Corrosion Assessment Effects of Structural Flexural Residual Capacity of Reinforcing Bars

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ABSTRACT

The research work evaluated the potency of Ficus sycomorus exudate / resin extrudes from tree as an inhibitory substances coated to reinforcing steel at varying thicknesses, embedded in concrete beam and exposed to corrosive media for 360 days and assessed the surface modifications, load carry capacity and other mechanical properties for the coated and non-coated samples. Comparative results showed that the maximum obtained values the flexural failure state are controlled -39.418% against corroded 68.290% and coated -38.904%. The results showed lower failure deflection loads in controlled and coated samples with decreased values over the corroded sample with higher failure deflection load and increased values compared to the reference range (controlled) and the coated samples. Results showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in diameter also decrease in both average and percentile values recorded by the corroded samples while controlled and coated samples showed maintained status with the coated having an increase in diameter resulting from varying coating thicknesses with exudate/resin. The reduction in cross-sectional area is been attributed to the effect of corrosion on reinforced concrete structures built within the coastal marine environment and the increase from the protective coating offered by exudate/resin.From the data obtained and compared, the yield strength and ultimate tensile strength values of corroded samples recorded decrease average and percentile values with load failure at low application. An attributed failure resulted in a corrosion effect on the mechanical properties of reinforcing steel through surface modifications that affected the ribs and fibre, whereas, coated samples recorded increasing average and percentile values from the reference range (controlled samples) with higher load-carrying capacity. The maximum recorded comparative values after corrosion test for controlled sample remained the same, with no traces of corrosion effect because it was pooled in freshwater, for the corroded and coated samples, the obtained values are -6.786% and 7.369%. The computed data showed a decreased value from corroded sample resulting from corrosion attack that has led to weight loss recorded whereas, coated samples has weight increase resulting from varying coating thicknesses in comparison to the reference range values obtained from controlled samples.

Key Words: *Corrosion, Corrosion inhibitors, Flexural Strength, Concrete and Steel Reinforcement*

1.0 Introduction

Corrosion reinforcing steel embedded in saltwater (chloride-induced) concrete structures in coastal areas creates tensile stress in concrete's steel reinforcement environments, resulting in early fractures. Cracks reduce the overall strength and rigidity of the concrete structure and accelerate the entry of aggressive ions, which can lead to other types of concrete degradation and result. Major factors such as concrete pH, chloride ions, oxygen and water need to be considered in the control of corrosion resistance of reinforcement. Procedures to control these factors include epoxy coatings, insulators, buffers, electrochemical protection systems and scavengers, all known as corrosion inhibitors.

McDonald [1] conducted research on inhibitors in solvents extracted from alkaline and cement. Extracts from the cement experiment revealed that corrosion was prevented using sodium nitrate in the presence of chlorides, whereas sodium benzoate did not. Furthermore, corrosion initiation with sodium nitrate is delayed, increasing with delayed inhibition content.

El-Maaddawy [2] investigated the flexural effect of the combined effects of corrosion and resistance loads on corroded beams made of reinforced concrete. The test results show that the presence of prolonged loading and associated flexural cracks during corrosion loading significantly shortens the time of corrosion crack formation and slightly increases the width of the corrosion cracks. They found that crack width widened 22% faster under load, and found that 6.4% and 20.0% strength losses occurred with 8.9% and 22.2% weight loss, respectively

Novokshcheov [3] has shown that calcium nitrate is not harmful to concrete properties as seen in the problem of inhibition based on sodium or potassium. Subsequent studies by Skotinck [4] and Slater [5] have shown that calcium nitrate has a good quality in terms of strength when considering long-term rapid testing.

Huang and Yang [6] investigated the relation between corrosion and load-bearing capacity of reinforced concrete beams. Their results showed a significant reduction in load-bearing capacity with an increase in corrosion in beams with low w / c or predetermined fractures (mix B or type K). They conclude that this behavior is caused by the easier access of reinforcing steel in cracked beams than chloride ions.

Charles et al. [7] investigated the effect of efficiency on the residual yield strength of non-corroded, corroded and inhibited steel bar. The results showed that the potential for corrosion on uncoated reinforcement was recorded with crack propagation and resin coating resistance. Results of a steel bar coated with three different resins / exudates extracts of Symphonia globulifera Linn, Ficus glumosa and acardium occidental L. Overall results showed that coated steel bar failure results in higher values of load and tensile strength, while elongation and midspan deflection are reduced.

Charles et al. [8] Investigated the effect of the flexural residual yield strength of three different resins / dacryodes eudulis, moringa oleifera lam, mangifera indica paste coated reinforcement.

Overall results showed that low load subjection was recorded in the coating members at failure loads, as was the case with high deflection and elongation, while corroded members recorded high yield with low load application and midspan deflection.

Gilbert et al. [9] Investigative work aimed to minimize the corrosion reduction of steel reinforcement that breakdown of concrete structures in the saltwater region by the introduction of exudates / resins of invingia gabonesis coated to reinforcing steel reinforcement with varying thicknesses, embedded into concrete beam and investigated the effect of the corrosion on both non - coated and coated members. Detailed test results showed potential corrosion resistance with coated members on the mechanical properties of reinforcing effects of weight loss, cracking, spalling and weight reduction. Experimental results show indications of non-coated members with corrosive properties that reduce the thickness of the steel bar surface, loss of unit weight, presence of cracks. These properties have resulted in failure of variable load and high retention capacity with low average use, high degree of anxiety, elongation and midspan deflection.

TrustGod et al. [10] Investigative work evaluated the effectiveness of the use of olibanum exudates/resins in reinforcing steel embedded in concrete, ponded in corrosive environments, with accelerated corrosion performance. Corroded members showed low flexural loads with high midspan deflection and elongation. The effect of corrosion on the mechanical properties of steel reinforcement was due to the poor performance of corrosive members.

Daso et al. [11] investigated the utilization of eco-friendly inorganic products of Artocarpus altilis exudates/resins in the prevention of corrosion attack on reinforcing steel embedded in concrete. Results of the corroded members on the mechanical properties of reinforcing steel embedded in the concrete and exposed to corrosive media showed high flexural load, midspan deflection, and coating of the exudates/resins and ultimate tensile strength against non-corroded members. Controlled results have low and reduced midspan deflection, higher load application to yielding strength, and lower strain rate compared to coated members. The entire results showed crack and spalling resistance to corrosion attack on reinforcing steel members was recorded from coated members while corroded member yielded to low load application with deep midspan deflection resulting to surface modification.

Nwabakata et al. [12] Explored the use of Garcinia Cola naturally available extracts as a protective layer to reinforced steel embedded in the concrete. Members were immersed in a highly corrosive environment and accelerated for 150 days with changes in the mechanical properties of the steel. Corroded members result showed poor yielding strength with lower utilization load, higher midspan deviation, and extension. The corroded member properties showed signs of corrosion that affected the surface properties of the steel reinforcement and the general mechanical properties of the steel. The results of the exudates/adhesive coated members showed lower flexibility than those of corroded members with lower midspan deviation. Signs show that coating members have properties that resist corrosion penetration. Non-corrosion member effects include high flexural load, low midspan deviation and yield strength, strain rate, and high values of extension of corrugated members.

Kanee et al.[13] Aimed at strengthening steel with the introduction of milicia excelsa exudates/resins for surface modifications and deterioration of mechanical properties that reinforce steel in concrete structures. The corrosion acceleration process is 150 days and the corrosion potential is determined. 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, and extension. Coated members showed less; Midspan deflection, extension, and ultimate yield, high flexibility failure load required and compared to corroded members.

2.1 Materials and Methods

2.1.1 Aggregates

Aggregates of fine and coarse were purchased. Both met the requirements of BS882 [14]

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 mixtures in this trial. Cement meets the requirements of BS EN 196-6[15]

2.1.3 Water

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

2.1.4 Structural Steel Reinforcement

Reinforcements are obtained from the market at Port Harcourt. Conformed to **B**S4449: 2005 + A3 [16]

2.1.5 Corrosion Inhibitors (Resins / Exudates) Ficus sycomorus

The crude gum exudates were gotten from Bassawa village in Sabon - Gari Local Government Area of Kaduna State Nigeria at coordinates (Latitude: 11° 06' 60.00'' N, Longitude: 7° 43' 59.99'' E). The gum was collected from the tree barks by tapping.

2.2 Methods

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

2.2.1 Sample Preparation and Casting of Concrete Beams

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

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

2.2.5 Flexure Testing of Beam Specimens

The universal testing machine was used for flexural testing according to BS EN 12390-2 [17] and a total of 36 beam samples were tested. After 28 initial and standard curing, days of treatment, 12 controlled beams (non-corroded) were kept in a state of control to prevent corrosion-related reinforcement, while 24 beam samples of non-coated and exudate/ resin/ coated samples were wholly immersed in corrosive media of 5% sodium chloride (NaCl) for 360 days, with 3 months interval of 90 days, 180 days, 270 days and 360 days inspections and testing to ascertained surface changes and mechanical properties modifications and effects on both uncoated and exudate/resin coated specimens. The Flexural test was conducted on an Instron Universal Testing Machine with a capacity of 100KN. Samples were placed in the specification in the machine, flexural testing was taken at the third point on the two supports. The load was applied to the computerized system with the registration of digitally registered cracks and failure with corresponding values of flexural strength load, midspan deflection, and all corresponding investigations of measured rebar diameter before test, rebar diameter- after corrosion, cross-sectional area reduction/increase, yield strength, ultimate tensile strength, strain ratio, elongation, rebar weights- before test, rebar weights- after corrosion, and weight loss /gain of steel were all observed and recorded.

Table 3.1 : Flexural Strength of Beam Specimens (Control)

Samples	Samples A			Samples B			Samples C			Samples D		
Items	FS	FS1	FS2	FS3	FS4	FS5	FS6	FS7	FS8	FS9	FS10	FS11
Flexural Strength Load (KN)	82.30	82.14	81.01	84.99	81.43	81.94	82.25	81.57	82.50	80.25	82.45	84.23
Midspan Deflection (mm)	7.65	7.73	8.33	8.44	7.53	8.47	7.56	7.73	7.53	7.61	7.61	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 Diamete 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- section Area Reduction/Increase (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)	409.92	409.03	405.90	407.80	408.97	408.92	408.51	409.32	408.91	409.73	409.54	408.29
Ultimate Tensile Strength, fu (MPa)	589.26	584.21	575.89	581.67	585.20	575.62	575.42	576.22	574.82	587.37	579.87	588.73
Strain Ratio	1.44	1.43	1.42	1.43	1.43	1.41	1.41	1.41	1.41	1.43	1.42	1.44
Elongation (%)	18.62	18.69	18.82	18.02	19.82	20.16	17.62	18.19	17.12	19.72	18.66	17.95
Rebar Weights- Before Test	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.52
Rebar Weights- After at 28 days (Kg)	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.52
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)

	FS1A	FS1B	FS1C	FS1D	FS1E	FS1F	FS1G	FS1H	FS1I	FS1J	FS1K	FS1L
Flexural Strength Load (KN)	65.88	63.03	64.59	65.22	65.01	66.81	65.83	65.15	66.08	65.52	65.53	68.57
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)	15.99	15.97	15.94	15.90	16.00	15.98	16.00	15.96	15.99	15.98	16.00	15.97
Rebar Diameter- After Corrosion(mm)	15.93	15.91	15.88	15.85	15.93	15.93	15.93	15.89	15.93	15.93	15.94	15.92
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05
Yield Strength, fy (MPa)	379.51	392.02	390.12	386.14	384.76	387.84	392.73	386.25	388.13	388.95	390.04	390.06
Ultimate Tensile Strength, fu (MPa)	563.47	558.42	550.10	555.88	559.41	549.83	549.63	550.43	549.03	561.58	554.08	562.94
Strain Ratio	1.42	1.41	1.40	1.43	1.44	1.41	1.39	1.41	1.40	1.43	1.41	1.43
Elongation (%)	25.98	26.05	26.18	25.38	27.18	27.92	24.98	28.35	28.48	27.08	26.02	27.91
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 Ficus sycomorus Exudate / Resin Coated Beam Specimens

	FS1A1	FS1B2	FS1C3	FS1D4	FS1E5	FS1F6	FS1G7	FS1H8	FS1I9	FS1J10	FS1K11	FS1L12
	150µm (Exudate/Resin) coated			300µm (Exudate/Resin) coated			450µm (Exudate/Resin) coated			600µm (Exudate/Resin) coated		
Flexural Strength Load (KN)	82.31	81.65	81.02	85.00	81.44	81.95	82.26	81.58	82.51	79.46	81.96	83.24
Midspan Deflection (mm)	7.72	7.80	8.40	8.51	7.60	8.54	7.63	7.80	7.60	7.68	7.68	8.53
Nominal Rebar Diameter	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Measured Rebar Diameter Before Test(mm)	15.99	15.99	15.97	15.99	15.99	15.93	15.99	15.98	15.90	15.97	15.95	15.98
Rebar Diameter- After Corrosion(mm)	16.06	16.06	16.04	16.07	16.07	16.01	16.07	16.06	15.97	16.04	16.03	16.05
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.08

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)	591.06	586.01	577.69	583.47	587.00	577.42	577.22	578.02	576.62	589.17	581.67	590.53
Strain Ratio	1.44	1.43	1.42	1.43	1.44	1.41	1.41	1.41	1.41	1.44	1.42	1.45
Elongation (%)	18.55	18.62	18.75	17.95	19.75	20.09	17.55	18.12	17.05	19.65	18.59	17.88
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 Ficus sycomorus Exudate/Resin Coated Beams			
Flexural Strength Load (KN)	81.82	82.72	82.48	82.79	65.31	64.85	64.67	64.49	81.66	82.55	82.48	82.79
Midspan Deflection (mm)	7.90	8.17	8.10	8.15	13.22	13.48	13.75	13.79	7.97	8.24	8.17	8.22
Nominal Rebar Diameter	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Measured Rebar Diameter Before Test(mm)	15.99	15.99	15.99	15.97	15.97	15.94	15.94	15.96	15.99	15.99	15.99	15.98
Rebar Diameter- After Corrosion(mm)	15.99	15.99	15.99	15.97	15.91	15.88	15.89	15.90	16.05	16.06	16.06	16.05
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
Yield Strength, fy (MPa)	419.34	417.21	414.79	414.03	387.22	389.43	387.01	386.25	419.34	417.22	414.80	414.04
Ultimate Tensile Strength, fu (MPa)	583.12	580.59	580.92	580.83	557.33	554.80	555.13	555.04	584.92	582.39	582.72	582.63
Strain Ratio	1.39	1.39	1.40	1.40	1.41	1.41	1.42	1.43	1.39	1.40	1.40	1.41
Elongation (%)	18.71	18.51	18.89	19.33	26.07	25.87	26.25	26.83	18.64	18.44	18.81	19.26
Rebar Weights- Before Test(Kg)	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56
Rebar Weights- After Corrosion(Kg)	1.56	1.56	1.56	1.56	1.52	1.52	1.52	1.52	1.63	1.63	1.63	1.63
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.07	0.07	0.07	0.07

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

	Average Percentile Flexural Strength of Control Beam Specimens				Average Percentile Flexural Strength of Corroded Beam Specimens				Average Percentile Flexural Strength of Exudate/Resin Coated Beam Specimens			
Flexural Strength Load (KN)	25.29	27.56	27.53	28.36	-20.02	-21.45	-21.59	-22.10	25.04	27.31	27.54	28.37
Midspan Deflection (mm)	-40.20	-39.42	-41.08	-40.94	65.78	63.68	68.29	67.90	-39.68	-38.90	-40.58	-40.44
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	0.37	0.39	0.36	0.39	0.34	0.33	0.38	0.39	0.34	0.37	0.38	0.37

Before Test(mm)												
Rebar Diameter- After Corrosion(mm)	0.69	0.67	0.63	0.66	-0.91	-1.10	-1.07	-0.91	0.92	1.11	1.08	0.91
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-11.76	-14.55	-14.62	-16.97	13.33	17.03	17.13	20.45
Yield Strength, fy (MPa)	8.29	7.13	7.18	7.19	-7.66	-6.66	-6.70	-6.71	8.30	7.14	7.18	7.19
Ultimate Tensile Strength, fu (MPa)	4.63	4.65	4.64	4.65	-4.72	-4.74	-4.73	-4.74	4.95	4.97	4.97	4.97
Strain Ratio	-1.47	-1.49	-1.58	-1.61	1.18	1.20	1.29	1.32	-1.17	-1.19	-1.28	-1.30
Elongation (%)	-28.24	-28.45	-28.05	-27.94	39.90	40.33	39.53	39.30	-28.52	-28.74	-28.33	-28.21
Rebar Weights- Before Test(Kg)	0.061	0.059	0.064	0.067	0.066	0.061	0.064	0.062	0.063	0.062	0.065	0.062
Rebar Weights- After Corrosion(Kg)	5.61	5.61	5.67	5.67	-6.86	-6.82	-6.79	-6.80	7.37	7.32	7.28	7.30
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	-28.54	-28.87	-30.51	-30.23	39.93	40.58	43.90	43.32

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. Considering the effect of corrosion on reinforced concrete structures built within the coastal areas of Niger Delta, Nigeria, with high salinity, the application of ficus sycomorus 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.

The experimental data of flexural test of concrete beams samples are presented in tables 3.1, 3.2, and 3.3, summarized in 3.4 of average values and percentile in 3.5, and results graphically represented in figures 3.1 - 3.7b. The computed minimum and maximum average and percentile values obtained from are flexural strength load from Instron Universal Testing machine with 100kN pressure load to failure state are controlled samples are 81.820kN and 82.788kN (25.286% and 28.364%), the corroded sample values are 64.494kN and 65.306kN (-22.103% and -20.024%), and the exudate/resin coated samples are 81.658kN and 82.794kN (25.038% and 28.374%). From the flexural strength load test, comparatively, the maximum values are controlled 28.364% against corroded and coated sample values of -20.024% and 28.374%. The differential averages and percentile ranges are controlled (0.97kN and 3.07%), corroded are (0.82kN and 2.08%), coated are (1.13kN and 3.33%).

The results showed that the reference percentile value of the controlled sample was placed in freshwater conforming to BS 3148 and the effect of corrosion was not noticed and hence, use at the reference value towards no-coated and coated that are immersed in corrosive media as described in the test program. The corroded sample failed at a lower load application while coated samples exhibited higher failure load application. Results further validated that the flexural failure load of controlled and coated samples maintained a close range of values over the corroded sample with averaged decreased and lower load application. The results of minimum and maximum average and percentile midspan deflection failure loads recorded of non-coated are 7.903kN and 8.166kN (-41.083% and -39.418%), corroded samples are 13.216kN and 13.794kN (63.676% and 68.290%) and the coated samples are 7.972kN and 8.236kN (-40.579% and -38.904%). Comparative results showed that the maximum obtained values to the failure state are controlled -39.418% against corroded 68.290% and coated -38.904%. The average and percentile differential values recorded are controlled (0.27kN and 1.66%), corroded (0.57kN and 4.61%) and coated are (0.27kN and 1.68%).

The results showed lower failure deflection loads in controlled and coated samples with decreased values over the corroded sample with higher failure deflection load and increased values compared to the reference range (controlled) and the coated samples. The comparative results obtained of flexural strength and mid-span deflection failure loads of corroded samples showed the effect of corrosion on the mechanical properties of reinforcing steel with ribs peeled off, a high surface modification which resulted in low load carrying capacity and high midspan deflection, see (Charles et al., [7]; Charles et al., [8]; Gilbert et al, [9]; TrustGod et.al., [10]; Daso et al., [11]; Kanee et al., [13]). From the obtained results, ficus sycomorus exudate/resin has proven to be an anti-corrosive material in reinforced concrete structures exposed to corrosive media with high resistivity and waterproofing membrane towards corrosion effects. From the results obtained, the loss and deterioration of the strength of steel reinforcement embedded in reinforced concrete structures is mainly due to the presence of corrosion. Corrosion of reinforcement, immersed or embedded in concrete, has led to the premature failure of the exposed of many structures that have been exposed to marine coastal environments with adverse weather conditions. The effect of corrosion on flexural strength has been studied by many researchers and is well understood. Several studies carried out in this field have been described with a critical assessment of their application to the effects of corrosion on the flexural strength of reinforced concrete beams.

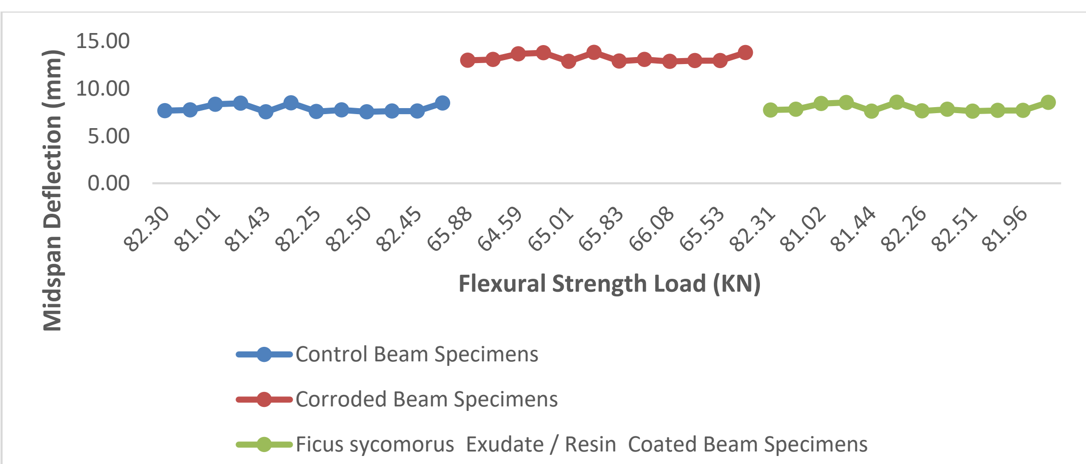

Figure 3.1: Failure Load versus Midspan Deflection of Beam Specimens

(Non-Corroded, Corrode and Resin Coated Specimens)

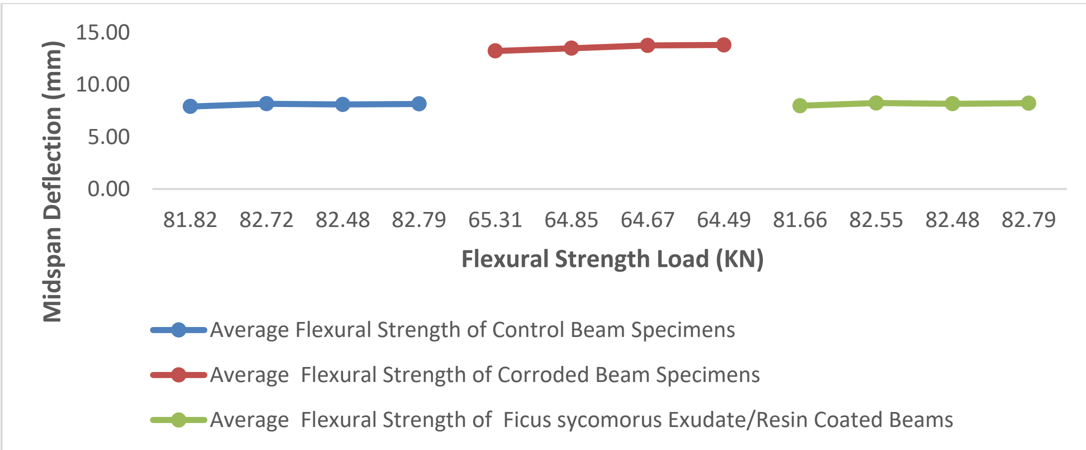

Figure 3.1A: Average Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

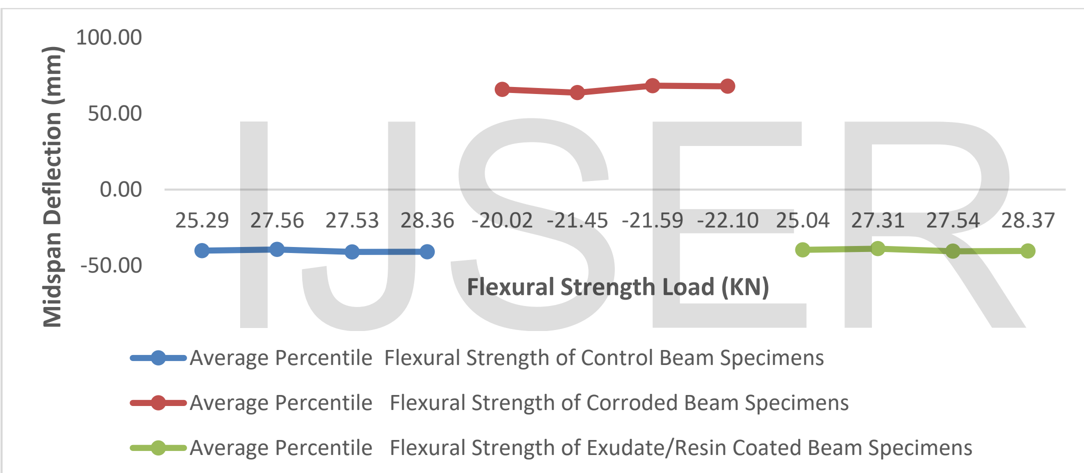

Figure 3.1B: Average Percentile Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

3.2 Results of Measured Rebar Diameter Before and After Corrosion Test

The results obtained of minimum and maximum average and percentile values for the the nominal rebar diameter is 16mm (100%) for all standard references. The measured rebar diameter before test for controlled samples are 15.974mm and 15.986mm (0.302% and 0.305 %), the corroded are 15.937mm and 15.966mm (0.326% and 0.313%) and the coated are 15.977mm and 15.990mm (0.3.13% and 0.327%). Obtained results showed the diameter of reinforcing steel varies in minute range due to rebar production from different companies, the production mold used led to the averages and percentile difference are negligible.

The minimum and maximum average and percentile values of the rebar diameter- after corrosion test of controlled are 15.974mm and 15.986mm (0.455% and 0.666%), the corroded sample values are 15.880mm and 15.908mm (-1.096% and -0.905%), the coated sample values are 16.047mm and 16.058mm (0.913% and 1.109%). Comparative results obtained during and after corrosion test on the rebar diameter maximum values are controlled 0.666% against the corroded -0.905% and coated sample 1.109%. The computed differential average and percentile values are controlled (0.02% and 0.06%), corroded values are (0.03kN and 0.19%) and coated values are (0.01kN and 0.02%). Results showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in diameter also decrease in both average and percentile values recorded by the corroded samples while controlled and coated samples showed a maintained status with the coated having an increase in diameter resulting from varying coating thicknesses with exudate/resin. The use of exudate/resin protected the reinforcing steel from the severe damages of corrosion. The average and percentile values obtained after and before correction test has an adverse effect on the reinforcing steel diameter resulting to decreased and increased in the cross-sectional area.

The minimum and maximum obtained "Cross-sectional Area Reduction/Increase (Diameter)" are of the controlled samples are 0.00mm indicating (100%) for all samples, the corroded samples are 0.057mm and 0.058 mm(-16.975% and -11.764%) and the coated samples are 0.066mm and 0.069mm (13.333% and 20.445%). The cross-sectional areas of the reinforcing steel recorded differential average and percentile computed values of corroded (0.01and 5.21%) and coated values are (0.02mm and 7.12%). The obtained results showed the effect of corrosion on the mechanical properties of reinforcing steel with decrease in rebar diameter of corroded samples while coated samples showed an increase resulting from the coating thicknesses from exudate paste. The reduction in cross-sectional area is been attributed to the effect of corrosion on reinforced concrete structures built within the coastal marine environment and the increase from the protective coating offered by exudate/resin as related to the works of (Charles et al., [7]; Charles et al., [8]; Gilbert et al, [9]; TrustGod et.al., [10]; Daso et al., [11]; Kanee et al., [13]).

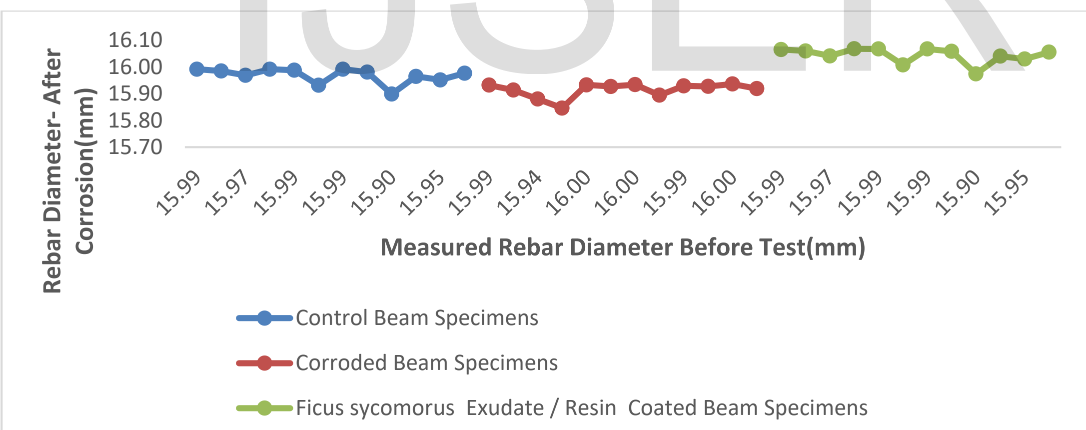

Figure 3.2: Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

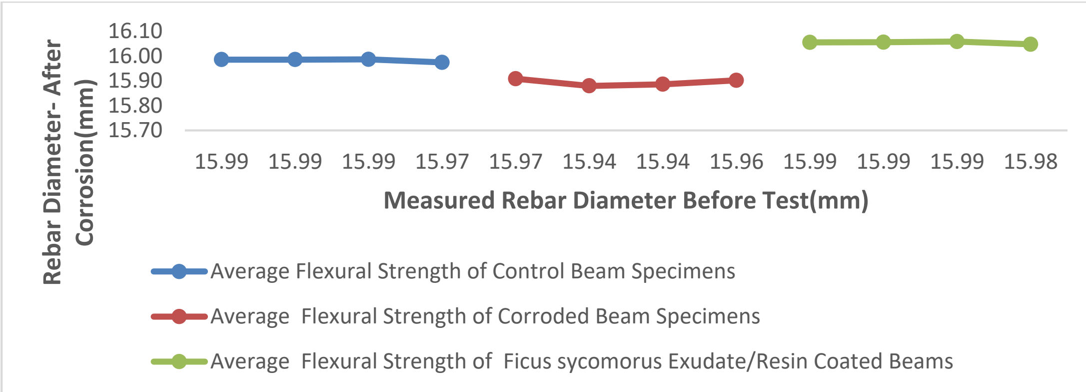

Figure 3.2A: Average Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

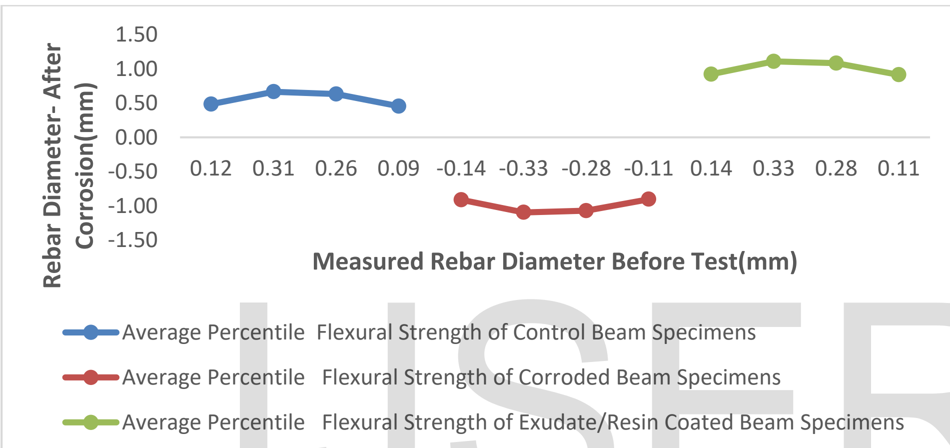

Figure 3.2B: Average Percentile Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

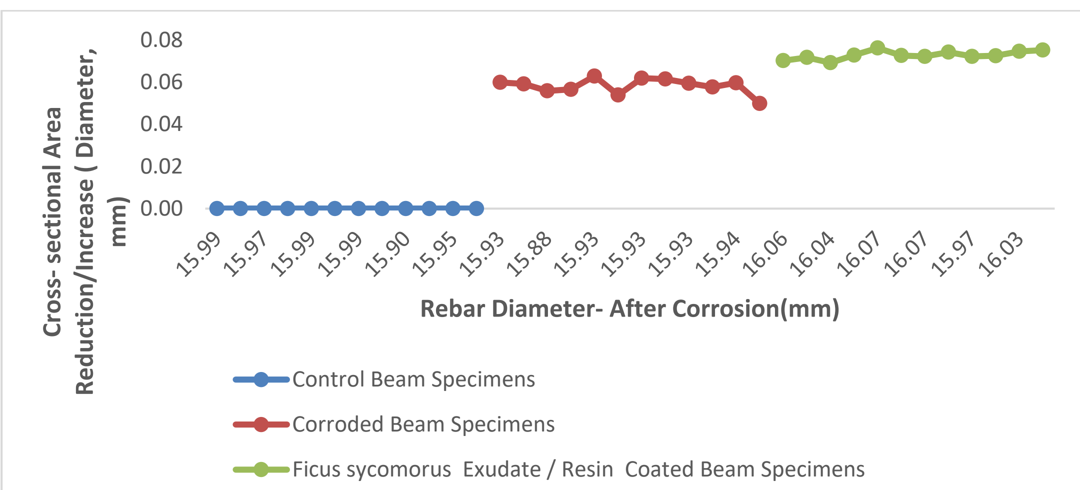

Figure 3.3: Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase (Diameter)

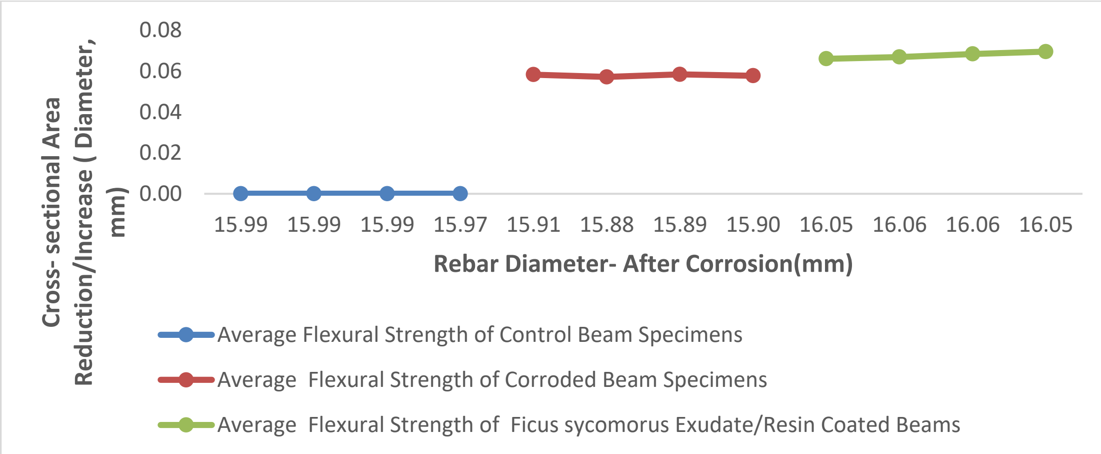

Figure 3.3A: Average Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase(Diameter)

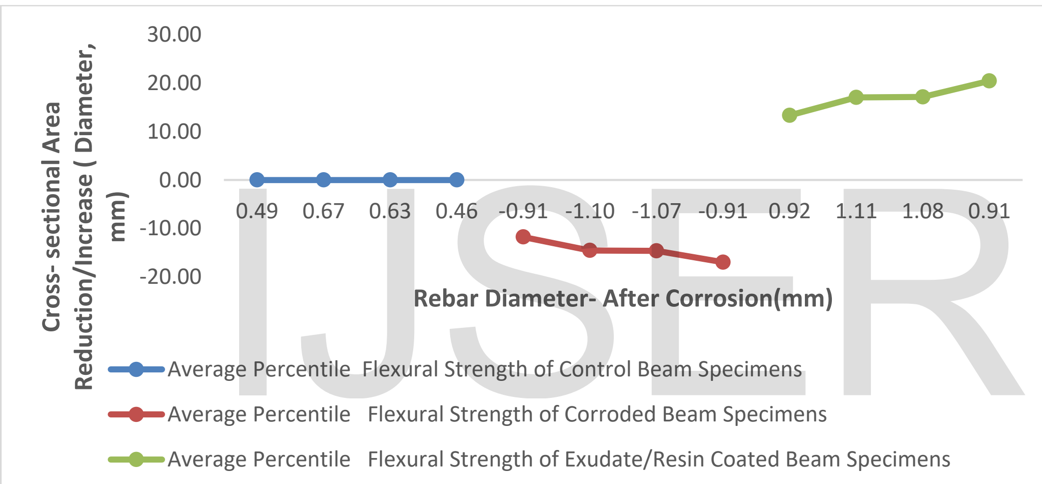

Figure 3.3A: Average Percentile Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase(Diameter)

3.3 Results of Ultimate Tensile Strength and Yield Strength

The results of the minimum and maximum average and percentile computed values in tables 3.4 and 3.5 obtained from tables 3.1 - 3.3 of yield strength of the controlled sample values are 414.032MPa and 419.335MPa (7.135% and 8.295%), the corroded samples are 386.247MPa and 389.427MPa (-7.660% and -6.661%), and the coated samples are 414.036Mpa and 419.340MPa (7.136% and 8.296%). The ultimate tensile strength values of the controlled samples are 580.588MPa and 583.118MPa (4.626% and 4.648%), the corroded samples are 554.804MPa and 557.334MPa (-4.737% and -4.717%), and the coated samples are 582.393MPa and 584.923MPa (4.950% and 4.973%). The results of computed maximum comparative values for both the yield strength and ultimate tensile strength for the controlled samples are 8.295% and 4.648% against the corroded and coated values of -6.661% and -4.717%, the coated values are 8.296% and 4.973% respectively. 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 1.02%) and (2.53MPa and 0.02%), the coated values are (5.3MPa and 1.16%) and (2.53MPa and 0.02%) From the data obtained and compared, the yield strength and ultimate tensile strength values of corroded samples recorded decrease average and percentile values with load failure at low application. An attributed failure resulted in a corrosion effect on the mechanical properties of reinforcing steel through surface modifications that affected the ribs and fibre, whereas, coated samples recorded increasing average and percentile values from the reference range (controlled samples) with higher load-carrying capacity as related to the works of ((Charles et al., [7]; Charles et al., [8]; Gilbert et al, [9];TrustGod et.al., [10];Daso et al., [11];Kanee et al., [13]). Exudate/resin showed effectiveness and potency in the protection of reinforced concrete structures exposed to corrosive media.

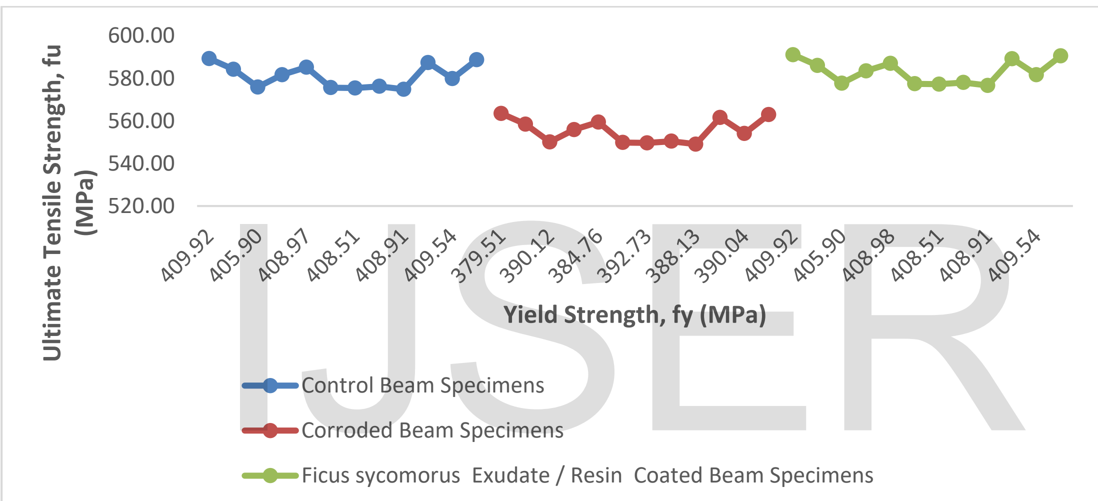

Figure 3.4: Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

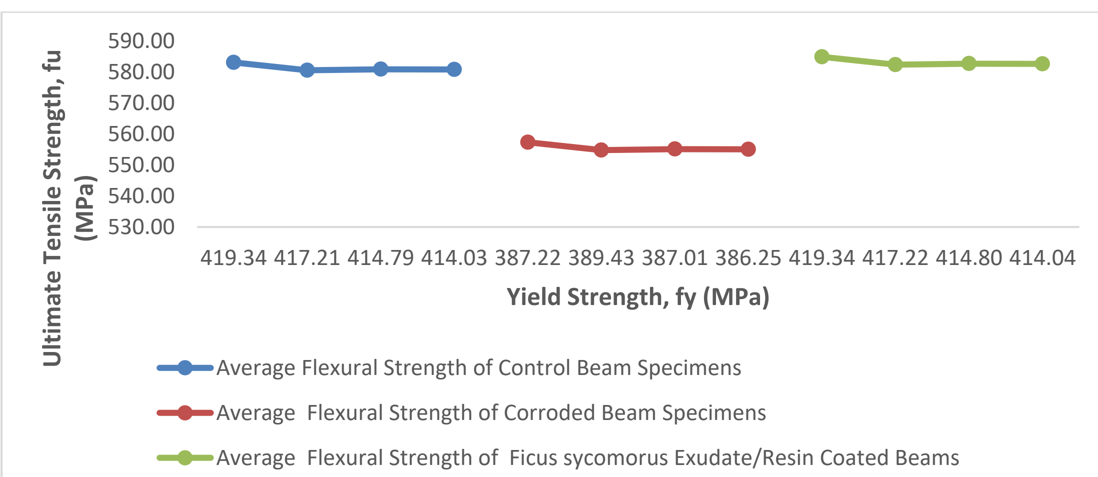

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Figure 3.4A: Average Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

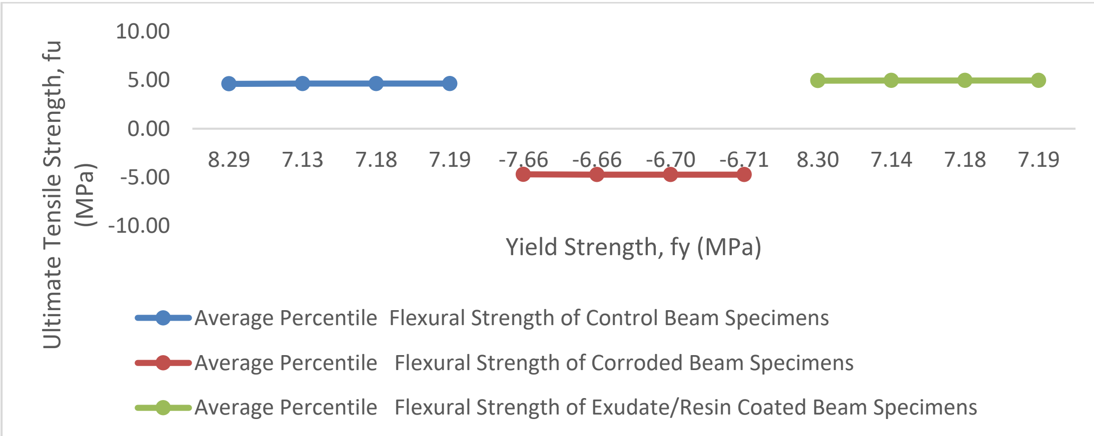

Figure 3.4B: Average percentile Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

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

The results of the minimum and maximum average and percentile computed values in tables 3.4 and 3.5 obtained from tables 3.1 - 3.3 of strain ratio values obtained of controlled samples are 1.391 and 1.403 (-1.606% and -1.472%), the corroded samples recorded 1.411 and 1.426 (1.182% and 1.318%), the coated samples values are 1.395 and 1.407 (-1.301% and -1.168%). The comparative strain ratio obtained of the maximum computed values for the average and percentile values for the controlled is -1.472% against corroded and coated values of 1.318% and -1.168%. 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 (0.02and 0.13%).

Results revealed that the corroded sample recorded a higher percentile strain ratio resulting from lower failure load and higher-yielding whereas, the coated recorded higher failure load application with lower yield. The lower load application and higher yields and straining resulted from the effects of corrosion on the mechanical properties of reinforcing steel that has affected the interface, surface modifications, fiber reduction, and rib peeled off. The above factors have reduced the load carry capacity of reinforced concrete structures as related to the works of (Charles et al., 2018; Daso et al., 2019; TrustGod et al., 2019; Nwabakata et al., 2019; Kanee et al., 2019; Charles et al., 2019; Gilbert et al., 2019; Huang and Yang, 1997).

The results of the elongation (%) minimum and maximum average and percentile values for controlled samples are 18.512% and 19.335% (-28.454% and -27.937%), the corroded values are 25.874% and 26.830% (39.302% and 40.334%), the coated samples values are 18.437% and 19.261% (-28.741% and -28.214%). The maximum comparative values for the controlled sample are -27.937% against the corroded and coated samples of 40.334% and -28.214%. Obtained differential average and percentile values for controlled samples are (0.82% and 0.51%), corroded values are (0.96% and 1.03%), and coated values are (0.82% and 0.53%).

In comparison, the corroded sample recorded a higher value of load application and also a higher elongation percentage whereas, the coated sample failure status is lower load application and decreased elongation. The effect of corrosion adversely affected the mechanical properties of reinforcing steel that has resulted in a low load to a higher failure state; the coated samples exhibited a closer value range to the reference (controlled samples). The application of exudative material to reinforcing steel has reduced the scourge and trend of corrosion attacks encountered by reinforced concrete structures built within the severe marine coastal areas as related to the works of (Charles et al., [7]; Charles et al., [8]; Gilbert et al, [9]; TrustGod et.al., [10];Daso et al., [11];Kanee et al., [13]).

The rebar weights- before test minimum and maximum average and percentile values computed in tables 3.4 and 3.5 and obtained from tables 3.1 - 3.3 of unit weight parameters of before and after corrosion test values of controlled samples are 1.563Kg and 1.563Kg (0.064% and 0.066%), the corroded values are 1.563Kg and 1.564Kg (0.064% and 0.063%), and the coated values are 1.562Kg and 1.564Kg (0.067% and 0.064%) and the rebar weights- after corrosion(Kg) obtained values of minimum and maximum average and percentile values are, controlled 1.563Kg and 1.563Kg (3.003% and 3.010%), corroded values are 1.517Kg and 1.517Kg (-6.863% and -6.786%), coated values are 1.628Kg and 1.629Kg (7.280% and 7.369%). The differential values obtained for the average and percentile of the controlled samples is (0.01kg and 0.29%), corroded values are (0.01Kg and 1.97%) and coated values are (0.01Kg and 3.97%).

The results of weight loss/gain of steel minimum and maximum average and percentile values are controlled (100%) for controlled samples resulting in its pooling in freshwater with no traces of corrosion attacks, the corroded sample values are 0.046kg and 0.047kg (-30.505% and -28.535%), the coated samples are 0.065kg and 0.066kg (39.929% and 43.895%). The computed data for maximum percentile values for rebar unit weights before corrosion test for controlled, corroded, and coated values are 0.066%, 0.063%, and 0.064%. The maximum recorded comparative values after corrosion test for controlled sample remained the same, with no traces of corrosion effect because it was pooled in freshwater, for the corroded and coated samples, the obtained values are -6.786% and 7.369%. The maximum percentile values of weight loss/gain for corroded and coated samples are -28.535% and 43.895%. The computed data showed a decreased value from corroded sample resulting from corrosion attack that has led to weight loss recorded whereas, coated samples has weight increase resulting from varying coating thicknesses in comparison to the reference range values obtained from controlled samples as related to the works of (Charles et al., [7]; Charles et al., [8]; Gilbert et al, [9]; TrustGod et.al., [10];Daso et al., [11]; Kanee et al., [13]).

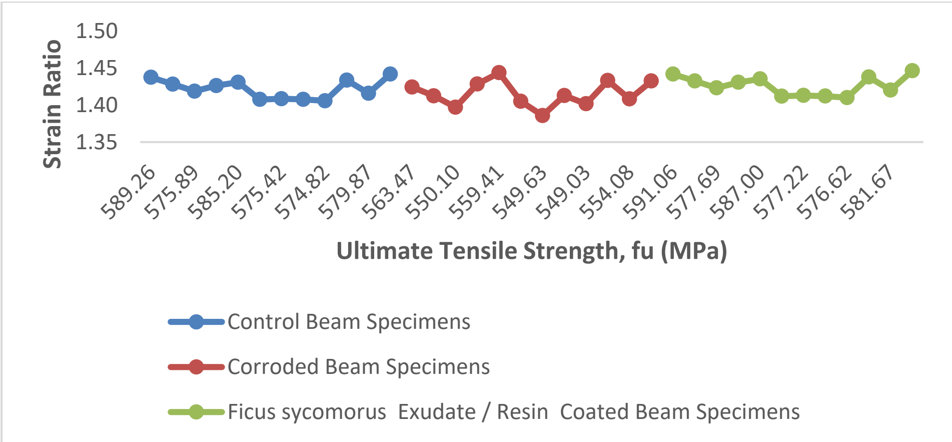

Figure 3.5: Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

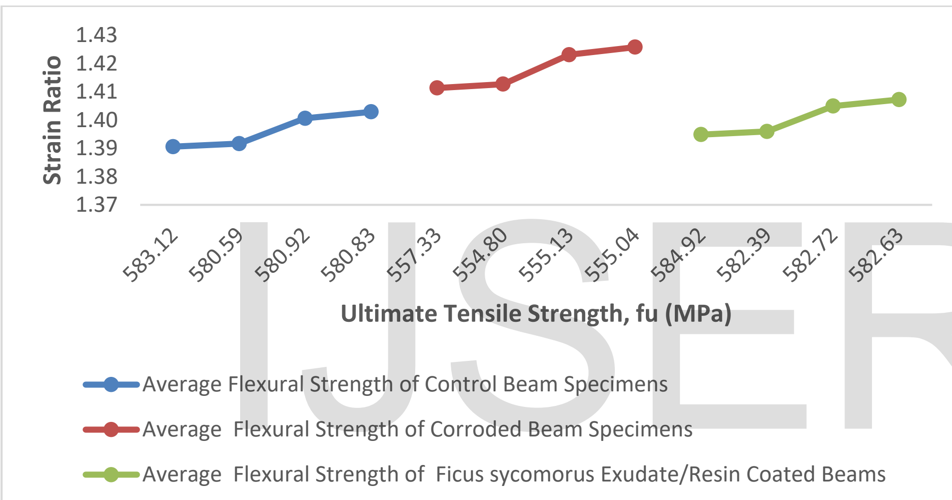

Figure 3.5A: Average Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

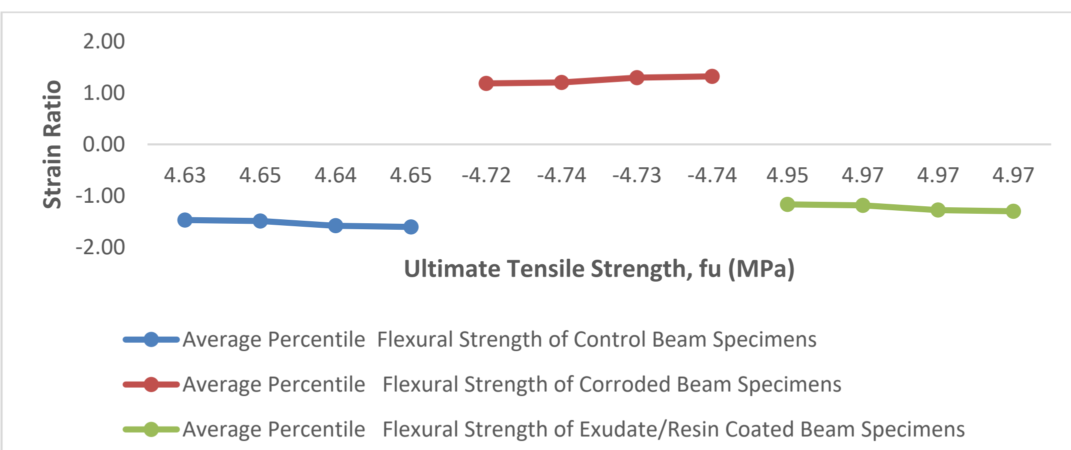

Figure 3.5B:Average Percentile Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

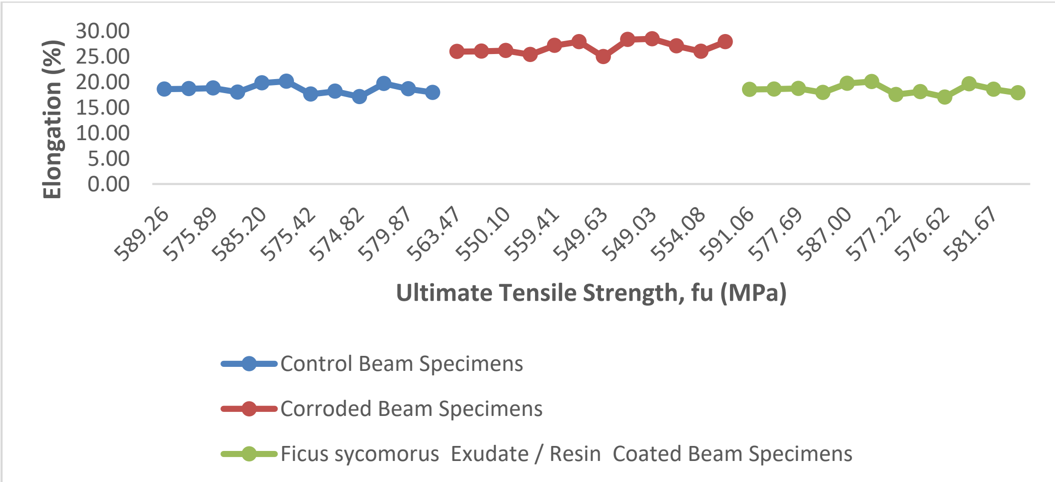

Figure 3.5: Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

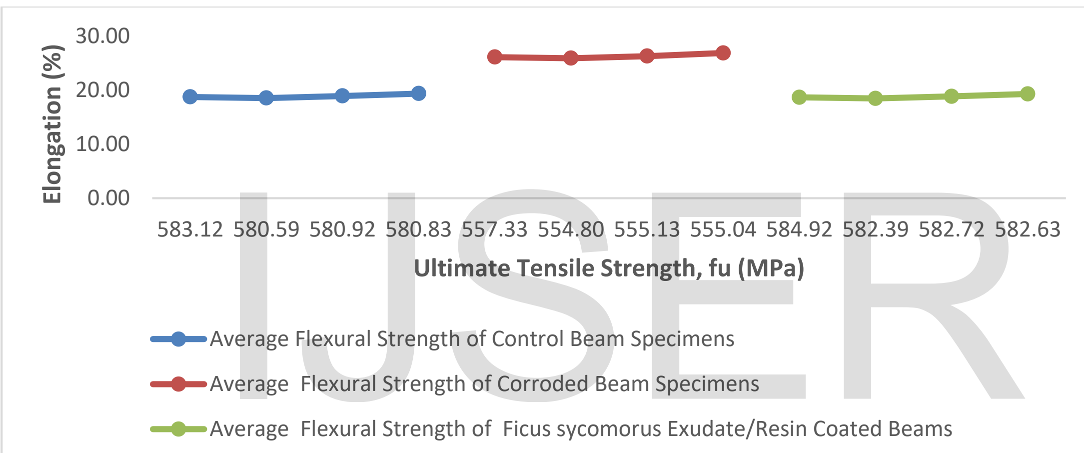

Figure 3.5A: Average Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

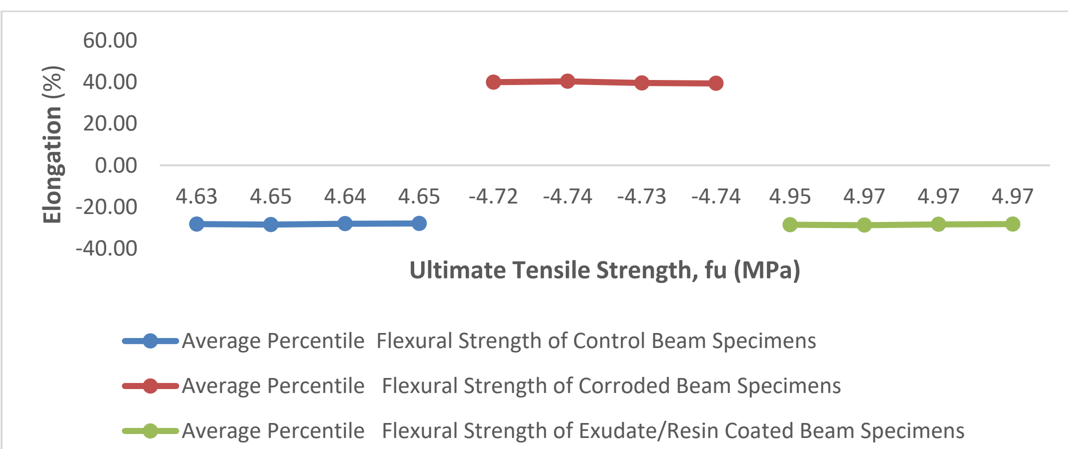

Figure 3.5B:Average Percentile Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

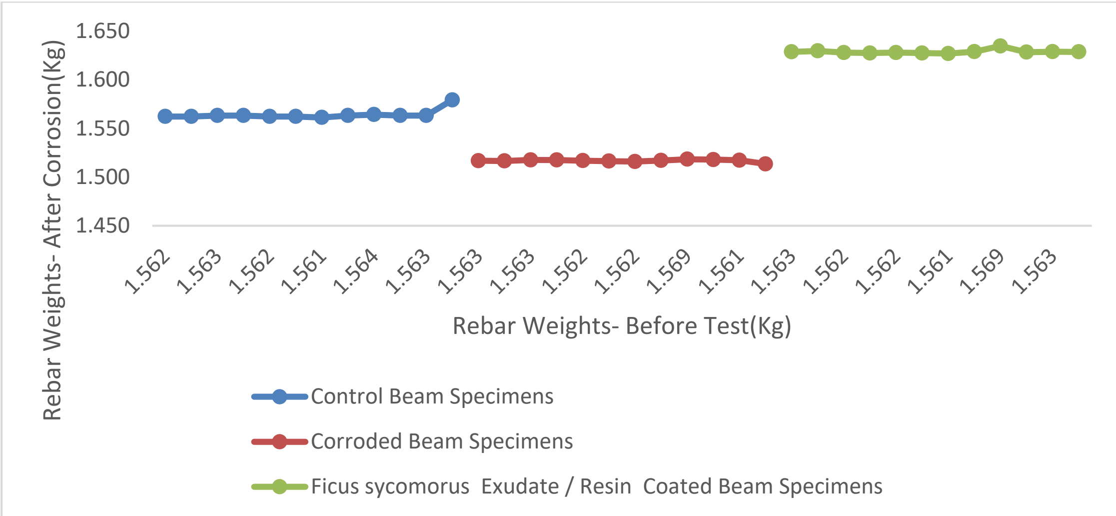

Figure 3.6: Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

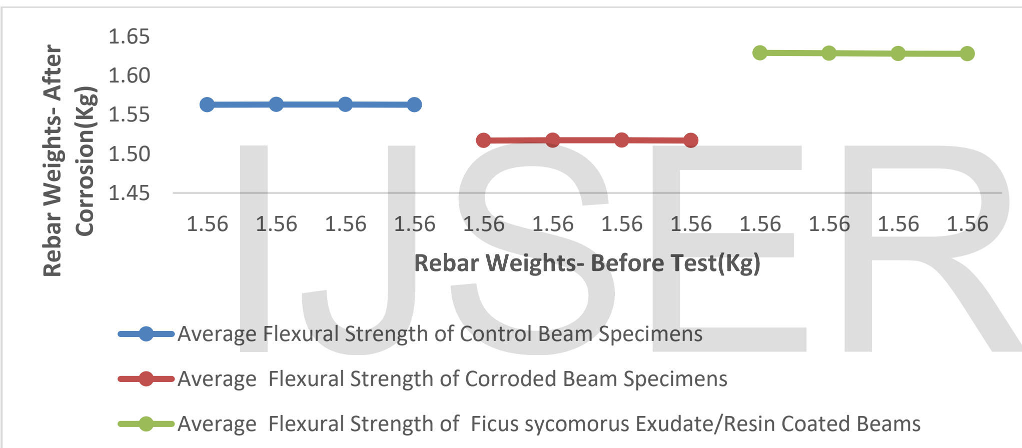

Figure 3.6A: Average Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

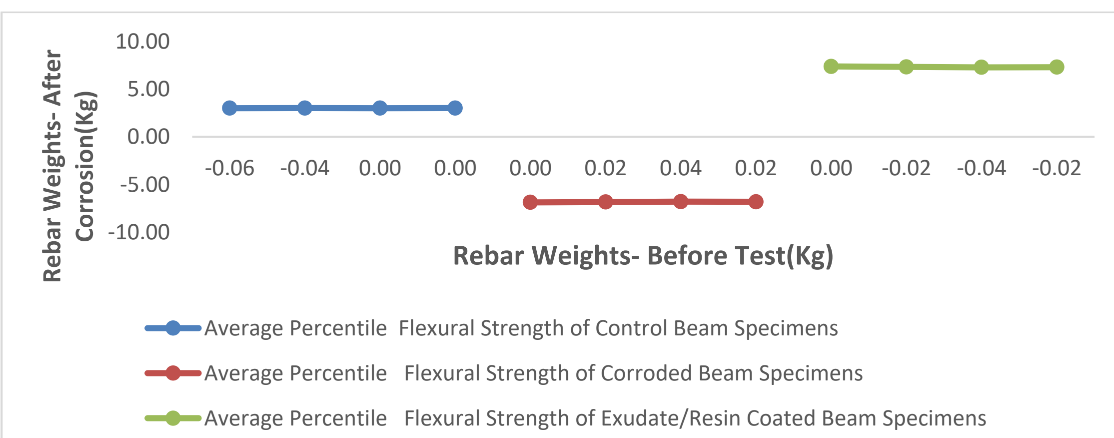

Figure 3.6B: Average Percentile Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

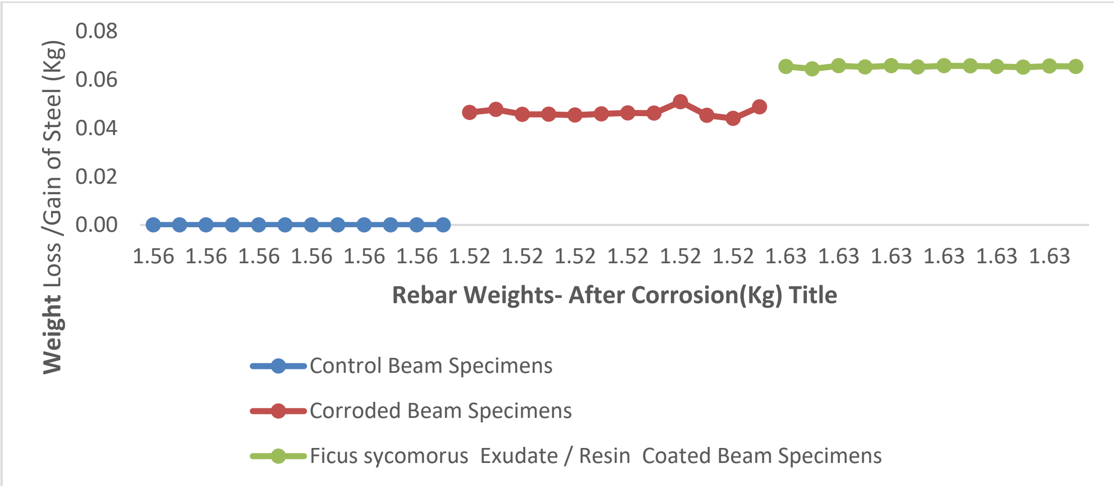

Figure 3.7: Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

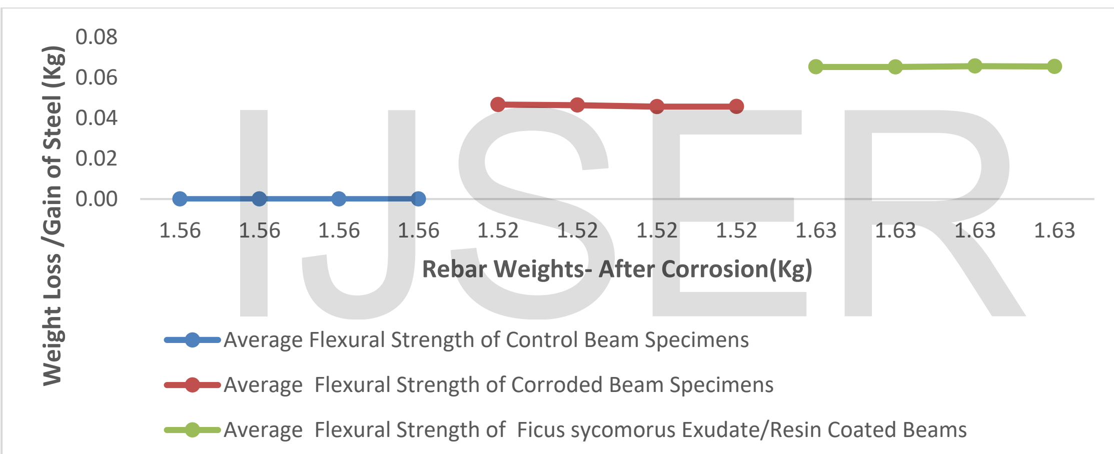

Figure 3.7A: Average Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

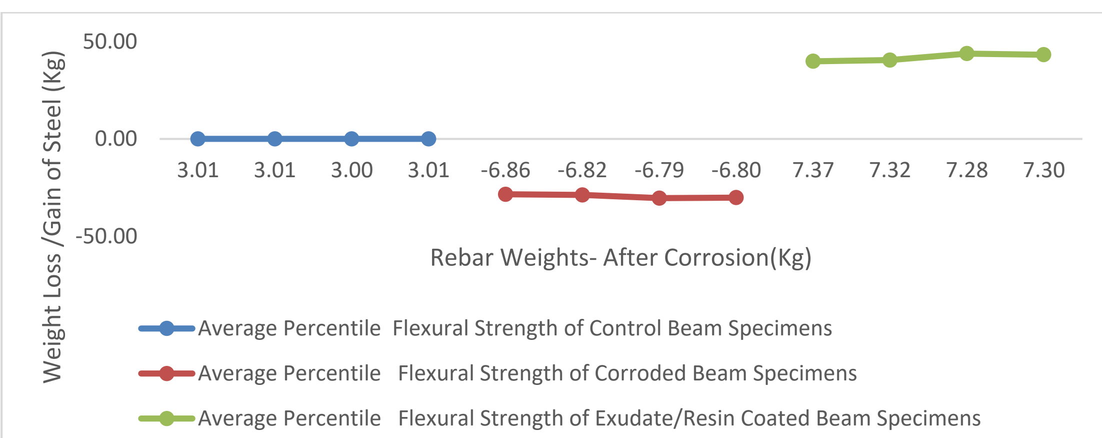

Figure 3.7B: Average Percentile Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

4.0 Conclusion

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

i. The results of the corroded specimen indicated that the effect of the mechanical properties of reinforcing steel embedded in the concrete media has a higher bending stress, moderate span deformation and maximum tensile strength compared to non-corroded elements coated with exudate / resin.
ii. The uncorroded (controlled) yield had a high central area deformation, normal yield strength with high ultimate strength and a low deformation ratio compared to corroded samples.
iii. The exudate / resin coated elements exhibit low bending loads, moderate span deformation, deformation ratio and maximum tensile strength.
iv. Shows high resistance to cracking and the adhesive effect of corrosion attack on reinforcing steel elements
v. Exudate/resin proved to be an anti-corrosive substance against corrosion attacks

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