity, tensile strength and high deformation of reinforcing steel.
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; stretch rate is higher than the average range.

REFERENCES

1. P.K. Mehta, and B.C. Gerwick, "Cracking-Corrosion Interaction in Concrete Exposed to Marine Environment," Concrete International, no.4, pp. 45-51, 1982.
2. K. Wang, and P. J. Monteiro," Corrosion Products of Reinforcing Steel and their Effects on the Concrete Deterioration, Third CANMET/ACI International Conference on Performance of Concrete in Marine Environment, New Brunswick, Canada, no.1, pp. 83-97, 1996.
3. S. Ahmad, "Reinforcement Corrosion in Concrete Structures, its Monitoring and Service Life Prediction," Cement and Concrete Composites, no. 25, pp. 459-471, 2003.
4. A. A. Torres-Acost, S. Navarro-Gutierrez, J. Terán-Guillén, "Residual Flexure Capacity of Corroded Reinforced Concrete Beams", Engineering Structures, vol. 29, no.6, pp. 1142-1152, 2007.
5. T. E. Ell-Maaddawy, K. Soudki, T. Topper, "Analytical Model to Predict Nonlinear Flexural Behavior of Corroded Reinforced Concrete Beams" *American Concrete Institute Structural Journal*, vol.102, no. 4, pp. 550-559, 2005.
6. K. Charles, O. Ishmael,B. M. Akatah, P. P. Akpan., "Comparative Residual Yield Strength Structural Capacity of Non-corroded, Corroded and Inhibited Reinforcement Embedded in Reinforced Concrete Structure and Exposed to severely Medium" *International Journal of Scientific and Engineering Research*, vol. 9, no. 4, pp.1135-1149, 2018.
7. V. Yu, R. Francois, V. H. Dang, V. L'Hostis, R. Gangne, "Structural performance of RC beams damaged by natural corrosion under sustained loading in a chlorine environment." Engineering Structures, no.96, pp. 778 30-40, 2015.
8. Zhu, W., and François, R. (2015). "Structural performance of RC beams in relation with the corroded period in chloride environment." Mater Struct, no.47, pp. 1-13.
9. W. Zhu, and R. François, "Corrosion of the reinforcement and its influence on the residual structural performance of a 26-year-old corroded RC beam." Construction and Building Materials, no.51, pp. 461–472, 2014.
10. A. H. Al-Saidy, H. Saadatmanesh, S. El-Gamal, K. S. Al-Jabri B. M. Waris, "Structural behavior of corroded RC beams with/without stirrups repaired with CFRP sheets." Materials and Structures vol. 49, no. 9, pp. 3733- 3747, 2016.
11. T. El Maaddawy, K. Soudki, T. Topper, "Long-Term Performance of Corrosion-Damaged Reinforced Concrete Beams." ACI Struct J., vol.102, no.5, pp. 649-656, 2005b.
12. K. Charles, E. I. Ogunjiofor, L. P. Letam,"Residual Flexural Strength of Corrosion Inhibited Resin Coated Beam in Corrosion Accelerated Media", *Global Scientific Journal*, vol. 6, no. 5, pp. 84-96, 2018.
13. A. Castel, R. Francois, G. Arliguie, "Mechanical behaviour of corroded reinforced concrete beams-Part 1: experimental study of corroded beams." Materials and Structures, vol.33, no.9, pp. 539-544, 2000.
14. E. Y. Branly, K. Charles, L. P. Letam, " Evaluation Of The Inhibitive Effect of Exudates / Resins on Corrosion Reduction in Flexural Strength Capacity of Reinforcing Steel in Concrete, "*Global Scientific Journal*, vol. 7, no. 10, pp. 575 - 588, 2019.
15. D. G. Gilbert, T. A. Nelson, and K. Charles, "Evaluation of Residual Yield Strength Capacity of Corroded and Exudates / Resins Coated Reinforcing Bars Embedded in Concrete**, "**European Journal of Advances in Engineering and Technology, vol. 6, no. 9, pp.48-56, 2019.
16. C. Nwaobakata, K. Charles, S. Sule, "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, vol. 7, no. 2, pp. 13-23, 2019.
17. Kanee, S., Petaba, L. D., Charles, K., "Inhibitory Action of Exudates / Resins Extracts on the Corrosion of Steel Bar Yield Strength in Corrosive Media Embedded in Concrete, "European Academic Research - Vol. 7, no. 7 , pp. 3381 – 3398, 2019
18. BS. 882; 1992- Specification for Aggregates from Natural Sources for Concrete. British Standards Institute. London, United Kingdom.
19. BS EN 196-6; 2010- Methods of Testing Cement. Determination of fineness, British Standards Institute. London, United Kingdom, 2010.
20. BS 3148; 1980 – Methods of test for Water for Making Concrete. British Standards Institute. London, United Kingdom.
21. BS 4449:2005+A3; 2010 – Steel for Reinforcement of Concrete. British Standards Institute. London, United Kingdom.
22. BS EN 12390-2; 2005 – Testing Hardened Concrete: Flexural Strength Test of Specimens, *British Standards Institute. London, United Kingdom*,
23. R. Palsson, and M. S. Mirza, "Mechanical response of corroded steel reinforcement of abandoned concrete bridge," *ACI Structural Journal*, vol.99, no.2, 2002.
24. Gang, Zhangunderstand, Liu Defu, 2012 Study on mechanical properties of corroded steel bars in concrete under chloride environment [J].Journal of Hydraulic Engineering, vol.43, no.4, pp. 452-459, 2012.
25. P. Burström, "*Byggnadsmaterial*, 2007.
26. A. A. A. U, "Effect of degree of corrosion on the properties of reinforcing steel bars', pp. 361–368, 2001.
27. K. Lau, and I. Lasa, "Corrosion of Steel in Concrete Structures," *Corrosion of Steel in Concrete Structures*, pp. 37–57, 2016.