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Original Research Article

Effects of Corrosion on Mechanical Properties of Reinforcing Steel Residual Flexural Strength

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Abstract

The study examined the use of exudates/resins from extracts of natural origin for environmentally friendly materials derived from tree trunks. Gummy exudates/resin was applied directly to the steel reinforcement by the coating of different thicknesses. The purpose of this study is to determine the role of exudates/resin against adverse attack on reinforcement embedded in concrete, exposed to the severe environment due to its waterproofing and resistance to surface modification of steel reinforcement and coating application. In the flexural strength test, the maximum value was 28.36% compared to the corroded and coated sample values of -20.02% and 28.37%, respectively. Mean differential and percentile range controlled (0.96kN and 3.07%), corroded (0.82kN and 2.08%), coated (1.13kN and 3.33%). The results of midspan deflection mean value and percentage difference were controlled (0.27kN and 1.66%), corroded (0.57kN and 4.61%), and coated (0.27kN and 1.68%). The results showed a lower elongation load in the controlled and coated samples with reduction values over the corroded samples with higher elongation loads and higher values compared to the reference range (controlled). The cross-sectional area of reinforcing steel recorded the mean differential values and calculated percentile values, corroded (0.06 mm and 5.21%) and coated values (0.05 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 differential computed average and percentile value of the yield strength and ultimate tensile strength are controlled (5.31MPa and 1.16%) and (2.53MPa and 0.02%), the corroded values are (3.18MPa and 1.05%) and (2.53MPa and 0.02%), the coated values are (5.3MPa and 1.16%) and (2.53MPa and 0.02%). The percentages of maximum weight loss/gain for corroded and coated samples were -28.54% and 43.9%, respectively. The calculated data showed a decrease in the value of the corroded sample as a result of the corrosion attack, which led to a decrease in the registered weight, whereas the coated sample showed an increase in weight compared to the reference value of the controlled sample due to the different coating thickness.

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

1.0 INTRODUCTION

Corrosion of reinforced steel is a major cause of degradation [1] as well as the weakening of the durability of reinforced concrete structures [2, 3]. The progressive spread of corrosion properties from the reinforcement and to the concrete surface causes a separating stress in the concrete and possibly cause cracking and hatching of the layer [4]. This weakens the bond strength between steel and concrete, which affects the flexural stiffness and shear capacity of the components [5-8]. In addition, corrosion corrosion causes local cross-sectional losses, which leads to a decrease in the ductility and strength of corroded reinforcing bars. Mechanical corrosion damage at the material level (concrete, steel and bond strength) therefore leads to reduced structural efficiency of reinforced concrete elements and further affects the overall behavior structural system.

Corrosion rate is considered as one of the main parameters to predict the useful life of corrosive reinforced concrete structures [3]. Concrete structures exposed to harsh environments are susceptible to intrusion damage and repairs require high maintenance costs [9]. However, engineers and workers who work in the field usually do not have basic principles to determine the corrosion status of reinforcement [10]. The presence of chloride at a sufficient concentration at the steel concrete interface causes damage to the reinforcement by attacking the passive layer. The reversible dilution shift directly affects the possibility of strength and moment redistribution and limits the carrying capacity of the static instability structure, and can severely reduce the capacity of a structure under seismic loads. Corrosion caused by carbonization and chloride causes a decrease in the mechanical properties of reinforced concrete structures. Although it has been found that corrosion damage does not significantly affect the ductility of reinforced concrete sections [11], it does lead to chipping and cracking of the concrete, reduced reinforcement properties, and loss of interfacial joints. The corrosion process once started causes damage and destruction of the RC members.

Experimented with corroded reinforced concrete beams; of 150 mm × 150 mm × 500 mm dimension of the 30 beams has 16 predetermined cracks, which helps to study the flexibility effect and behavior of the beams due to reinforcing the steel bar area loss. The current use of beams that accelerate the corrosion rate has reduced the beam's load capacity. Experimental results showed that the loading capacity was reduced by 10%[12].

Established a different method; that caused structural collapse resulting from reinforcement corrosion is indirectly related to the loss of the strength of the bars resulting from the cross-sectional deformation, such as crack growth in concrete and low bonding which in turn affect the structure greatly and reduce the service life [13].

Investigated the characteristics of beam failure in bonding due to corrosion of reinforcement, and conducted two series of tests; the beam tests were simulated with uniform corrosion, while exit tests were used to simulate severe local corrosion. They found that the ultimate bond pressure in the test of similar corrosion-pulling bonds was due to the failure of the steel rods, but not from the bond failure [14].

Investigated the loss of reinforced concrete structures reinforcing steel in tension due to the damage done from corrosion. The Beam section, which contained 0.95% reinforcement and the panel, was tested for various bar lengths exposed. A single-point load release from the mid-span of all bamboo structures was adopted and the load was applied to the part where the reinforcement remained attached to the concrete, differences in the fracture formation pattern were observed in samples with discarded bars. Disclosure of the reinforcement results in up to 20% of the beam space in the minimum load loss [15].

Investigated the residual strength of reinforcing steel of non-corroded, corroded and inhibited members with exudates / resins paste and subjected to flexural failure load, midspan deflection, tensile strength and elongation. The results entirety showed that the inhibited steel bar exhibits increased and higher values of failure load application and tensile strength while corroded members decreased with low failure load and midspan deflection. Results has it that corroded members failed on low load application with deep midspan deflection resulting from the effect of corrosion on the mechanical properties of reinforcing steel [16].

Investigated the impact of the durability of varying degrees of resin / exudates extract of dacryode edulis, moringa oleifera lam, and mangifera indica paste on reinforcing concrete. Overall results indicate that coated members exhibited anti-corrosion and inhibitory potential with high values to flexural failure load. Corroded members exhibited high yield on load application [17].

Evaluated the effects of corrosion inhibitors on flexural failure load, midspan deflection, tensile strength and elongation of steel reinforcement coated with resins / exudates of magnifera indica extracts, embedded in concrete and exposed to harsh corrosive media. The overall results showed corrosion effect on the flexural strength of the reinforcement, which resulted in low mid-span deflection on the failure load and the reduced mid-span deflection on the failure load and the low mid-span deflection on the non-corroded and coated concrete beam members[18].

Investigated yield strength capacity with the use of natural resin / exudates coated to reinforcing steel embedded in concrete under accelerated medium. Coated members exhibited corrosion-free. Overall results indicated that fatigue and decreased load on tensile strength resulted in an attack and decrease in yield strength due to low loads on the midspan and elongation with corrosion potential on non-coated members[19].

Investigated the effects of corrosion on residual structural capacity of steel bar coated with resins / exudates and non-coated reinforced concrete beams members exposed to sodium chloride media. The full test results showed that corroded specimens have low flexural load, high midspan deflection, low tensile strength, and excessive length of steel bar, fiber loss from corrosion degradation [20].

Investigated the effect of flexural strength and mid-spacing deflection of steel reinforcements coated with resin / exudates extract called corrosion inhibitors. For corroded steel reinforcement members, the flexural strength of the failure loads was lower than that of the dacryodes edulis coated and non-corroded steel reinforcement test, while the mid-span deflection was higher for corroded reinforced members [21].

Evaluated the effects of corrosion inhibitors (inorganic origin) resins / exudates on the residual flexural strength of reinforced concrete beam members immersed for 90-day for corrosion detection test on possible changes in sample investigation conditions. These results indicated that flexural flexure load and ultimate tensile strength increased and that midspan deflection and elongation decreased, respectively, in corroded concrete beam members [22].

Investigated the utilization of eco-friendly inorganic production of artocarpus altilis exudates / resins in the prevention of corrosion attack on reinforcing steel embedded in concrete. According to the results of the corroded members, the effect of the mechanical properties of reinforcing steel embedded in concrete media has high flexural load, midspan deflection and coating of the exudates / resins and ultimate tensile strength against non-corroded members. Controlled results have higher midspan deflection, higher yield strength, and lower strain rate compared to coated members. Entire results showed crack and spalling resistance to corrosion attack on reinforcing steel members [23].

Research work aimed at reducing the corrosion reduction of steel reinforcements in the brine by introducing exudates/resins of coated Indicia gabonensis to reinforce 150µm, 300µm, and 450m thick steel. Detailed test results have shown potential corrosion resistance with coating members on mechanical properties that strengthen the effects of weight loss, cracking, and spalling and weight loss. Experimental results show signs of corrosion for non-coated members with possession of corrosive properties that reduce the thickness of the metal surface, resulting in metallic weight loss and cracking. These symptoms lead to failure of variable load and high retention capacity with low average usage, high levels of anxiety, extension, and midspan deflection [24]**.**

Investigated the naturally available inorganic products of Garcinia cola extract as a protective layer to reinforce the steel embedded in concrete [25]. The members were immersed in an extremely corrosive environment and accelerated for 150 days with tests on changes in the mechanical properties of the steel. Indications have shown that the properties of depleted members are caused by corrosion that attacks the surface properties of reinforcing steel and reducing the general mechanical properties of the steel. Results from exudates/resins coated members showed less flexibility failure over corroded members with shorter, less midspan deflection. Non-corroded member outcomes include flexural flexure load, low midspan deflection and yield strength, strain ratio, and high values of extension over corroded members.

Investigated the deterioration of the surface modifications and mechanical properties of steel reinforcement in concrete structures constructed in salt water-related environments with 150 days of corrosion acceleration process and determined corrosion probability. The corrosion properties of the spalling and fractures in the non-coated members showed that the overall experimental results were indicative of the low flexibility failure load; Midspan deflection, extension, strain ratio, and ultimate yield. The effect of corrosion on the mechanical properties of reinforcing steel on corroded (controlled) members has not been observed. Coated members showed less; Midspan deflection, extension, and ultimate yield, high flexibility failure load required and compared to corroded members[26].

2.1 MATERIALS

2.1.1 Aggregates

Fine and coarse aggregates were purchased. Both met the requirements of [27].

2.1.2 Cement

Portland lime 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 [28].

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 [29].

2.1.4 Structural Steel Reinforcement

Reinforcements are obtained directly from the market at Port Harcourt, Confirmed at [30].

2.1.5 Corrosion Inhibitors (Resins / Exudates) Anogeissus latifolia (Combretaceae)

The ghatty gummy sticky exudates were obtained from tree trunk of Anogeissus leiocarpus from Benue State, in Achaba, Ebukodo and Ologba villages of Apa Local Government Area.

2.2 METHODS

The study examined the use of exudates/resins from extracts of natural origin for environmentally friendly materials derived from tree trunks. Gummy exudates/resin was applied directly to the steel reinforcement by the coating of different thicknesses, embedded in the concrete beams, and its application was studied as a corrosion inhibitor.

The study aims to use widely available local materials to control the negative impact of corrosion attacks on steel reinforcement embedded in concrete structures in marine environments with high salinity (sodium chloride). Concrete beam specimens of 175 mm x 175 mm 750 mm, thickness, width, and length were embedded with four (4) numbers 16 mm diameter reinforcing steel and cured for initial 28 days and transported for corrosion acceleration stimulation sodium chloride (NaCl) media tank for 360 days. The process of corrosion exposure is a long-term process naturally and it takes many years to complete, but the introduction of sodium chloride (NaCl) accelerates and stimulates the rate of corrosion rapidly, indicating the coastal area, and the period during which this process can be achieved. The purpose of this study is to determine the role of exudates/resin against adverse attack on reinforcement embedded in concrete, exposed to the severe environment due to its waterproofing and resistance to surface modification of steel reinforcement and coating application.

2.2.1 Preparation and Casting of Model Concrete Beams

The standard method for the concrete mix ratio is followed, which is set manually according to the weight of the material. Concrete mix ratio 1:2:4, water-cement ratio 0.65 according to the weight of the concrete. Manual mixing is used on clean concrete benches and the mix is checked and water is added slowly to create a complete concrete mix design. A constant uniform color and consistency is achieved by adding concrete cement, water and aggregate. The test carrier is poured into a 175 mm x 175 mm x 750 mm steel mold, which is compressed with air and embedded with 4 mm steel reinforcement with a diameter of 16 mm. Samples were deformed after 72 hours and treated for 28 days with standard procedures, and samples were treated for 90 days, 180 days, 270 days and 360 days at room temperature for rapid corrosion testing and crack observation.

2.2.2 Flexure Testing of Beam Specimens

According to [31], a universal testing machine was used to test flexibility and a total of 36 carrier models were tested. After curing for the first 28 days, 12 bar (uncoated) was checked for corrosion protection, while the 24 bar sample was uncoated and the exudates/resin sample was treated with 5% sodium chloride (NaCl) for 360 days. Investigations of surface changes and mechanical properties were carried out on uncoated (corroded) and coated samples at 3-month intervals of 90 days, 180 days, 270 days and 360 days. Flexibility was tested on a universal Instron testing machine with a capacity of 100 KN. The sample is placed in the machine according to specifications and, in a third step, a flexibility test is performed on two carriers. The results digitally record cracks and corresponding values of flexural strength loads, average span deformation and all relevant studies on reinforcement diameter measured before testing, reinforcement diameter - after corrosion, reduction/increase in cross-sectional area, yield point, deformation ratio , elongation, Weight of reinforcement - before testing, weight of reinforcement- after corrosion and weight loss/gain of steel were observed and recorded.

Table-3.1: Flexural Strength of Beam Specimens (Controlled)

Samples	**Samples A**			**Samples B**			**Samples C**			**Samples D**		
Items	AL	AL1	AL2	AL3	AL4	AL5	AL6	AL7	AL8	AL9	AL10	AL11
Flexural Strength Load (KN)	82.78	82.62	81.49	85.47	81.91	82.42	82.73	82.05	82.98	80.73	82.93	84.71
Midspan Deflection (mm)	7.94	8.02	8.62	8.73	7.82	8.76	7.85	8.02	7.82	7.90	7.90	8.75
Nominal Bar diameter (mm)	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Measured Rebar Diameter Before Test(mm)	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)	410.31	409.82	407.92	411.94	411.56	410.94	410.53	411.05	410.93	411.75	411.34	410.99
Ultimate Tensile Strength, fu (MPa)	587.72	582.67	574.35	580.13	583.66	574.08	573.88	574.68	573.28	585.83	578.33	587.19
Strain Ratio	1.43	1.42	1.41	1.41	1.42	1.40	1.40	1.40	1.40	1.42	1.41	1.43
Elongation (%)	18.92	18.99	19.12	18.32	20.12	20.46	17.92	18.49	17.42	20.02	18.96	18.25
Rebar Weights- Before Test	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.58	1.57	1.57	1.53
Rebar Weights- After at 28 days (Kg)	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.58	1.57	1.57	1.53
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)

	AL1A	**AL1B**	**AL1C**	**AL1D**	**AL1E**	**AL1F**	**AL1G**	**AL1H**	**AL1I**	**AL1J**	**AL1K**	**AL1L**
Flexural Strength Load (KN)	67.02	64.17	65.73	66.36	66.15	67.95	66.97	66.29	67.22	66.66	66.67	69.71
Midspan Deflection (mm)	12.96	13.04	13.64	13.75	12.84	13.78	12.87	13.04	12.84	12.92	12.92	13.77
Nominal Rebar Diameter	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Measured Rebar Diameter Before Test(mm)	15.95	15.94	15.93	15.95	15.95	15.89	15.95	15.94	15.86	15.92	15.91	15.94
Rebar Diameter- After Corrosion(mm)	15.89	15.87	15.83	15.80	15.89	15.88	15.89	15.85	15.88	15.88	15.89	15.87
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.07	0.08	0.07	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Yield Strength, fy (MPa)	382.67	395.18	393.28	389.30	387.92	391.00	395.89	389.41	391.29	392.11	393.20	393.22
Ultimate Tensile Strength, fu (MPa)	564.24	559.19	550.87	556.65	560.18	550.60	550.40	551.20	549.80	562.35	554.85	563.71
Strain Ratio	1.47	1.42	1.40	1.43	1.44	1.41	1.39	1.42	1.41	1.43	1.41	1.43
Elongation (%)	24.63	24.70	24.83	24.03	25.83	26.57	23.63	27.00	27.13	25.73	24.67	26.56
Rebar Weights- Before Test(Kg)	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.57	1.58
Rebar Weights- After Corrosion(Kg)	1.53	1.53	1.53	1.53	1.53	1.53	1.52	1.53	1.53	1.53	1.53	1.52
Weight Loss /Gain of Steel (Kg)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05

Table-3.3: Flexural Strength of Anogeissus latifolia Exudate / resin Coated Beam Specimens

	AL1A 1	**AL1B 2**	**AL1C 3**	**AL1D 4**	**AL1E 5**	**AL1F 6**	**AL1G 7**	**AL1H 8**	**AL1I 9**	**AL1J 10**	**AL1K 11**	**AL1L 12**
	150µm (Exudate/Resin) coated			300µm (Exudate/Resin) coated			450µm (Exudate/Resin) coated			600µm (Exudate/Resin) coated		
Flexural Strength Load (KN)	82.78	82.12	81.49	85.47	81.91	82.42	82.73	82.05	82.98	79.93	82.43	83.71
Midspan Deflection (mm)	8.01	8.09	8.69	8.80	7.89	8.83	7.92	8.09	7.89	7.97	7.97	8.82
Nominal Rebar Diameter	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Measured Rebar Diameter Before Test(mm)	16.00	15.99	15.98	16.00	16.00	15.94	16.00	15.99	15.91	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	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Yield Strength, fy (MPa)	410.31	409.82	407.92	411.94	411.56	410.94	410.53	411.05	410.93	411.75	411.34	410.99
Ultimate Tensile Strength, fu (MPa)	589.53	584.48	576.16	581.94	585.47	575.89	575.69	576.49	575.09	587.64	580.14	589.00
Strain Ratio	1.44	1.43	1.41	1.41	1.42	1.40	1.40	1.40	1.40	1.43	1.41	1.43
Elongation (%)	18.85	18.92	19.05	18.25	20.05	20.39	17.85	18.42	17.35	19.95	18.89	18.18
Rebar Weights- Before Test(Kg)	1.56	1.57	1.56	1.56	1.56	1.56	1.56	1.56	1.57	1.56	1.56	1.56
Rebar Weights- After Corrosion(Kg)	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63
Weight Loss /Gain of Steel (Kg)	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07

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

	Average Flexural Strength of Control Beam Specimens				**Average Flexural Strength of Corroded Beam Specimens**				**Average Flexural Strength of Exudate/Resin Coated Beam Specimens**			
Flexural Strength Load (KN)	82.30	83.19	82.95	83.26	65.64	65.42	66.08	66.82	82.13	83.03	82.96	83.27
Midspan Deflection (mm)	8.19	8.46	8.39	8.44	13.22	13.48	13.41	13.46	8.26	8.52	8.46	8.50
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)	15.88	15.88	15.85	15.88	15.74	15.89	15.94	15.93	15.89	15.89	15.86	15.85
Rebar Diameter- After Corrosion(mm)	15.99	15.99	15.99	15.97	15.86	15.83	15.84	15.86	16.05	16.06	16.06	16.05
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-0.08	-0.11	-0.10	-0.07	0.33	0.29	0.25	0.27
Yield Strength, fy (MPa)	409.35	409.89	410.47	411.48	390.38	392.59	390.17	389.41	409.35	409.89	410.47	411.48
Ultimate Tensile Strength, fu (MPa)	581.58	579.05	579.38	579.29	558.10	555.57	555.90	555.81	583.39	580.86	581.19	581.10
Strain Ratio	1.42	1.41	1.41	1.41	1.43	1.42	1.42	1.43	1.43	1.42	1.42	1.41
Elongation (%)	19.01	18.81	19.19	19.64	24.72	24.52	24.90	25.48	18.94	18.74	19.12	19.56
Rebar Weights- Before Test(Kg)	1.57	1.57	1.57	1.57	1.58	1.58	1.58	1.58	1.56	1.56	1.56	1.56
Rebar Weights- After Corrosion(Kg)	1.57	1.57	1.57	1.57	1.53	1.53	1.53	1.53	1.63	1.63	1.63	1.63
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.07	0.07	0.07	0.07

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

	Average Percentile Flexural Strength of Control Beam Specimens				**Average Percentile Flexural Strength of Corroded Beam Specimens**				**Average Percentile Flexural Strength of Exudate/Resin Coated Beam Specimens**			
Flexural Strength Load (KN)	25.38	27.17	25.54	24.62	-20.09	-21.22	-20.35	-19.76	25.14	26.93	25.55	24.63
Midspan Deflection (mm)	-38.02	-37.28	-37.46	-37.33	59.99	58.14	58.59	58.27	-37.50	-36.76	-36.95	-36.82
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)	0.3757	0.3617	0.3197	0.3487	0.3833	0.3693	0.3573	0.3563	0.396	0.3837	0.3417	0.3697
Rebar Diameter- After Corrosion(mm)	0.78	0.96	0.93	0.75	-1.20	-1.38	-1.36	-1.’19	1.22	1.40	1.38	1.21
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-9.50	-9.33	-9.36	-9.54	20.10	14.76	15.55	21.41
Yield Strength, fy (MPa)	4.86	4.41	5.20	5.67	-4.63	-4.22	-4.95	-5.36	4.86	4.41	5.20	5.67
Ultimate Tensile Strength, fu (MPa)	4.21	4.23	4.22	4.23	-4.33	-4.35	-4.35	-4.35	4.53	4.55	4.55	4.55
Strain Ratio	-0.85	-0.88	-0.94	-0.87	1.35	1.43	1.63	1.47	-1.35	-1.13	-1.33	-1.06
Elongation (%)	-23.08	-23.27	-22.92	-22.92	30.52	30.85	30.24	30.23	-23.39	-23.58	-23.22	-23.21
Rebar Weights- Before Test(Kg)	0.068	0.068	0.067	0.069	0.06	0.068	0.065	0.068	0.067	0.065	0.065	0.068
Rebar Weights- After Corrosion(Kg)	3.82	3.83	3.82	3.83	-6.32	-6.28	-6.24	-6.26	6.75	6.70	6.66	6.68
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	-22.06	-22.39	-24.07	-23.77	28.31	28.84	31.70	31.19

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, and the application of exudates extract/resin from Anogeissus latifolia from wood sources with direct environmentally friendly effect on reinforced concrete built-in concrete beams was evaluated for its effectiveness as a corrosion inhibitor.

Corrosion of reinforcing steel in concrete structures takes many forms and the resulting product occurs when chemical reactions occur between the metal and its surroundings. Corrosion products formed on the bars, which increase their volume and generate stress in the surrounding concrete, which causes cracking, flaking, and discoloration of the concrete and reduces the effective cross-sectional area of the reinforcing bars and thus has a lower load-bearing capacity. The corrosion of steel rods in concrete is affected by a large number of parameters such as the water-cement ratio, permeability, concrete layer, crack width, and the use of additional cementitious materials.

Stated that bonding affects the load-carrying capacity rather than the loss of tensile strength of reinforcement due to general corrosion [32].

Experimental data for flexural tests on concrete girder samples are shown in Tables 3.1, 3.2, and 3.3, summarized in 3.4, mean and percentile values in 3.5, and the results are shown graphically in Figures 3.1 - 3.7b. The average value and the minimum and maximum percentage calculated are the Flexural Strength Load obtained from the Instron Universal Testing Machine with a load of 100kN under compression until the failure state and the controlled sample values are 81.82kN and 82.79kN (25.29% and 28.36 %), the corroded values of the samples were 64.49kN and 65.31kN (-22.1% and -20.02%) and the exudate/resin coated samples were 81.66kN and 82.79kN (25.04 % and 28.37%).

In the flexural strength test, the maximum value was 28.36% compared to the corroded and coated sample values of -20.02% and 28.37%, respectively. Mean differential and percentile range controlled (0.96kN and 3.07%), corroded (0.82kN and 2.08%), coated (1.13kN and 3.33%).

The corrosion of reinforcing steel in concrete construction has many forms and the product is obtained when a chemical reaction occurs between the metal and its surroundings. Corrosion products form on the bars, which increase their volume and put stress on the surrounding concrete, which causes cracking, peeling, and staining of the concrete and reduces the effective cross-sectional area of the reinforcing bars and thus has a lower load-bearing capacity. The results show that the reference percentage of the controlled sample was placed in freshwater according to BS 3148 and no corrosion effect was observed and was therefore used as a reference value for uncoated and coated in a corrosive environment as described in the test program. Corroded specimens failed with a lower load, whereas coated specimens have a higher load if the failure occurs. The results further confirm that the flexural stress-strain of controlled and coated specimens maintains a narrow range of values over the corroded specimens at moderate, reduced, and lower loads.

The results of midspan deflection minimum and maximum average and percentage of deformation recorded in the controlled material were 7.93kN and 8.17kN (-41.08% and -39.42%), corroded samples were 13.22kN and 13.79kN (63.68). % and 68.29%) and the coated samples were 7.97kN and 8.24kN (-40.58% and -38.9%). The differential comparative results showed that the maximum value of the failure state was checked at (-39.42% against 68.29% corroded and -38.9% coated samples.

The midspan deflection mean value and percentage difference were controlled (0.27kN and 1.66%), corroded (0.57kN and 4.61%), and coated (0.27kN and 1.68%). The results showed a lower elongation load in the controlled and coated samples with reduction values over the corroded samples with higher elongation loads and higher values compared to the reference range (controlled) and the results of the differential comparative of flexural strength and deformation load in the midspan of the corroded sample showed the effect of corrosion on the mechanical properties of reinforcing steel with detached ribs, high surface modification, which led to low load carrying capacity and high deformation at the midspan which is associated with the works of [17, 20, 16, 26, 23]. From the results obtained, ficus plane tree exudate/resin 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.

3.2 Results of Measured Rebar Diameter Before and After Corrosion Test

Reinforced concrete structures constructed in the coastal marine environments are most at risk of chloride-induced corrosion due to their high saltwater content. The formation of a surface film covering the metal, although generally protective, can lead to localized corrosion attack and pitting [33]. The phenomenon of corrosion in reinforced concrete structures causes two main forms of spalling and cracking of the concrete surface as a result of unconfined corrosion and local extraction of reinforcement at the anode, resulting in a sharp reduction in the cross-sectional area.

Concluded that steels in an oxidizing atmosphere such as air have direct film formation and after observing “passive” and oxidized or “rusting” metal film formation the “Delayed” becomes less than 0.04 million per year (mpy). The results of the minimum and maximum mean and percentile values for values the nominal diameter of the value is 16 mm (100%) for all common standards. The fitting diameters measured before testing for controlled samples were 15.97 mm and 15.99 mm (0.36% and 0.39%), which corroded were 15.94 mm and 15.97 mm (0.33% and 0, respectively). 34%) and coverage of 15.98 mm and 15.99 mm (0.34% and 0.38%). The results obtained indicated that the diameter of the reinforcing steel fluctuates within a few minutes due to the manufacture of reinforcement by different companies; the manufacture of the mold used has caused the average value and the percentage difference to be insignificant [34-36].

The average values and the minimum and maximum percentages of the anchor diameter - after the controlled corrosion test were 15.97mm and 15.99 mm (0.63% and 0.69%), the corroded sample values were 15.88mm and 15. 91mm (-1.10% and -0.91%), the values of the coated samples were 16.05mm and 16.06mm (0.91% and 1.11%).

The differential comparative results obtained during and after the corrosion test the maximum value of the diameter of the anchor checked was 0.69% compared to the corroded one at -0.91% and the sample with a coating of 1.11%. The calculated mean differential and percentile values were checked (0.02kN and 0.06%), corroded values were (0.03kN and 0.19%) and coated 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 percentage recorded from the corrosion samples, while the controlled and coated samples showed 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 mean and percentile values determined after and before the correction test hurt the diameter of the reinforcing steel, which leads to a reduction and an increase in the cross-sectional area.

The minimum and maximum "decrease/increase in cross-sectional area (diameter)" of the controlled samples was 0.00 mm, which indicates (100%) for all samples, the corroded samples were -0.06 mm and -0.06 mm (-16.97% and -11.76%), and coated samples were 0.07 mm and 0.07 mm (13.33% and 20.45%).

The cross-sectional area of reinforcing steel recorded the mean differential values and calculated percentile values, corroded (0.06 mm and 5.21%) and coated values (0.05 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 of, as stated in the studies of [16, 18, 22, 25].

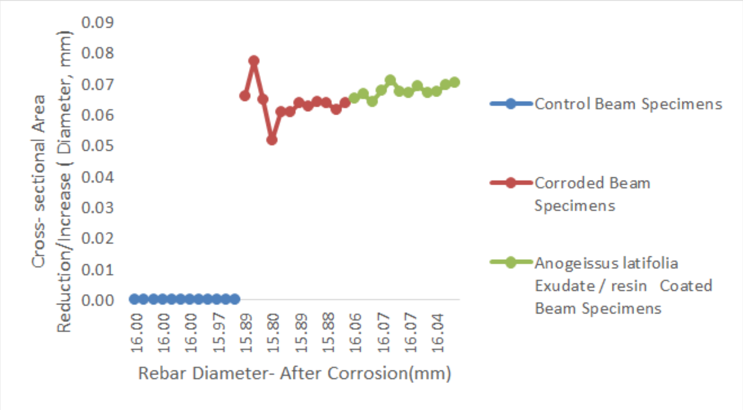

Fig-3.3: Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase (Diameter)

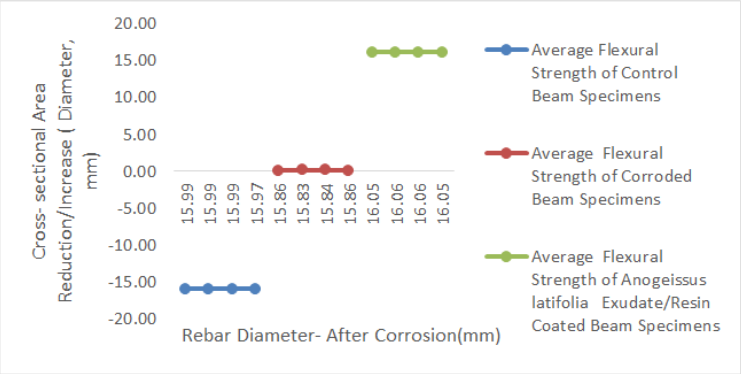

Fig-3.3A: Average Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase(Diameter)

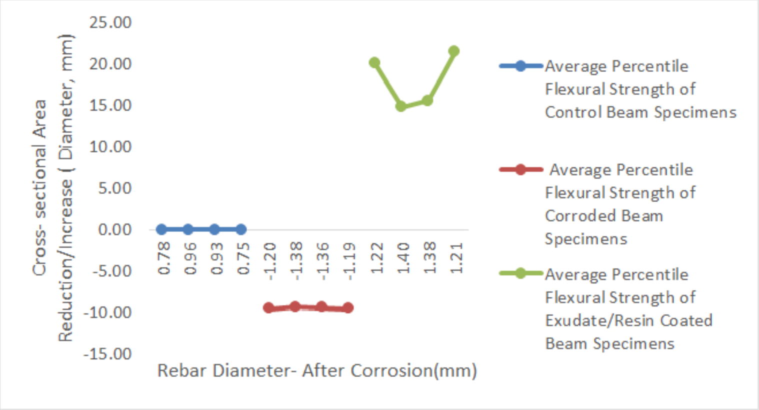

Fig-3.3B: Average Percentile Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase (Diameter

3.3 Results of Ultimate Tensile Strength and Yield Strength

Corrosion of steel bars embedded in concrete can lead to several unintended consequences, such as potentially severe damage resulting in a loss of cross-sectional area of the steel, yield and tensile strength reduction, which reduces both the capacity and ductility of the reinforcement; see [19, 24, 25]. In addition, corrosion products act on the surrounding concrete by occupying a larger volume than the original steel, increasing the mechanical stress around the reinforcement.

The results of the calculation of the average and minimum and maximum percentage values in Tables 3.4 and 3.5 obtained from Tables 3.1-3.3 at the point of control of the sample-controlled values are 414.03MPa and 419.34MPa (7.13% and 8.29%), corroded samples were 386.25MPa and 389.43MPa (-7.66% and -6.66%) and coated samples were 414.04MPa and 419.34MPa (7.14% and 8.3%).

The ultimate tensile strength values of the controlled samples were 580.59MPa and 583.12MPa (4.63% and 4.65%), corroded samples were 554.8MPa and 557.33MPa (-4.74% and - 4.72 %) and coated samples were 582.3MPa and 584.92MPa (4.95% and 4.97%).

The results of the calculation of the maximum differential comparative value for both yield and tensile strength of the controlled sample are 8.29% and 4.65%, for the corroded and coated values -6.66% and -4.72% are the range of values at 8.3% and 4.97%, respectively. The differential computed average and percentile value of the yield strength and ultimate tensile strength are controlled (**5.31**MPa and **1.16**%) and (**2.53**MPa and **0.02**%), the corroded values are (**3.18**MPa and **1.05**%) and (**2.53**MPa and **0.02**%), the coated values are (**5.3**MPa and **1.16**%) and (**2.53**MPa and **0.02**%). From the data obtained and compared, the tensile strength and tensile strength values of the corroded samples showed 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 area (controlled samples) showed an increase in the mean and percentage values with higher loads carrying capacity associated with the researches of [16,18, 22,25]. Exudates/resins show efficiency and effectiveness in protecting reinforced concrete structures exposed to corrosive media.

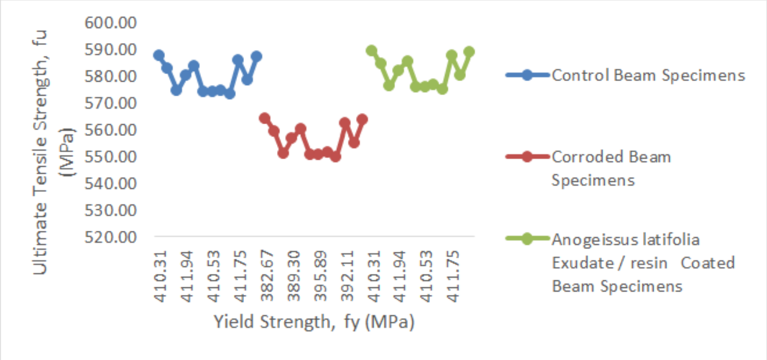

Fig-3.4: Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

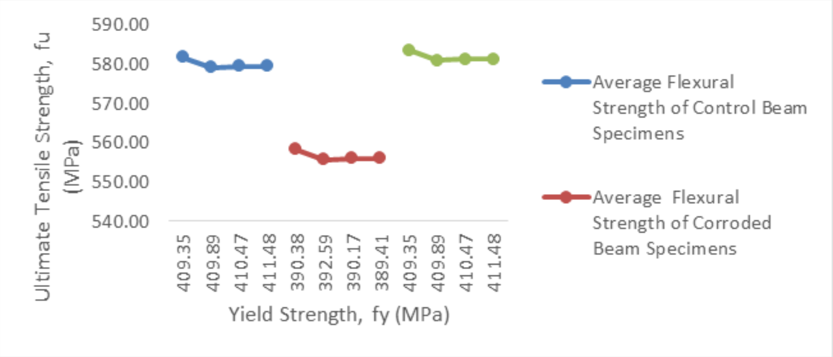

Fig-3.4A: Average Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

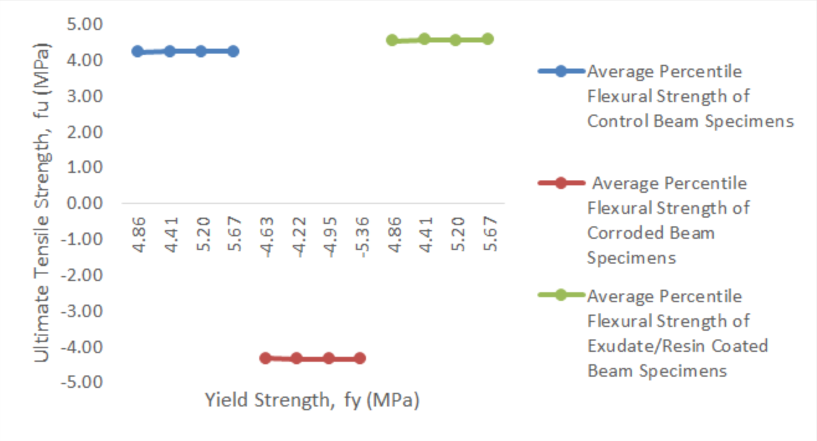

Fig-3.4B: Average percentile Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

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

Reduction of the cross-sectional area of reinforcement causes reduced shear and torsional resistance and reduced structural rigidity. Changing the ductility of reinforcement directly affects the possible redistribution of forces and moments and limits the load-carrying capacity of the structure is statically indeterminate and can also greatly reduce the load-carrying capacity of the structure in the event of seismic loads. In addition, corrosion causes an expansion of the reinforcement volume, which can lead to cracking and spalling of the surrounding concrete as well as a reduction in the cross-section of the reinforcing steel and the concrete layer. On the pressure side of the concrete element, dropping the cover reduces the inner arm of the lever, which in turn reduces its flexibility.

The results of the mean and minimum and maximum percentile values calculated in Tables 3.4 and 3.5 are obtained from Tables 3.1-3.3 of the strain ratio values obtained of controlled samples are 1.39 and 1.431 (-1.61and -1.47%), the corroded samples recorded 1.41and 1.43 (1.18% and 1.32%), the coated samples values are 1.39and 1.41 (-1.3% and -1.17%).

The comparative strain ratio obtained of the maximum computed values for the average and percentile values for the controlled is 1.47% against corroded and coated values of 1.32% and -1.17%. Obtained differential average and percentile values for the controlled are (**0.01** and **0.14%**), corroded values are (**0.02**and **0.14**%) and coated values are (**0.02** and **0.13**%). The mean differential and percentile values obtained for control were (0.01 and 0.14%), corrosion values (0.02 and 0.14%) and coated values (0.02 and 0.13%).

The results showed that the corroded samples had a higher percentage 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-carrying capacity of work-related reinforced concrete structures as stated in the studies of [17, 26, 24, 25].

The results of the minimum and maximum strain values for the controlled sample were 18.51% and 19.33% (-28.45% and -27.94%), corroded values were 25.87% and 26.83% (39 .3% and 40.33%), the values of the coated samples were 18.44% and 19.26%), -28.74% and -28.21%).

The maximum evaluation value for the controlled sample was -27.94% compared to the corroded and coated sample of 40.33% and -28.21%, respectively. The mean differential and percentile values obtained for the controlled samples were (0.82% and 0.51%), corroded values (0.96% and 1.03%), and masking values (0.82% and 0.53%). In differential comparative, 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 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 the works of [17, 26, 24, 25].

The unit weight of the minimum and maximum mean and percentage values before testing, 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 are 1.56Kg and 1.56Kg (0.059% and 0.067%), the corroded values were 1.56Kg and 1.56Kg (0.061% and 0.066%) and the included values were 1.56Kg and 1.56Kg (0.062% and 0.065) %) and the reinforcement weight - after corrosion (kg) the values of the minimum and maximum mean and percentile values, were checked 1.56 kg and 1.56 kg (3.04% and 3.01%), the corrosion values were 1.51kg and 1.54kg (-6.86% and -6.79%), the values covered are 1.65kg and 1.68kg (7.28% and 7.37%). The difference values obtained for the mean and percentile of controlled samples are (0.01 and 0.84%), corrosion values (0.006kg and 0.15%), and coated values (0.003 kg and 0.09%).

The results of weight loss/weight gain of the minimum and maximum mean values and percentage of controlled steel (100%) for the controlled sample, leading to their combination in freshwater without any trace of corrosive attack, the corroded sample values were 0.05kg and 0.05kg (-30.51% and -28.54%), coated samples were 0.06kg and 0.06kg (39.93% and 43.9%).

The calculated data for the maximum percentage of rebar weight before corrosion test for controlled, corroded, and coated values were 0.067%, 0.067%, and 0.066%. The maximum differential comparative values recorded after the corrosion test for the controlled sample remained the same, without any trace of a corrosive effect, because they were combined in freshwater, for the corrosive and coated samples the values were -6.79% and 7.37% respectively. The percentages of maximum weight loss/gain for corroded and coated samples were -28.54% and 43.9%, respectively. The calculated data showed a decrease in the value of the corroded sample as a result of the corrosion attack, which led to a decrease in the registered weight, whereas the coated sample showed an increase in weight compared to the reference value of the controlled sample due to the different coating thickness, as stated in the studies of [18, 23, 25].

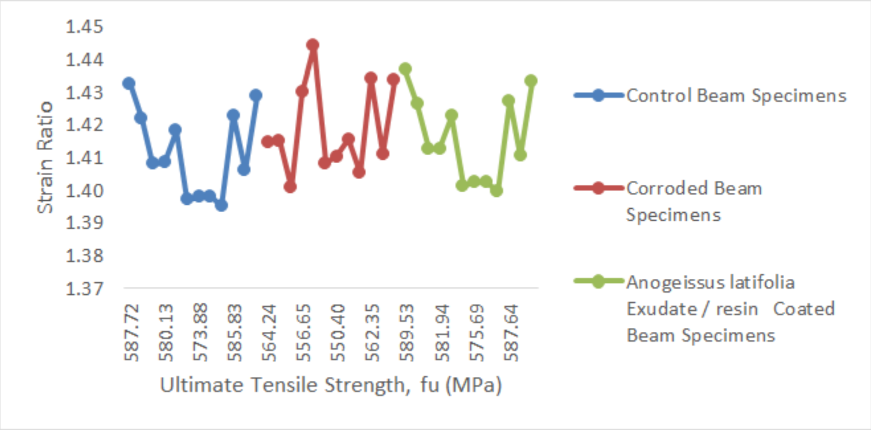

Fig-3.5: Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

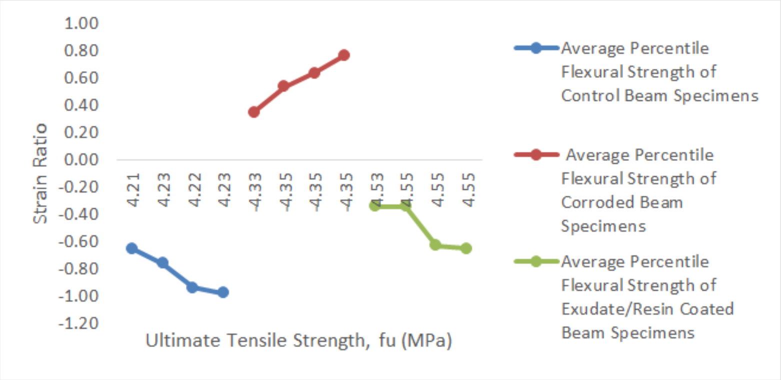

Fig-3.5A: Average Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

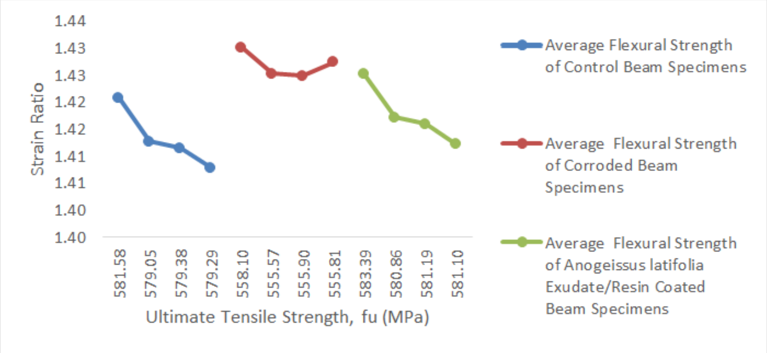

Fig-3.5B: Average Percentile Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

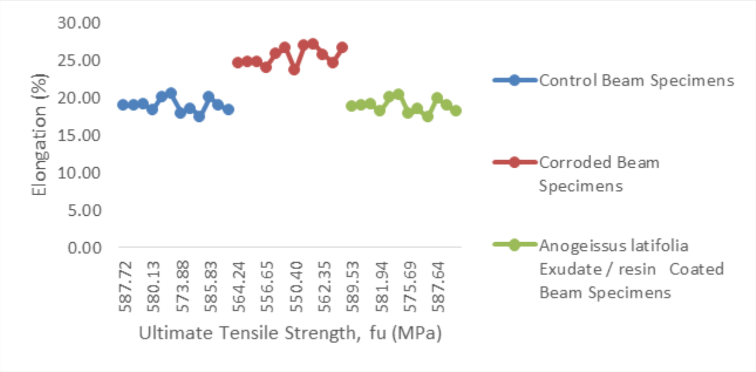

Fig-3.6: Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

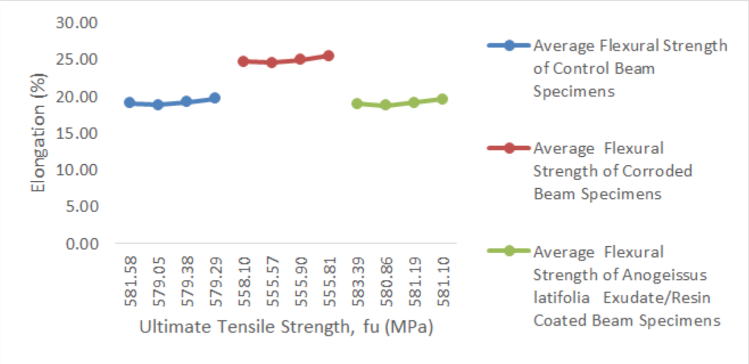

Fig-3.6A: Average Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

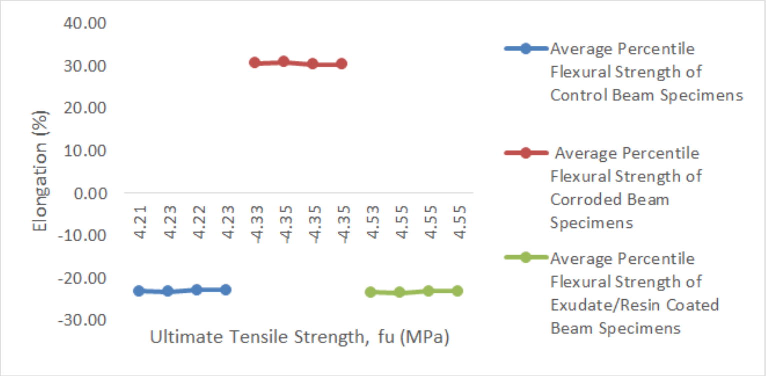

Fig-3.6B:Average Percentile Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

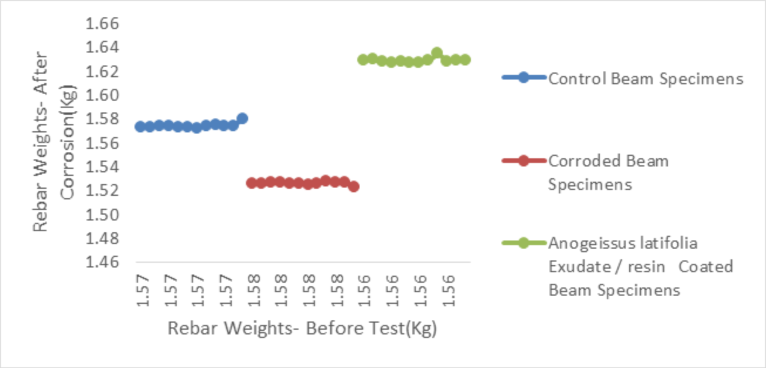

Fig-3.7: Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

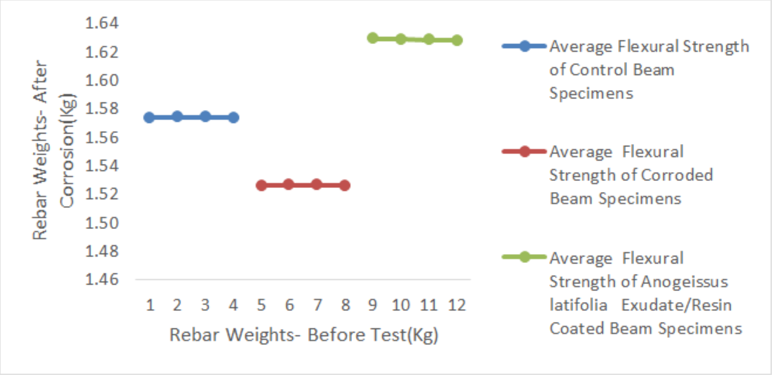

Fig-3.7A: Average Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

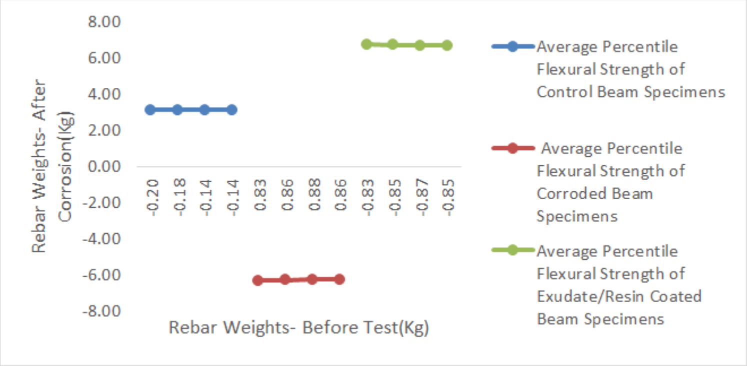

Fig-3.7B: Average Percentile Rebar Weights- Before Test versus Rebar Weights-After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

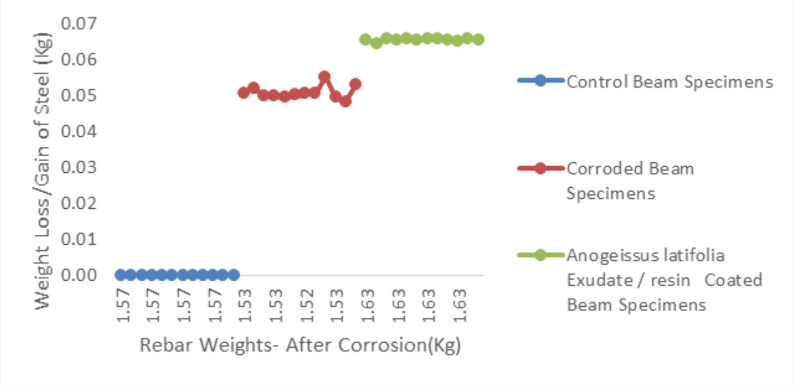

Fig-3.8: Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimen

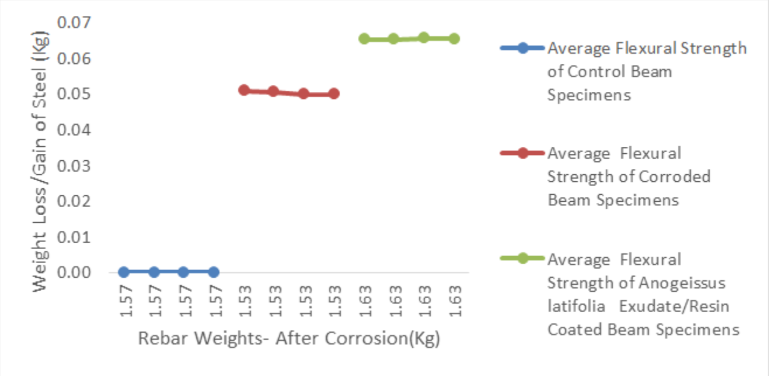

Fig-3.8A: Average Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

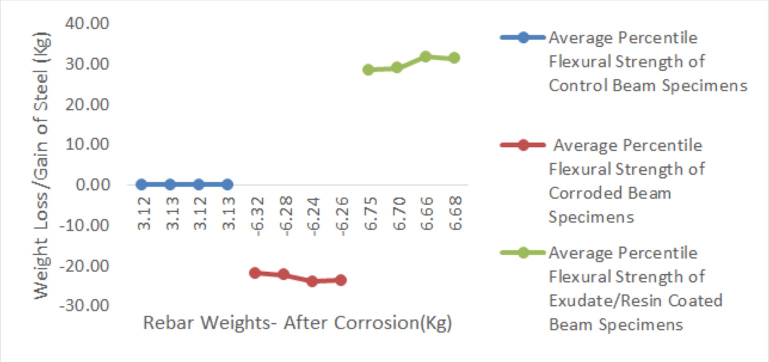

Fig-3.8B: Average Percentile Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

4.0 CONCLUSION

The experimental results obtained are summarized as thus:

1. The results showed that exudates / resin is a corrosion protection material in reinforced concrete structures exposed to a corrosive environment with high resistance and as a waterproofing 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 increased work-related exudates/resin protective layer
4. Exudates / resins have been proven to be effective and efficient in protecting reinforced concrete structures exposed to corrosive environments.
5. Results show lower elongation loads for controlled and coated samples with lower values than corroded samples with higher elongation loads and increased values compared to reference ranges (controlled) and coated samples.
6. The results of the differential comparative of flexural strength and elongation load in the center

of the corroded sample indicate the effect of corrosion on the mechanical properties of reinforcing steel with bent reinforcement, high surface modification, low load carrying capacity, breaking 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 properties of the corroded sample with low flexural deformation, low deviation in the medium deformation range, normal yield strength, high ultimate strength, low deformation / deformation ratio.
8. Corrosion sample results show a high deformation load when bending; the degree of deformation is higher than the average range.

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