

Residual Yield Strength Assessment of Reinforcing Steel in an Induced Corrosive Media

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Abstract

The study examined the use and potency of extruded exudates/resins obtained from tree trunks. The gummy exudates/resins were applied directly to the steel reinforcement by the coatings varying their thicknesses and embeddings them into concrete beams, and studying their possible effects as an inhibitor to corrosion attacks on reinforcing steel of concrete structures built within the coastal marine region with highly acidic nature. From the flexural strength test, the maximum value was 24.64% compared to the corroded and coated sample values of -18.46% and 24.41%, respectively and the average differential and percentile range controlled (2.25kN and 2.01%), corroded (0.66kN and 1.16%), coated (2.09kN and 1.77%). The results illustrated that the reference percentage of controlled samples according to [30] 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. The calculated average differential and percentile values were checked (0.01mm and 0.009%), corrosion values (0.01mm and 0.063%) and closed values (0.01mm and 0.069%). The results illustrated 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 percentage recorded from the corrosion samples, while the controlled and coated samples illustrated preserved conditions with increasing layers of different diameters of exudates/resin layer thickness. The cross-sectional area of reinforcing steel after corrosion test gives different average and percentile values of corroded values (0.02 mm and 4.84%) and coated values (0.03 mm and 1.57%). The calculated maximum comparative values for both yield and ultimate tensile strength for the controlled samples were 9.66% and 3.54% to the corroded and coated values of -7.45% and -3.7%, coated values are 9.66% and 3.86%, respectively. From the data obtained and compared, the yield strength and ultimate tensile strength values of the corroded samples illustrated a decrease in the average and percentage values for load failure with few applications. The average differential and percentile values obtained for the control were (0.01 and 1.4%), corrosion values (0.02 and 1.54%), and closed values (0.01 and 1.4%). The maximum elongation comparative value for the controlled sample was -12.92% compared to the corroded and coated sample of 20.62% and -23.82%, respectively. The average differential and percentile values obtained for the controlled samples were (0.83% and 0.77%), corrosion values (0.82% and 1.38%), and coated values (0.82% and 0.78%). In comparative, the corroded samples illustrated higher stress values and higher elongation rates, whereas the damaged state of coated samples was lower load and reduced elongation. The calculated data illustrated 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 illustrated an increase in weight compared to the reference value of the controlled sample due to the different coating thicknesses.

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

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1.0 INTRODUCTION

The loss of reinforcement area is a direct result of corrosion and is usually measured as mass loss. It has been shown that the yield strength and the maximum stress and strain deteriorate at the final reinforcement stress and the yield strength becomes narrower or even disappears with the development of corrosion [1]. This

reduction can cause the valve to rupture prematurely before giving way. The manifestation of corrosion in reinforced concrete structures has resulted in two extreme forms of cracking and cracking of the concrete cover, resulting in uncontrolled corrosion yield and locally reinforced pitting at the anode, resulting in a great reduction of the bar cross-sectional area.

Reinforced concrete structures built in coastal marine environments are at high risk for chloride-induced corrosion. Localized corrosion and pitting are the results of the formation of surface films on reinforcing steel [2-5]. It is concluded that steel has an instantaneous film structure, and that the metal is "inactive" after the formation of the membrane.

Found that the maximum pitting depth had the greatest effect on the load bearing capacity and not on the average corrosion penetration in relation to the reinforcing radius. They also reported that corrosion-related concrete cracking was greater in a dry environment, although wet rebar accelerated the formation of holes in the exterior of the rebar. Experimental results show that a 10% reduction in the average corrosion penetration along the initial radius of the longitudinal reinforcement results in a 60% reduction in the flexural strength of the reinforced concrete beam [6].

Investigated reinforcement behavior of concrete-steel interface assumed to have zero bonds at different lengths of the beam, and the ability of the beam to be reduced with shorter bond lengths was observed. They conclude that even with the use of complex un-bonded lengths, the beams fail through concrete crushing regardless of the steel ratio. Their results confirm that the beams have considerable strength, even if they are completely removed in part of the bond, if the ends of the bars are sufficiently anchored [7].

Studied the reinforced beams of double reinforcement of the upper and lower 10mm and 12 mm diameter bars and the effects of 8 mm diameter stirrups corrosion. Rapid corrosion techniques are sought to reduce tensile reinforcement by applying an unknown current density. In view of the importance of detention from cover and binding links [8].

Conducted an experimental test on reinforced concrete beams that were corroded and aged 14 years during bending. They found that about 20% corrosion resulted in a decrease in flexural stiffness of about 35% and a decrease in ductility of about 70% for corroded reinforced concrete beams. They found that the residual flexural strength of corroded reinforced concrete beams was mainly dependent on the mass loss of the tensile reinforcement and was not significantly affected by the loss of bond strength [9].

Studied the potential effects of corrosion on the residual yield strength non-coated and coated steel bar embedded in concrete and pooled in corrosive media. The obtained results illustrated the presence of corrosion potential on uncoated members with cracks and spalling. Overall experimental results have shown that corroded models have low flexural load, high

midspan deflection, low tensile strength, and high extension due to the loss of steel bar fiber [10].

Conducted a similar experiment by Zhu and Francois [11, 17, 18], with the same dimensions, Loading conditions and coating thickness as samples. Control beam damaged by compressed concrete Crushing, accompanied by breaking of the two 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.

Investigated the effects of corrosion on the residual structural steel bar efficiency of resins / exudates. The obtained results illustrated the presence of corrosion potential on uncoated members with cracks and spalling. Overall experimental results have shown that corrugated models have low flexural load, high midspan deflection, low tensile strength, and high extension due to the loss of steel bar fiber [12].

Investigated the naturally available inorganic products of *Garcinia cola* Extracts (Exudates / Resins) as a protective layer to reinforce the steel embedded in concrete. Decreased member ensemble results illustrated higher yield strength with lower applied load, higher midspan deflection and extension. Results from exudates / resins coated members illustrated less flexibility failure on corrugated members with shorter, less midspan deflection. Non-corroded member results include flexural failure load, low midspan deflection and yield strength, strain ratio and high values of extension over all depleted members [13].

Introduced coated reinforced steel, 150 μm , 300 μm and 450 μm thick with exudates/resins aimed at reducing the corrosion of steel reinforcement in the saltwater area. Investigated the impact of corrosion on concrete beam and coated and non-coated members. Extensive test results have shown potential corrosion resistance with coating members on mechanical properties that strengthen the effects of weight loss, cracking, spalling 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 failed variable load and high retention potential with low average usage, high levels of anxiety, stretching, and midspan deviation [14].

Assesses the behavior of coated reinforcing steel layered with acacia senegal exudates/resins and non-coated members, embedded in concrete members and exposes to corrosive media for corrosion accelerated processes. The results obtained after the fast

period confirm that non-coated member with corrosion potential properties of fractures and spalling. High flexibility loads are shown and displayed against corroded specimens; Midspan deflection rates are higher for corroded specimens and the ultimate tensile strength of corroded specimens. Overall experimental tests have shown that the presence of mechanical properties that reinforce steel was negatively affected by corrosion [15].

Illustrated that a loss of about 1% in the cross-sectional area of longitudinal reinforcement causes a decrease in the relative tensile strength of about 1% and the ultimate load bearing capacity of 0.85%. However, it turned out that this was caused by the breaking of the concrete. Five blocks for an experiment were thrown in 1984; three of these are held in a chloride medium, one in a chloride medium under an applied load, and the other has simulated slot corrosion [16-18].

Evaluated the effectiveness of the application of olibanum exudates/resins for reinforcing embedded steel in concrete, through the rapid process of sinking in a corrosive medium for the possibility of corrosion. The embedded concrete members of the coated and non-coated members were first examined for cracking and spalling. Corroded members show less flexibility over corroded and uncoated specimens, but midspan deflection rates are higher for corroded samples, and the ultimate tensile strength of corroded members imposes higher loads and decreased values with high midspan deflection and elongation. Coated members has less flexural failure load, midspan deflection, strain ratio, and ultimate tensile strength over corroded members [19].

Investigated the use of environmentally friendly mineral products of the exudates/resins of *Artocarpus altilis* in the prevention of corrosion attack on steel reinforcement embedded in concrete. The results of the decreasing member properties of the steel reinforcement embedded in corrosive and corrosive media have shown greater tensile loads, midspan deflection, and ultimate tensile strength against coated and corroded members of exudates/resins. Controlled results include higher midspan deflection, higher yield strength, and lower strain rate compared to coating members. Overall the results illustrated fractures and tremendous resistance to the corrosion attack that strengthened the steel members [20].

Investigated surface modifications, reduction in diameter, and weight loss of steel reinforcing in the occupied environment of corrosive, non-coated, and exudates/resins coated members. Non-coated and coated members of varying thicknesses were embedded in concrete structures, exposed and monitored for 150 days. Corroded members illustrated steel reinforcement failure mechanisms due to corrosion, resulting in higher midspan deflection and higher yields, while coated

members maintain greater structural integrity. The coated members illustrated high flexibility before failure due to high yields and reduced load to elongation [21].

Conducted experimental tests on corroded and uncorroded reinforced concrete beams with different reinforcement details in pure bending. They use an accelerated corrosion process to corrode the sample. Experimental tests include super-strengthened, balanced, amplified and highly amplified RC carriers. They reported that corrosion changed the fracture mode of the super-reinforced beam from brittle fracture to less brittle and even to plastic fracture mode, but reduced the ductility of the reinforced beam to less plastic or even very brittle. They also found that the corrosion mass loss was more than 10% causes premature damage to the tensile reinforcement in the case of severely inadequately reinforced beams, leading to a strong reduction in the ductility of these beams. Experimental results show that a 10% reduction in the average corrosion penetration along the initial radius of the longitudinal reinforcement results in a 60% reduction in the flexural strength of the reinforced concrete beam [22].

Investigated the effect of reinforcing steel with the introduction of *milicia excelsa* exudates/resins for surface modification and the reduction of steel in concrete structures. The corrosion acceleration process was 150 days and corrosion efficiency was determined. Overall the experimental results illustrated that the corrosion properties of spills and cracks in the coating members indicate a low flexibility failure load; Midspan deflection, extension, and ultimate yield, high flexibility failure load required and compared to corroded members [23].

Investigated the comparative effect of reinforcing steel coated with *Khaya senegalensis* exudates/resins and non-coated members on the residual flexural strength of reinforcing steel after 150 days corrosion fast periods. Obtained results of the corroded member's flexural failure loads are higher, midspan deflection and shear ultimate tensile strength against controlled and coated members. The mechanical properties of reinforcing steel were adversely attacked by corrosion presence [24].

Investigated the potential application of resin extract of inorganic resistant natural exudates *grewia*. The range of values of corrosion models indicates significant corrosion potential for high, low, moderate, and low. The results illustrated a high ultimate yield of corroded specimens for controlling and coating the specimens due to the effect of corrosion on the mechanical properties of steel reinforcement. The results of the weight loss of steel due to the effect of corrosion on mechanical properties illustrated higher

percentage values against control and coating members [25].

2.1 MATERIALS

2.1.1 Aggregates

The fine and coarse were purchased. Both met the requirements of [26].

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 [27].

2.1.3 Water

The water samples were clean and free from contaminants. Used fresh water was obtained from the Civil Engineering Laboratory, Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State. Water met the requirements of [28].

2.1.4 Structural steel reinforcement

Reinforcements are obtained directly from the market at Port Harcourt. Confirmed at [29].

2.1.5 Corrosion Inhibitors (Resins / Exudates) *Pycnanthus angolensis*(African/false nutmeg)

The reddish like gum exudates was obtained from the tree bark by tapping process from the forestry reserves of Trans – Amadi in Port Harcourt, Rivers State.

2.2 METHODS

The study examined the use and potency of extruded exudates/resins obtained from tree trunks. Gummy exudates/resins were applied directly to the steel reinforcement by the coatings varying their thicknesses and embeddings them into concrete beams, and studying their possible effects as an inhibitor to corrosion attacks on reinforcing steel of concrete structures built within the coastal marine region with highly acidic nature. Concrete beam specimens of 175 mm x 175 mm 750 mm, thickness, width, and length were embedded with four (4) numbered 16 mm diameter reinforcing steel and cured for the initial 28 days and pooled for corrosion acceleration process with sodium chloride (NaCl) media tank for 360 days. The process of corrosion occurrence is naturally a long process that takes several years to manifest, but the

introduction of sodium chloride (NaCl) accelerates and stimulates the rate of corrosion, which indicates the coastal area representation, and the duration of this process can be reached with a short term. This study tends to determine the role of exudate/resin against adverse attack on reinforcement embedded in concrete and exposed to severe and harsh weather; it's waterproofing, and resistivity to surface changes and modifications resulting from coating application.

2.2.1 Preparation and Casting of Sample Concrete Beams

The standard method of concrete mixing ratio was followed with manual mixing and material by weight was applied to a clean concrete slab, and the mixture was inspected and slowly added water to obtain a complete mixing design concrete. A concrete mix ratio of 1: 2: 4 and a water-cement ratio of 0.65 was maintained. Constant uniform color and consistency were obtained by adding concrete cement, water, and aggregate. The test beams were cast into a 175 mm x 175 mm x 750 mm steel mold, which was compressed in air-free tight and embedded with 4 lengths of 16 mm diameter of reinforcing steel. The samples were demolded after 72 hours and cured under standard procedures for 28 days and the samples were cured for 90 days, 180 days, 270 days, and 360 days for rapid corrosion acceleration testing at room temperature, and observations were made for the first crack appearance.

2.2.2 Flexibility Testing of Beam Models

Flexural testing was conducted on 36 numbers of concrete beams of controlled, corroded, and coated samples on a Universal Testing Machine to [30], with a load of 100kN to ascertain the effects of corrosion on samples cured for 360 days in 5% sodium chloride (NaCl). The flexural test was conducted on samples on 90 days, 180 days, 270 days, and 360 days with a 3 months interval evaluation on the mechanical properties surface modification of reinforcing steel. 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	PA	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8	PA9	PA10	PA11
Flexural Strength Load (KN)	90.12	89.31	88.83	84.99	89.25	87.27	90.07	89.39	90.32	90.26	88.27	89.36
Midspan Deflection (mm)	6.34	6.42	7.02	7.13	6.22	7.16	6.25	6.42	6.22	6.30	6.30	8.46
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)	15.99	15.98	15.97	15.99	15.99	15.93	15.99	15.98	15.90	15.96	15.95	15.98
Rebar Diameter at 28 days(mm)	15.99	15.98	15.97	15.99	15.99	15.93	15.99	15.98	15.90	15.96	15.95	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)	409.9 2	409.0 3	405.9 0	407.8 0	408.9 7	408.9 2	408.5 1	409.3 2	408.9 1	409.7 3	409.5 4	408.2 9
Ultimate Tensile Strength, fu (MPa)	579.0 0	573.9 5	565.6 3	571.4 1	574.9 4	565.3 6	565.1 6	565.9 6	564.5 6	577.1 1	569.6 1	578.4 7
Strain Ratio	1.41	1.40	1.39	1.40	1.41	1.38	1.38	1.38	1.38	1.41	1.39	1.42
Elongation (%)	19.44	19.51	19.64	18.84	20.64	20.98	18.44	19.01	17.94	20.54	19.48	18.77
Rebar Weights- Before Test	1.60	1.60	1.60	1.60	1.60	1.59	1.60	1.60	1.58	1.60	1.60	1.60
Rebar Weights- After at 28 days (Kg)	1.60	1.60	1.60	1.60	1.60	1.59	1.60	1.60	1.58	1.60	1.60	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)

	PA1 A	PA1 B	PA1 C	PA1 D	PA1 E	PA1 F	PA1 G	PA1 H	PA1I	PA1J	PA1 K	PA1 L
Flexural Strength Load (KN)	72.3 9	71.7 3	71.1 0	71.0 8	71.5 2	70.6 3	72.3 4	71.6 6	72.5 9	69.5 4	70.0 4	67.2 7
Midspan Deflection (mm)	11.6 5	11.7 3	12.3 3	12.4 4	11.5 3	12.4 7	11.5 6	11.7 3	11.5 3	11.6 1	11.6 1	13.7 7
Nominal Rebar Diameter	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0
Measured Rebar Diameter Before Test(mm)	16.0 1	15.9 8	16.0 4	15.9 8	16.0 3	15.9 3	16.0 3	15.9 5	15.8 2	15.9 8	16.0 2	15.9 7
Rebar Diameter- After Corrosion(mm)	15.5 9	15.5 6	15.6 2	15.5 6	15.6 1	15.5 1	15.6 1	15.5 3	15.4 0	15.5 6	15.6 0	15.5 5
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Yield Strength, fy (MPa)	378. 83	378. 34	376. 44	372. 46	371. 08	374. 16	379. 05	372. 57	374. 45	375. 27	376. 36	376. 38
Ultimate Tensile Strength, fu (MPa)	559. 51	554. 46	546. 14	551. 92	555. 45	545. 87	545. 67	546. 47	545. 07	557. 62	550. 12	558. 98
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 (%)	25.8 4	25.9 1	26.0 4	25.2 4	27.0 4	27.3 8	24.8 4	25.4 1	24.3 4	26.9 4	25.8 8	25.1 7
Rebar Weights- Before Test(Kg)	1.56	1.56	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)	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.51
Weight Loss /Gain of Steel (Kg)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05

Table 3.3: Flexural Strength of Pycnanthus angolensis Exudate / resin Coated Beam Specimens

	PA1 A1	PA1 B2	PA1 C3	PA1 D4	PA1 E5	PA1 F6	PA1 G7	PA1 H8	PA1 I9	PA1 J10	PA1 K11	PA1 L12
	150µm (Exudate/Resin) coated			300µm (Exudate/Resin) coated			450µm (Exudate/Resin) coated			600µm (Exudate/Resin) coated		
Flexural Strength Load (KN)	90.1 2	88.8 1	88.8 3	85.0 0	89.2 5	87.2 7	90.0 7	89.3 9	90.3 2	89.4 6	87.7 7	88.3 6
Midspan Deflection (mm)	6.41	6.49	7.09	7.20	6.29	7.23	6.32	6.49	6.29	6.37	6.37	8.53
Nominal Rebar Diameter	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0	16.0 0
Measured Rebar Diameter Before Test(mm)	15.9 9	15.9 9	15.9 7	15.9 9	15.9 9	15.9 3	15.9 9	15.9 8	15.9 0	15.9 7	15.9 5	15.9 8
Rebar Diameter- After Corrosion(mm)	16.0 6	16.0 6	16.0 4	16.0 7	16.0 7	16.0 1	16.0 7	16.0 6	15.9 7	16.0 4	16.0 3	16.0 5
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	0.08
Yield Strength, fy (MPa)	409. 92	409. 03	405. 90	407. 80	408. 98	408. 92	408. 51	409. 32	408. 91	409. 73	409. 54	408. 29
Ultimate Tensile Strength, fu (MPa)	580. 80	575. 75	567. 43	573. 21	576. 74	567. 16	566. 96	567. 76	566. 36	578. 91	571. 41	580. 27
Strain Ratio	1.42	1.41	1.40	1.41	1.41	1.39	1.39	1.39	1.39	1.41	1.40	1.42
Elongation (%)	19.3 7	19.4 4	19.5 7	18.7 7	20.5 7	20.9 1	18.3 7	18.9 4	17.8 7	20.4 7	19.4 1	18.7 0
Rebar Weights- Before Test(Kg)	1.60	1.59	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.58
Rebar Weights- After Corrosion(Kg)	1.65	1.65	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.64
Weight Loss /Gain of Steel (Kg)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

Table 3.4: Average Flexural Strength of Beam Specimens (Control, Corroded and 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 Specimens			
Flexural Strength Load (KN)	89.4 2	87.7 1	87.6 9	87.1 7	71.74	71.31	71.24	71.08	89.26	87.55	87.69	87.17
Midspan Deflection (mm)	6.59	6.86	6.79	6.84	11.91	12.17	12.10	12.15	6.66	6.93	6.86	6.91
Nominal Rebar Diameter	16.0 0	16.0 0	16.0 0	16.0 0	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Measured Rebar Diameter Before Test(mm)	15.9 8	15.9 8	15.9 8	15.9 7	1.60	1.60	1.60	1.60	15.98	15.98	15.99	15.97
Rebar Diameter- After Corrosion(mm)	15.9 8	15.9 8	15.9 8	15.9 7	1.56	1.56	1.56	1.56	16.05	16.06	16.06	16.05
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-0.04	-0.04	-0.04	-0.04	0.07	0.07	0.07	0.07
Yield Strength, fy (MPa)	408. 28	407. 58	407. 56	408. 56	377.8 7	375.7 5	373.3 3	372.5 7	408.29	407.58	407.56	408.57
Ultimate Tensile Strength, fu (MPa)	572. 86	570. 33	570. 66	570. 57	553.3 7	550.8 4	551.1 7	551.0 8	574.66	572.13	572.46	572.37
Strain Ratio	1.40	1.40	1.40	1.40	1.46	1.47	1.48	1.48	1.41	1.40	1.40	1.40
Elongation (%)	19.5 3	19.3 3	19.7 1	20.1 6	25.93	25.73	26.10	26.55	19.46	19.26	19.64	20.08
Rebar Weights- Before Test(Kg)	1.60	1.60	1.60	1.60	1.56	1.56	1.56	1.56	1.60	1.60	1.60	1.60
Rebar Weights- After Corrosion(Kg)	1.60	1.60	1.60	1.60	1.52	1.52	1.52	1.52	1.66	1.66	1.66	1.66
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06

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

	Average Percentile Flexural Strength of 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)	24.64	23.00	23.09	22.63	-19.62	-18.55	-18.77	-18.46	24.41	22.78	23.10	22.64
Midspan Deflection (mm)	-44.63	-43.66	-43.90	-43.73	78.71	75.72	76.46	75.94	-44.04	-43.09	-43.33	-43.16
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)	0.369	0.379	0.346	0.363	0.354	0.363	0.365	0.359	0.374	0.377	0.378	0.377
Rebar Diameter-After Corrosion(mm)	0.646	0.647	0.639	0.648	-0.981	-1.013	-1.044	-0.995	0.942	1.011	1.008	0.9931
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-10.11	-14.84	-14.06	-14.95	16.98	16.03	17.60	17.29
Yield Strength, fy (MPa)	8.05	8.47	9.17	9.66	-7.45	-7.81	-8.40	-8.81	8.05	8.47	9.17	9.66
Ultimate Tensile Strength, fu (MPa)	3.52	3.54	3.54	3.54	-3.70	-3.72	-3.72	-3.72	3.85	3.86	3.86	3.86
Strain Ratio	-4.19	-4.55	-5.17	-5.59	4.05	4.44	5.12	5.59	-3.89	-4.25	-4.87	-5.29
Elongation (%)	-24.65	-24.84	-24.49	-24.07	33.22	33.57	32.93	32.19	-24.94	-25.13	-24.77	-24.35
Rebar Weights- Before Test(Kg)	2.31	2.33	2.28	2.20	-2.10	-2.17	-2.31	-2.24	2.15	2.22	2.36	2.29
Rebar Weights- After Corrosion(Kg)	5.45	5.46	5.35	5.27	-8.40	-8.44	-8.53	-8.47	7.17	7.22	7.32	7.25
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	-20.95	-21.40	-22.70	-22.58	26.50	27.22	29.36	29.17

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

Corrosion of reinforced concrete or concrete has led to the sudden collapse of many of the exposed structures in coastal areas with severe weather. The effect of corrosion on flexural forces has been investigated by a large number of investigators and is well understood. Many studies conducted in this area have been described by critical tests of their effectiveness in the effects of corrosion on the flexibility of reinforced concrete beams. Considering the effect of corrosion on reinforced concrete structures built within the coastal areas of Niger Delta, Nigeria, with high salinity, the application of *Pycnanthus angolensis* exudates/resin extracts of tree sources with eco-friendly was introduced, applied directly to embedded reinforcing steel in concrete beams and assessed its effectiveness as an inhibitory substance against corrosion.

Corrosion of reinforcement and the corresponding loss of strength, but also the volume of rust products in the form of iron oxide or hydroxide, the volume of which is 3-6 times the volume of steel [30]. Corrosion of reinforcement is the main cause of damage, which however interferes with the covering area (concrete shell) of the concrete. [31], found that the corrosion of steel is accompanied by a loss of the

corresponding cross-sectional area and thus a decrease in the flexural strength of the concrete. In fact, as steel corrodes, it takes up a larger share of the original steel as it gradually spreads and exerts significant tensile forces on the concrete medium, causing it to crack and peel, reducing its service life. Experimental data for flexural tests on concrete beam samples are shown in Tables 3.1, 3.2, and 3.3, summarized in 3.4, average and percentile values in 3.5, and the results are shown graphically in Figures 3.1 - 3.8b.

The average values and the minimum and maximum percentages calculated from the flexural strength of the Instron Universal Testing Machine at the compression of 100kN under pressure to failure were controlled samples 87.17kN and 89.42kN (22.63% and 24.64%), the values of the samples that were corroded were 71.08kN and 71.74kN (-19.62% and -18.46%), and the samples coated with exudates/resin were 87.17kN and 89.26kN (22.64 % and 24.41%).

From the flexural strength test, the maximum value was 24.64% compared to the corroded and coated sample values of -18.46% and 24.41%, respectively and the average differential and percentile range controlled (2.25kN and 2.01%), corroded (0.66kN and 1.16%), coated (2.09kN and 1.77%). The results illustrated that the reference percentage of controlled samples according to [30] 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 failed with a lower load, whereas coated specimens have a higher load. 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 midspan deflection (deformation) loads reported on the controlled samples were 6.59kN and 6.86kN (-44.63% and -43.66%), the corroded samples were 11.91kN and 12.17kN (75.72% and 78.71%) and the coated samples were 6.66kN and 6.93kN (-44.04% and -43.09%).

The midspan deflection comparative results illustrated that the maximum value obtained is controlled until the failure state (-43.66% compared to corroded 78.71% and closed -43.09%. The average and

percentage difference values are controlled (0.27kN and 0.97%), the corroded (0.26kN and 2.99%) and coated (0.27kN and 0.95%).

The results illustrated a lower elongation load in the controlled and coated samples with reduction values over the corrosion samples with higher elongation loads and a higher value compared to the reference range (controlled) and the comparative results obtained for the flexural strength and elongation load in the center of the corroded specimen indicate the effect of corrosion on the mechanical properties of reinforcing steel with stripped ribs, high surface modification causes low load carrying capacity and high deformation from a midspan as validated by the in works of [12, 14, 19, 20, 25, 13]. From the results obtained, the exudates/resin of *Pycnanthus angolensis* 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.

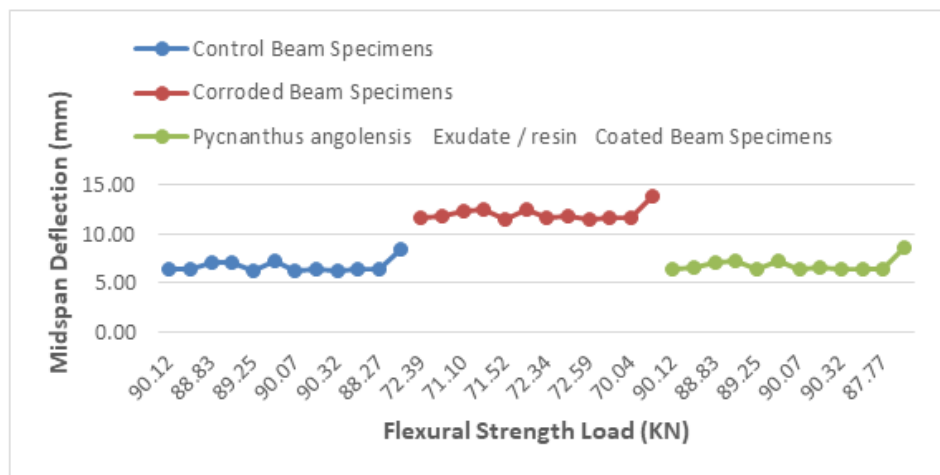


Figure 3.1: Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

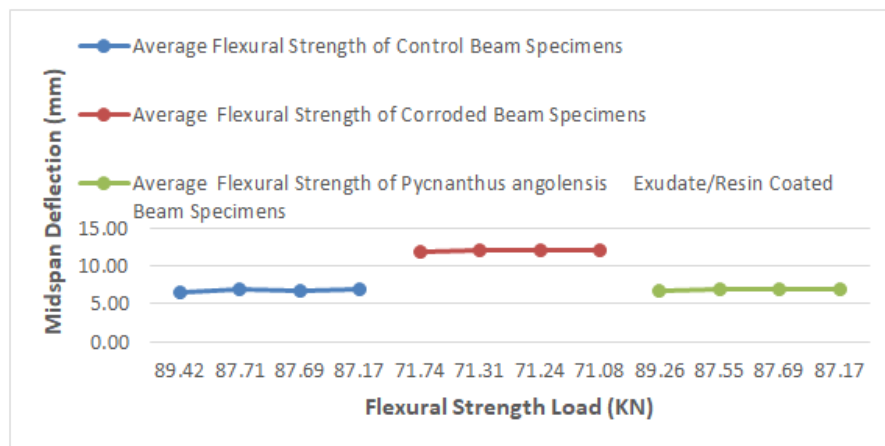


Figure 3.1A: Average Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

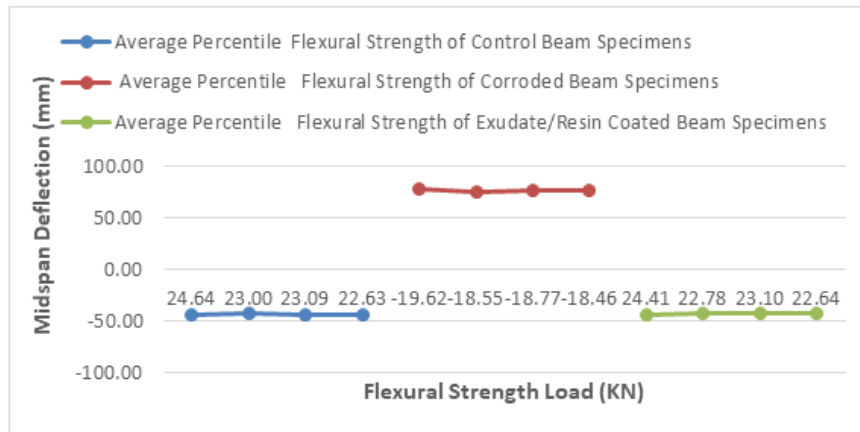


Figure 3.1B: Average Percentile Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

3.3 Results of Measured Rebar Diameter Before and After Corrosion Test

Chloride ions and carbon dioxide that penetrate the structure from the environment cause chemical changes in the pore solution of the concrete, which can lead to the destruction of the thin protective layer, called the passivation layer that forms on the steel surface under alkaline conditions. After that, the active corrosion of reinforcement is thermodynamically favored, which leads to the emergence of two main crushing mechanisms, namely a reduction in the cross-sectional area of the steel bar and an expansion in the volume of the resulting corrosion product. The value for the nominal diameter of the value is 16 mm (100%) for all common standards. The rebar diameters measured before the test for the controlled sample were 15.97 mm and 15.98 mm (0.346% and 0.379%), the corroded ones were 16.00 mm and 16.00 mm (0.354% and 0.354%), and the coated are 15.97 mm and 15.99 mm (0.374% and 0.378%). The results obtained indicate that the diameter of the reinforcing steel varies in the range of minute due to the production of reinforcement by different companies production mold used, the products average value and the percentage difference is not significant.

The average values and the minimum / maximum percentage of rebar diameter - after controlled corrosion test were 15.97mm and 15.98mm (0.639% and 0.648%), the values of corroded samples were 1.56mm and 1.56mm (-1.044% and -0.981%), coated sample values were 16.05mm and 116.06mm (0.942% and 1.011%).

The comparative results obtained during and after the corrosion test at the maximum value of the rebar diameter were examined at 0.648% compared to the corroded one at -0.981% and the sample with a

coating of 1.011%. The calculated average differential and percentile values were checked (0.01mm and 0.009%), corrosion values (0.01mm and 0.063%) and closed values (0.01mm and 0.069%). The results illustrated 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 percentage recorded from the corrosion samples, while the controlled and coated samples illustrated preserved conditions with increasing layers of different diameters of exudates/resin layer thickness. The use of exudates/resin protects the reinforcing steel from severe corrosion damage. The average and percentile values determined after and before the corrosion test hurts the diameter of the reinforcing steel, which leads to a reduction and an increase in the cross-sectional area.

The minimum and maximum obtained “decreased/increased” in cross-sectional area “(diameter)” of the controlled samples was 0.00 mm, which (100%), corroded -0.04 mm and -0.04 mm (14.95% and -10.11%) and the coated samples were 0.07 mm and 0.07 mm (16.03% and 17.6%). The cross-sectional area of reinforcing steel after corrosion test gives different average and percentile values of corroded values (0.02 mm and 4.84%) and coated values (0.03 mm and 1.57%).

The results obtained illustrated 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 illustrated 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 [12, 14, 19, 20, 25, 13].

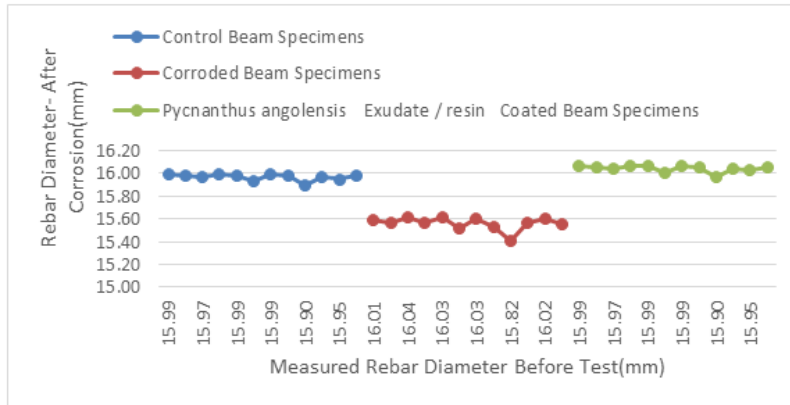


Figure 3.2: Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

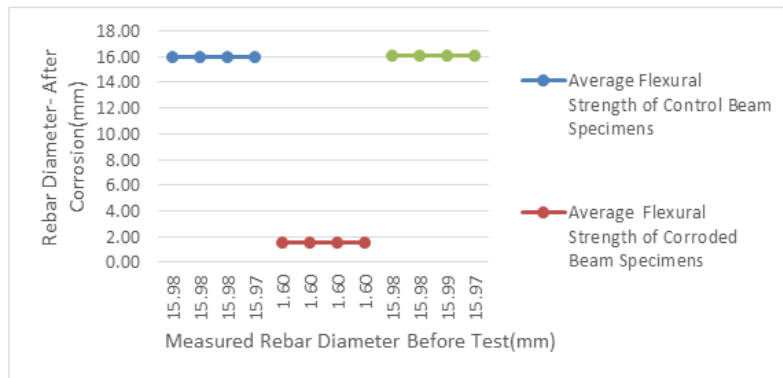


Figure 3.2A: Average Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

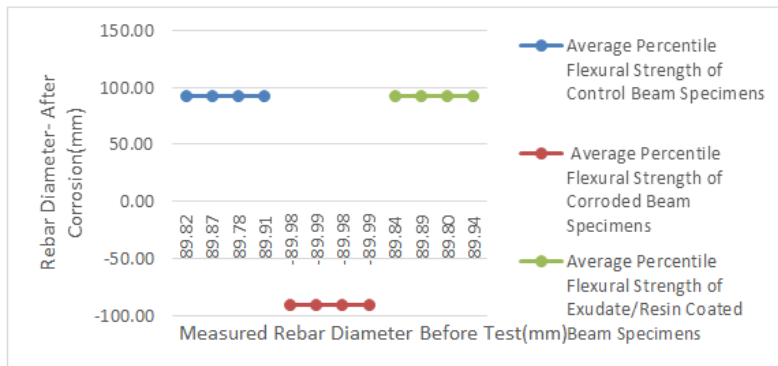


Figure 3.2B: Average Percentile Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

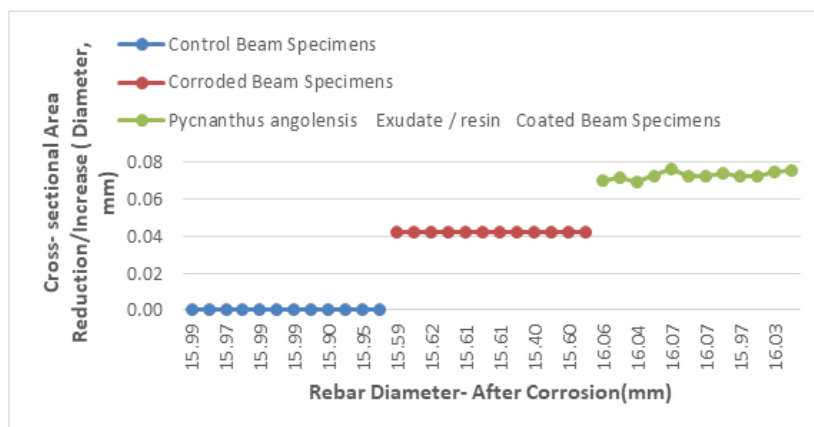


Figure 3.3: Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase (Diameter)

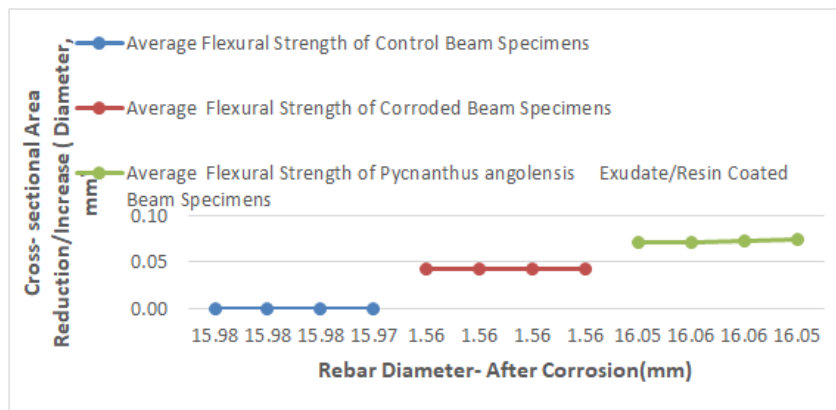


Figure 3.3A: Average Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase(Diameter)

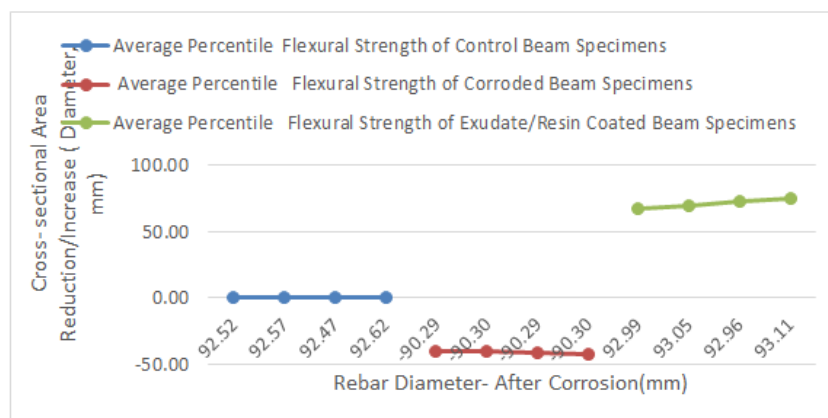


Figure 3.3B: Average Percentile Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase(Diameter)

3.4 Results of Ultimate Tensile Strength and Yield Strength

The corrosion effect of steel can be seen on several levels: at the structural level as structural reduction maximum resistance and ability to redistribute the load due to a change in failure mode; in global or sectional level, such as reducing bending capacity and cutting parts; and at the local or material level, such as the decreased bond between steel and concrete due to cracks in the seams and changes in the material properties of steel reinforcement. The results obtained from the average and minimum and maximum percentile values calculated in Table 3.4 and Table 3.5 from Tables 3.1-3.3 at the yield strength of the controlled sample values are 407.56MPa and 408.56MPa (8.05% and 9.66%), corroded samples are 372.57MPa and 377.87MPa (-8.81% and -7.45%) and coated samples were 407.56MPa and 408.57MPa (8.05% and 9.66%).

The ultimate tensile strength values of controlled samples were 570.33MPa and 572.86MPa (3.52% and 3.54%), corroded samples 550.84MPa and 553.37MPa (-3.72% and -3.7%), and coated samples were 572.13MPa and 574.66MPa (3.85% and 3.86%).

The calculated maximum comparative values for both yield and ultimate tensile strength for the controlled samples were 9.66% and 3.54% to the corroded and coated values of -7.45% and -3.7%, coated values are 9.66% and 3.86%, respectively. Differently calculated average and percentage values of yield strength and maximum tensile strength (1.124MPa and 1.61%) and (2.53MPa and 0.02%) were examined, the corrosion values were (5.3MPa and 1.36%) and (2.53MPa and 0.02%), the values covered are (1.01MPa and 1.61%) and (2.53MPa and 0.01%). From the data obtained and compared, the yield strength and ultimate tensile strength values of the corroded samples illustrated a decrease in the average and percentage values for load failure with few 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 range (controlled samples) illustrated an increase in the average and percentage values with higher loads carrying capacity associated with the studies of [12, 14, 19, 20, 25, 13]. Exudates / resins show efficiency and effectiveness in protecting reinforced concrete structures exposed to corrosive environments.

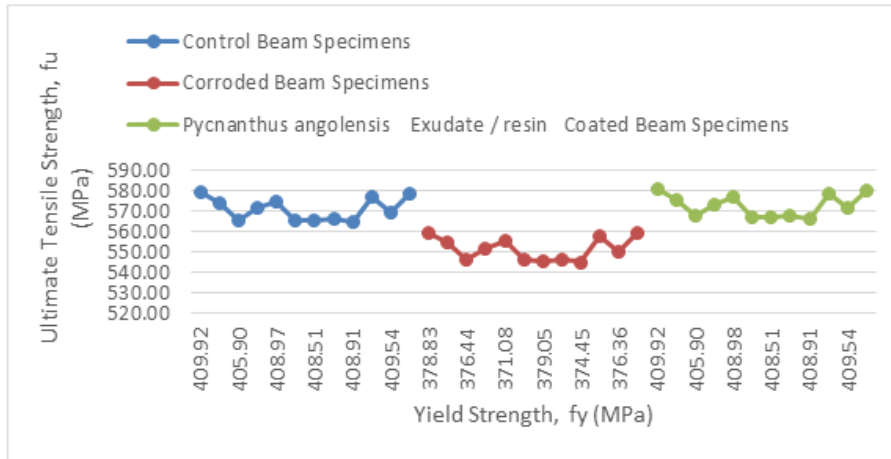


Figure 3.4: Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

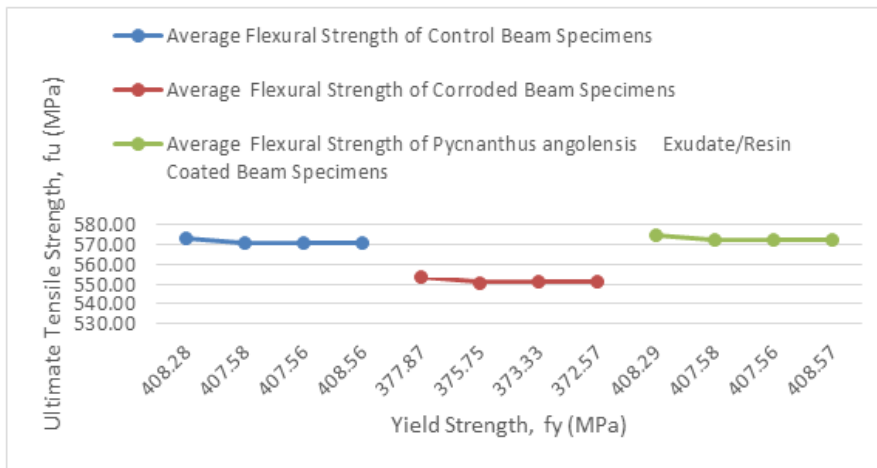


Figure 3.4A: Average Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

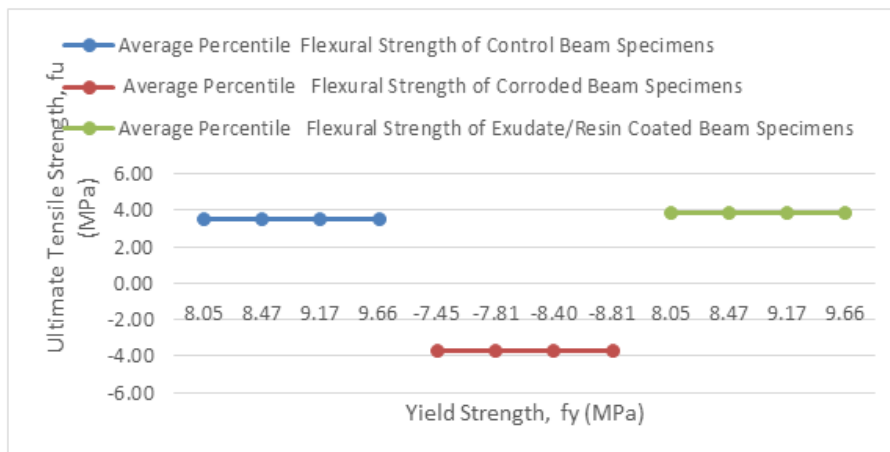


Figure 3.4B: Average percentile Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

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

The corrosion effect of steel becomes more critical when assessing the mechanical properties of

corroded steel bars. Changes in the behavior of corroded steel reinforcement due to monotonous tensile loading have various causes. In the height of the material, the distribution is not homogeneous over the cross-section of the strip of different materials different

these phases are derived from modern production systems. The results of the minimum and maximum average and percentile values calculated in Tables 3.4 and 3.5 from Tables 3.1 to 3.3 elongation values obtained from the controlled sample are 1.4 and 1.4 (-5.59% and -4.19%), the corroded samples gave 1.46 and 1.48 (4.05% and 5.59%), coated sample values were 1.4 and 1.41 (-5.29% and -3.89%). The maximum calculated strain ratio for the average and percentile values for the control was -4.19% compared to the corroded and overlaid values of 5.59% and -3.89%, respectively. The average differential and percentile values obtained for the control were (0.01 and 1.4%), corrosion values (0.02 and 1.54%), and closed values (0.01 and 1.4%).

The results illustrated 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 as validated in recent works of [12, 14, 19, 20, 25, 13].

An additional mechanism to explain the observed modification of the mechanical properties of corroded rods accounts for the geometric effect of uneven reduction from the cross-section of the beam.

The results of the minimum and maximum elongation values (%) for the controlled sample were 19.33% and 20.16% (-24.84% and -24.07%), corrosion values were 25.73% and 26.55% (32.19% and 33.57%), the values of the coated samples were 19.26% and 20.08% -25.13% and -24.35%.

The maximum elongation comparative value for the controlled sample was -12.92% compared to the corroded and coated sample of 20.62% and -23.82%, respectively. The average differential and percentile values obtained for the controlled samples were (0.83% and 0.77%), corrosion values (0.82% and 1.38%), and coated values (0.82% and 0.78%). In comparative, the corroded samples illustrated 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 at low loads; coated samples show a range of values closer to the reference (controlled sample).

The use of exudates materials for rebar has reduced the scourge and tendency of corrosive attack to which reinforced concrete structures in marine coastal areas are heavily exposed in connection with works [12, 14, 19, 20, 25, 13].

The unit Weight - Before testing the average and percentage values of the minimum and maximum calculated in Tables 3.4 and 3.5 and obtained from Tables 3.1-3.3 of the parameters per unit weight before and after corrosion testing, the controlled sample values were 1.6 kg and 1.6 kg (0.063% and 0.068%), corrosion values were 1.56 kg and 11.56 kg (0.064% and 0.069%) and values with coating were 1.64 kg and 1.64 kg (0.067% and 0.069%) and weight of reinforcement - after corrosion (Kg) the average and minimum and maximum percentile values were checked 1.63 kg and 1.63 kg (5.27% and 5.46%), which corrosion values were 1.52 kg and 1.52Kg (-8.53% and -8.4%) are values with a coated of 1.66 kg and 1.66kg (7.17% and 7.25%). The difference values obtained for the average and percentile of the controlled samples were (0.03 and 0.04%), corrosion values (0.04kg and 0.05%), and values with a coating (0.06kg and 0.09%).

The results of the weight loss/weight gain of the minimum and maximum average values and percentage of controlled steel (100%) for the controlled sample, leading to their combination in freshwater without any trace of corrosive attack, corroded sample values of 0.05kg and 0.05kg (-22.7% and -20.95%), coated samples 0.06kg and 0.06kg (26.5% and 29.36%).

The calculated data for the maximum percentage of reinforcement beam weight before corrosion test for controlled, corroded, and coated values were 0.063%, 0.065%, and 0.069%. The maximum comparative values recorded after the corrosion test for the controlled sample remained the same, without any trace of a corrosive effect, because it was incorporated in freshwater, for the corroded and coated samples the values were -7.28% and 6.52%, respectively.

The percentage of maximum weight loss/gain for corroded and coated samples was -20.95% and 29.36%, respectively. The calculated data illustrated 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 illustrated an increase in weight compared to the reference value of the controlled sample due to the different coating thicknesses as seen in recent works of [12, 14, 19, 20, 25, 13].

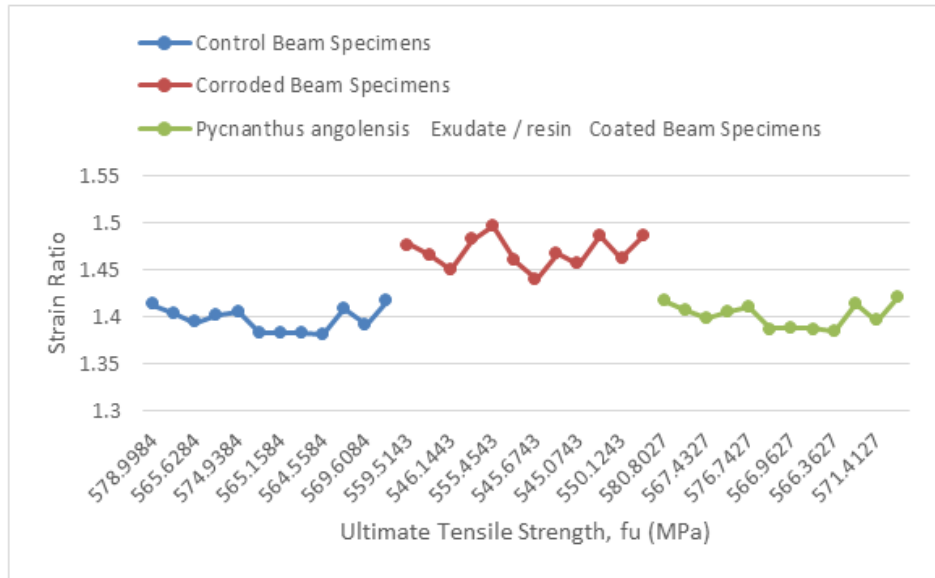


Figure 3.5: Ultimate Tensile Strength versus Strain Ratio of Beam Specimens

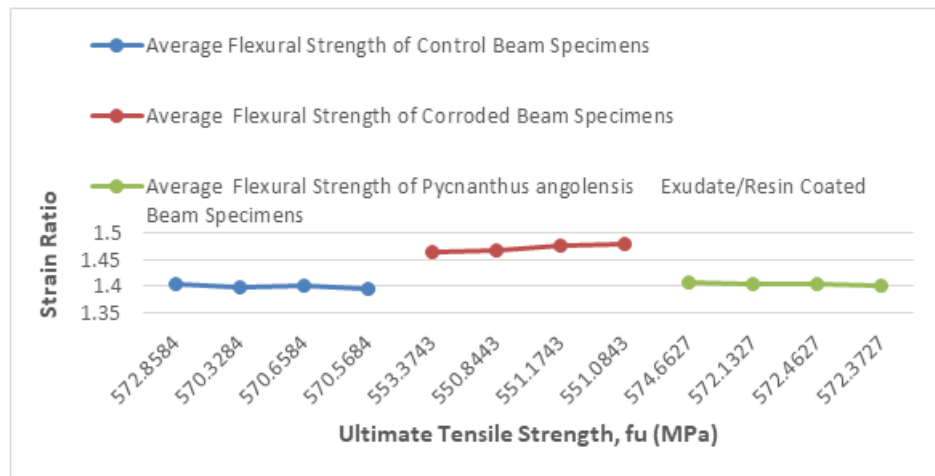


Figure 3.5A: Average Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

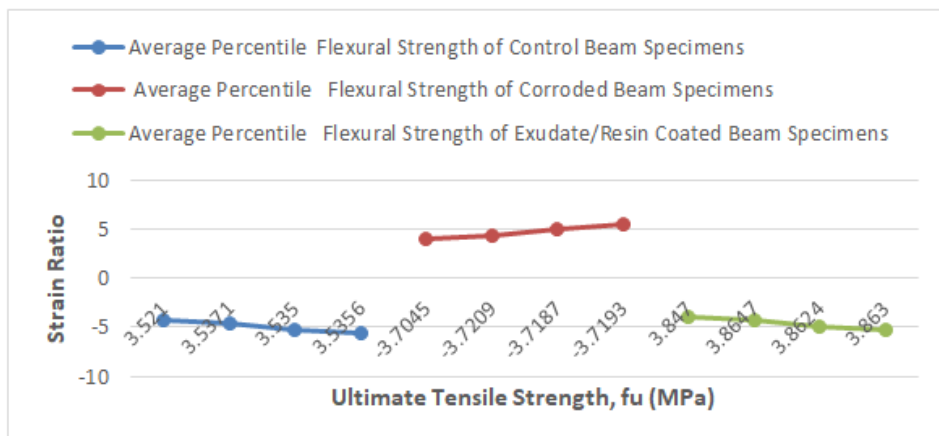


Figure 3.5B: Average Percentile Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

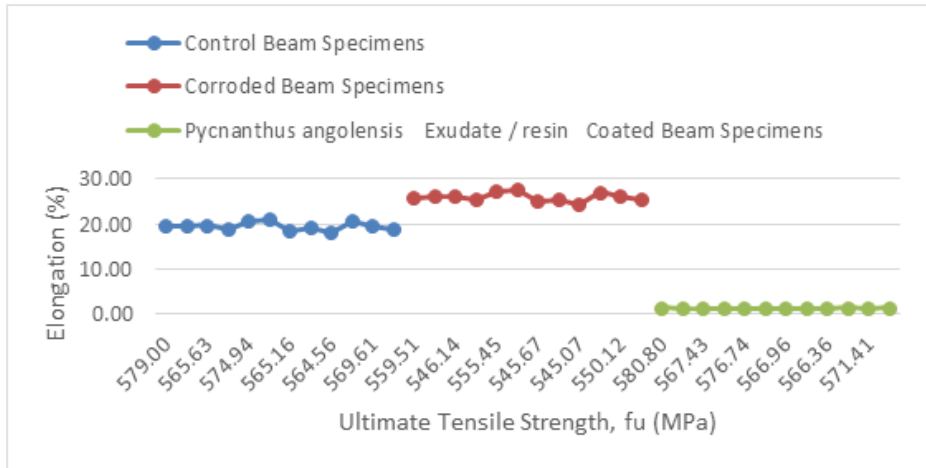


Figure 3.6: Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

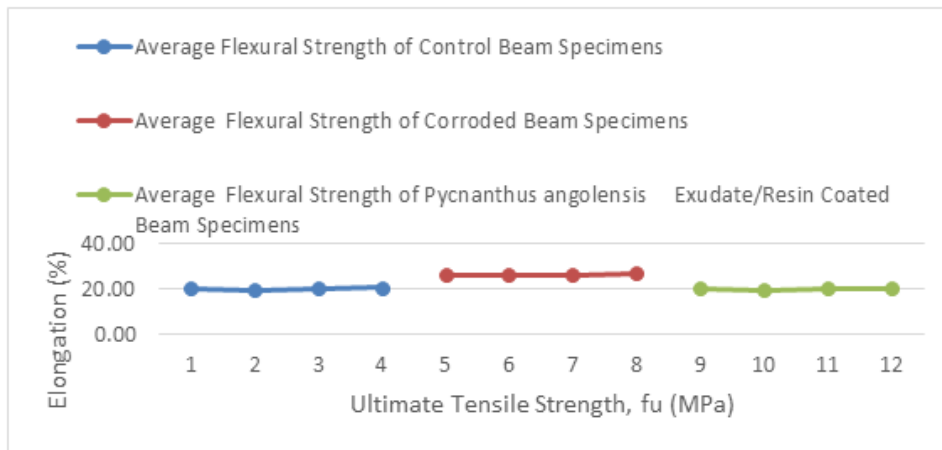


Figure 3.6A: Average Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

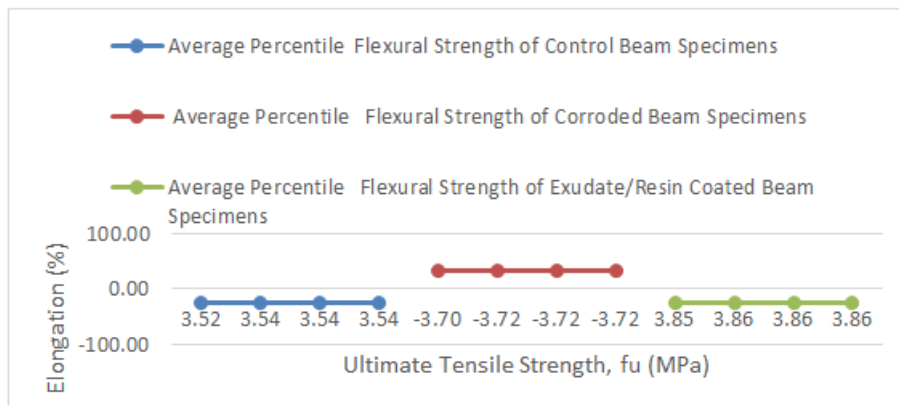


Figure 3.6B: Average Percentile Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

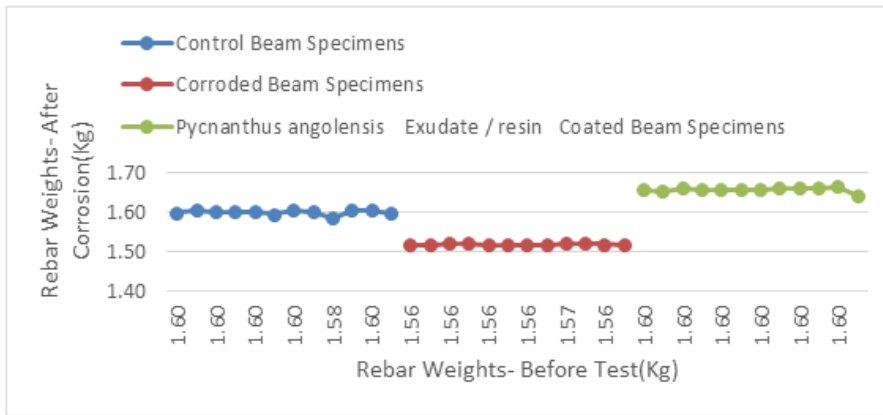


Figure 3.7: Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens)

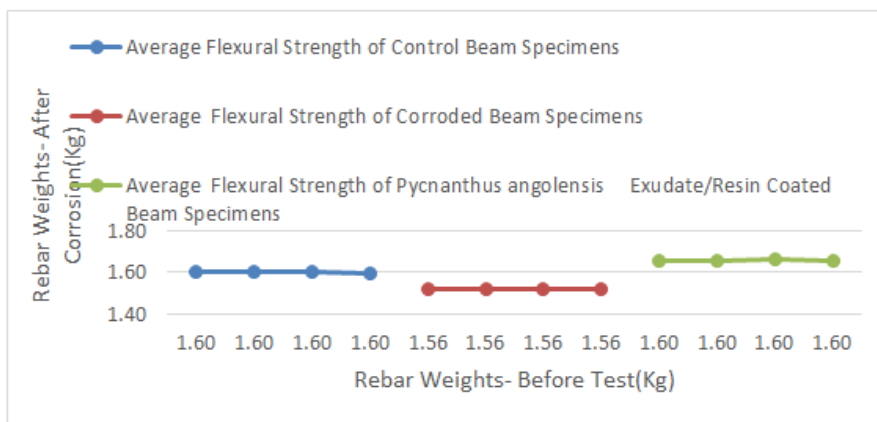


Figure 3.7A: Average Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens)

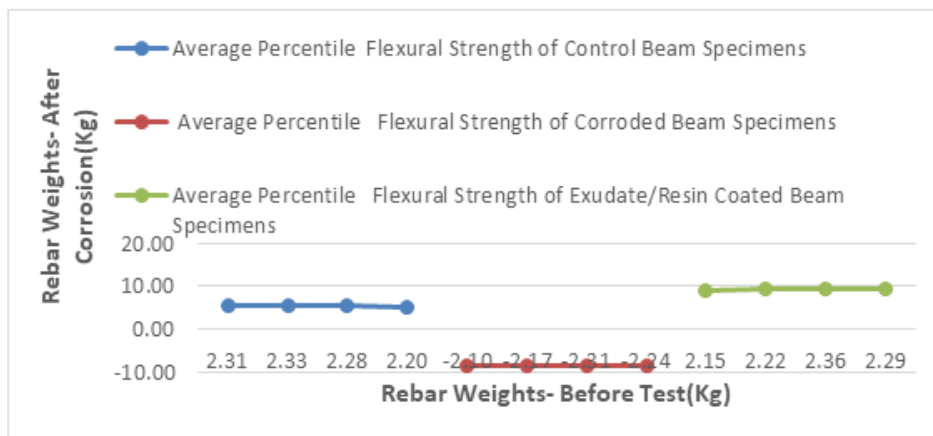


Figure 3.7B: Average Percentile Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens)

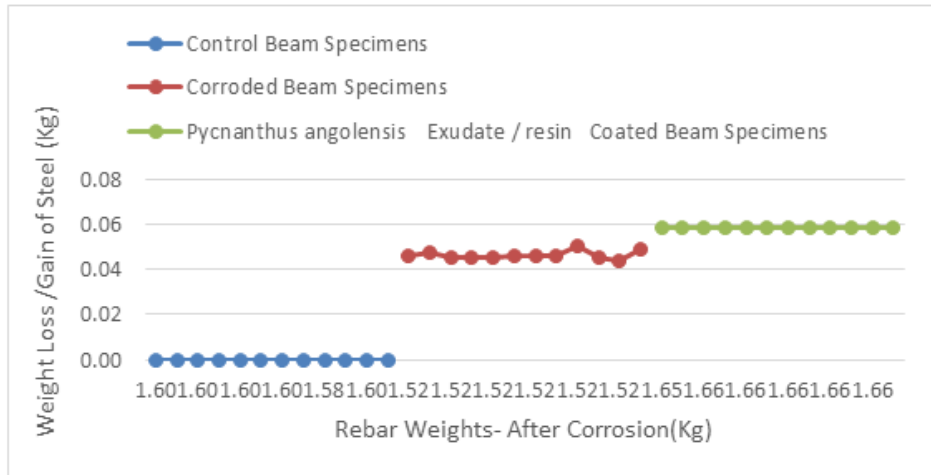


Figure 3.8: Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimen

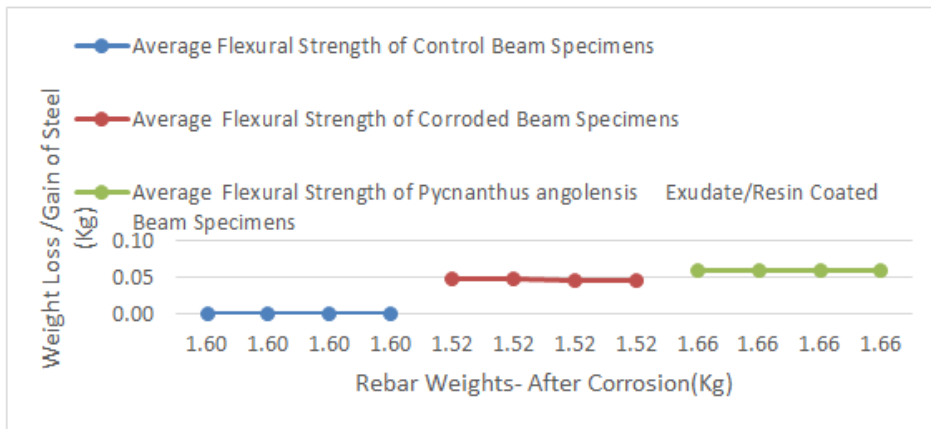


Figure 3.8A: Average Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

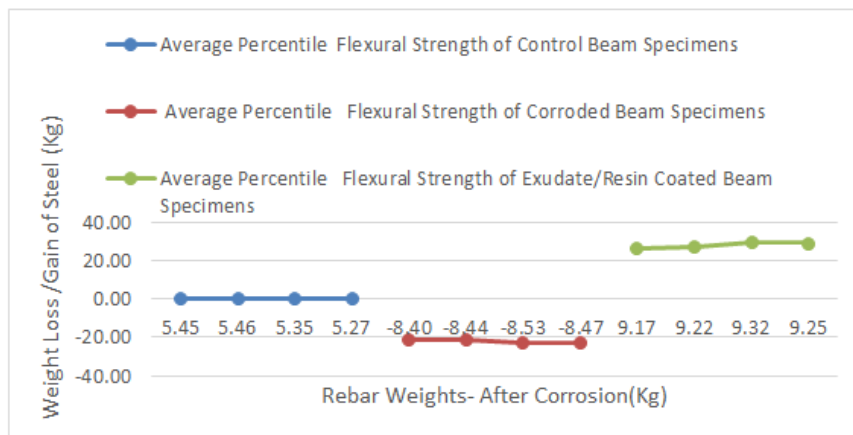


Figure 3.8B: Average Percentile Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

4.0 CONCLUSION

The experimental results obtained are summarized as follows:

1. The results illustrated 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 illustrated 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 illustrated 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 comparative 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 rang.

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