OPEN ACCESS
Saudi Journal of Civil Engineering
Abbreviated Key Title: Saudi J Civ Eng
ISSN 2523-2657 (Print) |ISSN 2523-2231 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com/journal/sjce/home

Original Research Article

Structural Residual Strength Performance of Corroded and Inhibited Reinforced Concrete Structures in Corrosive Media

Gabriel Okonkwo Nnaji[1], Eze Chinonso Emmanuel[2], Charles Kennedy[3*]

[1,2]Department of Civil Engineering, Enugu State University of Science and Technology, Enugu State
[3]Faculty of Engineering, Department of Civil Engineering, Rivers State University, Nkpolu, Port Harcourt, Nigeria.

DOI: 10.36348/sjce.2021.v05i07.002 | **Received:** 13.07.2021 | **Accepted:** 17.08.2021 | **Published:** 21.08.2021

***Corresponding author:** Charles Kennedy

Abstract

This study evaluated the naturally extruded exudates/resin from plants of inorganic origin with eco-friendly and environmentally non-hazardous materials derived from tree trunks. Exudates/viscous adhesive is then embedded into the concrete beam after layers of different thickness and applied directly to the steel reinforcement. This study further aimed to determine the role of exudates/resins in harmful attacks on reinforcement by water tightness and durability (resistance) and modifications of steel reinforcement surface due to coating. In comparison, the results of the flexural strength exhibited at the maximum for the controlled sample is 27.86% compared to the corroded with -20.75% and coated sample of 27.87%, respectively. Differential mean values and percentile ranges were checked to be (0.55kN and 1.43%) for the controlled, (0.66kN and 1.04%) corroded and (0.52kN and 1.69%) coated. Corroded specimens fail with a lower load applications and high yielding, whereas coated specimens have a higher load to failure and lower yield occurrence. The results further confirmed that the flexural failure loads of the controlled and coated specimens maintain a narrow range of values over the corroded specimens at moderate, reduced and lower loads. The comparative results showed that the maximum value of the controlled state is -38.58% compared to 63.61% corroded and controlled -37.96%. The recorded mean and percentage difference values were examined and computed to be (0.26kN and 0.93%), corroded (0.26kN and 2.42%) and coated (0.27kN and 0.92%). The results showed a lower failure deflection load in the controlled and coated samples with a reduced value over the corroded sample with a higher failure deflection load and an increasing value compared to the reference range (controlled) and the layered (coated) sample. The comparative obtained results during and after the corrosion test for the maximum value of the rebar diameter is 0.53% compared to the corroded -0.74% and the coated sample 0.85%. The computed mean differential and percentile values were (0.02% and 0.03%), the corroded values were (0.03kN and 0.11%) and the coated values were (0.01kN and 0.11%). The results showed the effect of corrosion on the mechanical properties of reinforcing steel with a smaller diameter, where the average value and the percentage of corroded samples decreased, while the controlled and coated samples showed a preserved condition, with an increase in the diameter of the coating emanating from the varying coating thicknesses from the exuates /resin. The cross-sectional area of the reinforcing steel mean and percentile values calculated from the corroded values are (0.02 and 6.19%) and the coated values (0.02 mm and 5.21%). 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 in the thickness of the exudate paste layer. The differential calculated average and percentage yield strength and ultimate tensile strength (6.93MPa and 5.46%) and (2.53MPa and 0.02%), the corrosion value was (2.81 MPa and 5.01%) and (2.53 MPa and 0.02%). the values covered are (3.98MPa and 5.46%) and (2.56MPa and 0.01%). From the data obtained and compared, the yield strength and tensile strength values of the corroded sample take into account the mean and percentile values reduced with load damage with low application. The comparative strainn ratio obtained from the calculated maximum values for the mean and percentile values for the control was -3.19% compared to the corroded and overlaid values of 3.29% and -2.88%, respectively. The mean differential and percentile values obtained for the control were (0.42 and 0.3%), corroded values (0.42 and 0.32%) and closed values (0.43 and 0.31%). The results showed that the corroded sample had a higher percentage of deformation due to lower breaking load and higher yield strength, while the coating had a higher breaking load with lower yield strength. The calculated data for the maximum percentage of reinforcement weight before corrosion test for controlled, corroded and coated values were 0.05%, 0.05% and 0.07%. The maximum comparison values recorded after the corrosion test for the controlled sample remained the same, with no trace of a corrosive effect, as it was collected in fresh water, for the corroded and coated samples the values obtained were -6.82% and 7.76%, respectively.

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

1.0 INTRODUCTION

The effect of corrosion causes the reduction of steel reinforcement in concrete and this resulted due to: aggressive agents in the environment which affect the durability of the structure and increase premature deterioration. Some of the causes of damage to reinforced concrete are chloride, acid and sulfate attacks, as well as the reaction of alkaline pore solutions with carbon dioxide in the atmosphere [1]. Deterioration of reinforced concrete structure and infrastructure is affected by aggravating corrosion, particularly those exposed to coastal/marine of severe and corrosive conditions. In a chloride-containing environment, daily and seasonal fluctuations in temperature and humidity are triggered resulting to expansion-contraction and hydration-dehydration cycles leading to the initiation and spread of reinforcement corrosion resulting in cracking, disintegration and loss of load bearing capacity of reinforced concrete structures [2]. To protect reinforcing steel from corrosion, the mechanism of chloride entry into the concrete and influencing factors must be understood and curbed with the application of inhibitive materials [3].

One of the most economical and recently used techniques for controlling or slowing the corrosion of concrete reinforcement is corrosion inhibitors. Inhibitors can be applied to reinforced concrete structures while the concrete is being mixed or can be applied to the surface of existing reinforced concrete structures for repair work [4].

Inhibitors can be organic or inorganic depending on their use. Organic inhibitors include plant extracts. The advantages of green inhibitors compared to their chemical inhibitor analogues are their availability, are less toxic, biodegradable, do not contain heavy metals, are environmentally friendly and easily renewable [5].The use of organic compounds to resist corrosion of reinforcing steel has been of great importance because of its application in preventing corrosion under various corrosive environments [6, 7] found that bonding affects the load bearing capacity rather than the loss of tensile strength of reinforcement due to general corrosion. The test results show that the degree of corrosion of reinforcement does not affect the tensile strength of steel bars (calculated based on the actual cross-sectional area), but steel bars with corrosion of more than 12% show brittle damage.

Came to the conclusion that the strength ratio and modulus of elasticity of reinforcement are not significantly affected by corrosion and therefore the strength and modulus of elasticity of uncorroded bars are practically acceptable [8].

Investigated the combined effect of corrosion load and resistance in reinforced concrete beams corroded to flexure [9]. By applying 5% NaCl solutions to the corrosion process accelerated by constant current corrosion of tensile steel bars. The beam is tested under its own weight, less than 10% of the final load and less than 33% of the final load. They came to the conclusion that the neutral axis depth for beams without flexural cracks and beams without corrosion did not depend on the degree of corrosion, but for corroded beams with flexural cracks it decreased significantly with increasing degree of corrosion. In addition, the longitudinal deformation, depth of neutral axis and curvature depend on the degree of corrosion and the applied load, while the moment of inertia depends only on the degree of corrosion.

Investigated the loss of flexibility with loss of steel cross section due to general corrosion of embedded steel in a sample of concrete beams with a cross section of 100 mm × 150 mm and a length of 1500 mm, which were poured with chloride [10]. The sample is tested under flexion at a three-point load. They concluded that the flexural load capacity was reduced by 60% only at the 10% ratio, the main parameter affecting the reduction in flexural load, because pitting significantly reduces the cross-sectional area of the steel to some extent, and the steel from placement changes the plastic behavior to brittleness.

Investigated the flexural effects of the combined effects of corrosion and resistance loads on corroded beams made of reinforced concrete [11]. The test results show that the presence of prolonged loading and associated flexural cracking during corrosion loading significantly shortens the time of corrosion crack formation and slightly increases the width of the corrosion crack. They found that crack width spread 22% faster under load, with 8.9% and 22.2% mass loss, 6.4% and 20.0% strength loss, respectively.

Stated that concrete integrity is badly affected by sulfate ions before expanding to steel, which usually takes a long time, except for rapid conditions [12].

Concluded that the coated and sealed cement emulsion leads to greater efficiency than coating economy and other coating systems [13].

Explored the effect of structural capacity on the residual yield strength of an uncoated, corroded and coated steel bar. Comparative results of steel bars coated with three different resins /exudates extracts of symphonia globulifera Linn, ficus glumosa and acardium occidentale L. The overall results showed that the coating steel bars had higher values of failure load and tensile strength over corrode members, low failure load and high yields [14].

Studied the flexural strength failure loads of members coated with dacryodes edulis, moringa oleifera lam and mangifera indica exudates. The summary results showed that the higher loads to failure state was observed in the coated members while corroded members recorded lower failure applied loads to higher yields and elongations which resulted from the effects corrosion attacks[15].

Investigated the effect and impact of corrosion inhibitors on failure load, midspan deflection, tensile strength and elongation of steel reinforcement. The results recorded in the test work were for flexural strength failure load, midspan deflection, tensile strength and elongation. The summarized results showed the effect of corrosion on the flexural strength of the reinforcement, leading to a lower load on the failure load and a higher midspan deflection on the corroded beams and a lower midspan deflection on the non-corrosive and coated concrete beam members [16].

Investigated the use of extracts of resin / exudates to evaluate the yield strength efficiency of reinforced concrete beam members under corrosion-accelerated media [17]. Corroded and coated members increased by 23.8% and 29.59% over the flexural strength failure load compared to 22.30% elastic, tensile strength of non-coated and coated are 12.03%, 12.14% over 10.17%, and decreased values on midspan deflection of 28.30% and 22.30%. Elongation 31.5% and 32.46% of non-coated steel and coated concrete beam members as against 39.30% and 46.30% respectively. The overall results of the corroded member showed degradation of the yield strength potential due to the low failure loads of the yield and tensile strength, the high load on coated member to failure resulted from the protective member exhibited or formed by the exudates that prevented the entrance of corrosion to the reinforcing steel embedded in concrete beam while the corroded member exhibited corrosion potential that resulted to high midspan and elongation.

Explored the effects of corrosion on steel bar residual structural steel bar capacity of resins / exudates coated and non-coated reinforced concrete beam members [18]. Results of controlled member failure load are 29.09%, midspan deflection 28.30%, tensile strength 12.03% and elongation 31.50%. For coated beam members, failure load 29.42%, midspan deflection 27.42%, tensile strength 12.09% and elongation 31.80%. For corroded beam members, failure load 22.50% decreased, midspan deflection increased by 39.30%, tensile strength increased by 10.17% and elongation by 46.30%. The entire 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.

Investigated the effect of flexural strength and mid-spacing deflection of steel reinforcements coated with resins / exudates extract known as inhibitors (dacryodes edulis-African Pear r). Steel reinforcement members were embedded in concrete and exposed to harsh and saline environments (NaCl solution) [19]. The results obtained showed that the flexural failure strength and extension and midspan deflection of corrode samples experienced high yield on lower load applications.

Investigate potential changes in surface conditions of reinforcing steel studied for 90 days in corrosion-accelerated media on the residual elastic strength of concrete beam members coated with exudates and non-coated reinforcing steel [20]. These results indicate an increase in flexural failure load and ultimate tensile strength and a decrease in midspan deviation and extension, respectively, in corrugated concrete beam members. It is less loaded and more distorted in corrugated members and higher in corrosive and coated greater length in corrugated and less in corrugated and coated.

Researched on uncoated and corrosion resistors (symphonia globulifera Linn) resins paste coated steel reinforcing bar exposed to harsh and corrosive environment. The results obtained compared to the uncoated (corrugated) and coated are 22.50% to 29.50% of the flexural failure load, the midspan deflection 39.30% to 31.14%, the tensile strength 10.17%. Thus, the results showed a decrease in the failure load and the tensile strength of the corroded members, while an increase in the midspan deflection and extension. These attributes were due to the effect of corrosion and the reduction of strength from degradation properties. The resins / exudates coated members showed higher failure loads with lower deviation [21].

Conducted and tested 160 x 100 x 1500 mm beams, reinforced with a single 16 mm diameter bottom bar and a pair of 8 mm diameter upper bars with initiated corrosion carbonation and accomplished by placing CO2 filled beams in the pressure chamber (at 80kPa Placed) and provide a current of 400 μA /cm2. The beams were simultaneously corroded and loaded to 23% and the final load (pu) to 34%, the deflection rates were calculated by dividing the average deflection of the corroded beams. Conclusions attributed this initial increase to the initial crack formation, as the formation and expansion of the cracks improved at a slower rate after a certain point [22].

Conducted seven years of site exposure tests and evaluated the effectiveness of corrosion resistant steels in chloride media concrete. Evaluation of plain mild steel, galvanized, epoxy-coated and stainless steel reinforced steels studied by the embedding process in concrete with three different levels of chloride content (0.6, 1.2 and 4.8% by weight of cement). It has been concluded that bare mild steel bars at three chloride levels suffer severe corrosion damage, while the use of galvanized steel in concrete containing high levels of chloride delays concrete failure, while epoxy-coated bars have lower chloride levels [23].

Investigated the strengthening steel with the introduction of milicia excelsaudates / resins to reduce surface changes and mechanical properties of reinforce steel in concrete structures built in saltwater environments [24]. The corrosion acceleration process was 150 days and the corrosion potential determined. The flexural strength of the beam failure load results in an average of -39.11% for corroded, non-corroded 49.51% and milicial excelsa- coated 47.14%. Midspan deflection average values of non-coated and coated are -47.01% and -52.67% versus 88.73% of corroded samples. Average ultimate tensile strength of -13.59% for corroded, 15.73% and 15.33% with non-coated and coated specimens. 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; The effect of corrosion on the mechanical properties of reinforcing steel was observed.

Aimed to reduce the corrosion effect of steel reinforcement in the saltwater area by introducing exudates/resins of coated reinforced steel with 150μm, 300μm and 450μm thick **[25]** . Investigated the impact of corrosion on the concrete beam of coated and non-coated members. Extensive test results have shown potential corrosion resistance with coated members on mechanical properties that strengthen the effects of weight loss, cracking, and spalling and weight loss. Experimental results showed signs of corrosion but not corrosion with corrosive properties that reduce the thickness of the metal surface, resulting in metal weight loss and cracking. These features failed variable load and high retention potential with low average usage, high levels of anxiety, stretching, and midspan deviation.

Evaluated the effectiveness of the olibanum exudates/resins application of reinforcing embedded steel in concrete, sunk in a corrosive media for corrosion potential possibility through an accelerated process. The embedded concrete members of the coated and non-coated members were monitored for the first cracking and spalling. Corroded members show lower flexural loads on corroded and coated samples, while midspan deflection rates are higher for corroded and uncoated samples, the ultimate tensile strength of corroded members yields higher loads over or against non-corroded and coated samples. Coated members less; flexural failure load, midspan deflection, strain ratio, and ultimate tensile strength over corroded members[26].

Investigated the use of environmentally friendly mineral products of the exudates/resins of Artocarpus altilis in the prevention of corrosion attack on steel reinforcement embedded in concrete[27]. The results of the decreasing member properties of the steel reinforcement embedded in corrosive and corrosive media have shown greater tensile loads, midspan deflection, and ultimate tensile strength against coated and corrugated members of exudates/resins. Controlled results include higher midspan deflection, higher yield strength, and lower strain rate compared to coating members. Overall the results showed fractures and tremendous resistance to the corrosion attack that strengthened the steel members.

Examined surface changes, diameter reduction, and weight loss of reinforcing steel of non-coated and exudates/resins coated members installed in concrete and pooled in an aggressive environment for 150 days [28]. Non-coated (corroded) members showed a decrease in the mechanical properties of reinforcing steel due to corrosion attack, resulting in higher midspan deflection and greater yield, while coated members maintained higher structural integrity. Coated members showed higher flexibility before failure due to higher yield and decreased load to elongation.

Evaluated the flexural characteristic of reinforcing steel of non-coated and coated with different thicknesses of acacia senegal exudates/resins paste, embedded in concrete members, immersed into concentrated corrosive media and accelerated for 150days[29]. The results obtained after the exponential period was confirmed by the coating members with no corrosion potential properties of fractures and spalling. High flexural loads have been shown of non-coated against coated specimens, midspan deflection rates are higher for corroded members, and the ultimate tensile strength of corroded members. Overall, experimental tests have shown that the presence of corrosion strikes negatively affects the mechanical properties of steel reinforcement.

2.1 MATERIALS AND METHODS

2.1.1 Aggregates

Fine and course, both meet [30] requirements

2.1.2 Cement

Class 42.5 Lime Cement is the most common type of cement in the Nigerian market. It is used for all concrete mixtures in this test. Cement complies with [31] requirements.

2.1.3 Water

The clean water used is sourced from the Civil Engineering Department laboratory of Kenpoly, Rivers State. Water meets [32] requirements.

2.1.4 Structural Steel Reinforcement

Reinforcements are sourced directly from the Port Harcourt market. Confirmed according [33].

2.1.5 Corrosion Inhibitors (Resins / Exudates) Terminalia tomentosa

The gum exudate/resins were obtained from the tree barks in Amachara Village, in Mpu District, Aninri Local Government Area of Enugu State.

2.2 Methods

This study evaluates naturally extruded exudate/resin from plants of inorganic origin with eco-friendly and environmentally non-hazardous materials derived from tree trunks. Exudate / viscous adhesive is then embedded into the concrete beam after layers of different thickness and applied directly to the steel reinforcement. Its use is estimated as reinforced concrete structures resistant to corrosion exposed to the harsh regional marine environment.

This study aims to use the locally available raw material to prevent the negative effects of corrosion attack on steel reinforcement at a very high salt concentration (sodium chloride) in the marine environment. Concrete beams of 175mm x 175 mm x 750 mm, was modeled with 4 numbers of 16mm diameter reinforcing steel and embedded with and fully immersed in 5% sodium chloride (NaCl) for 360 days after 28 days initial standard curing in a pooling tank. The process of corrosion is a natural phenomenon and as well a long-term process that can last for many years. However, the introduction of artificial sodium chloride (NaCl) accelerates and stimulates the corrosion rate, with a high salt concentration and this process takes a very short time. Besides, this study aims to determine the role of exudates/resins in harmful attacks on reinforcement by water tightness and durability (resistance) and modifications of steel reinforcement surface due to coating.

2.2.1 Preparation and Casting of Model Concrete Beams

Standard methods for manual handling of concrete mix ratio and material weights are followed. The ratio of concrete mix is 1: 2: 4 and the water-cement ratio is 0.65. The manual mixer is used to clean the concrete platform and the mixer is checked and slowly added water to give a complete concrete mix design. By adding cement, water, and gravel, consistent color and consistency are achieved. The test beam is cast into a steel mold measuring 175 mm x 175 mm x 750 mm and supplied with suction air, and reinforced steel with 4 number lengths of diameter 16 mm. The samples were de-molded after 72 hours, preserved for 28 days using standard procedures, and the first crack appearance and pit observations were performed at room temperature for 360 days in a collection tank with 3 months intervals routine tests at 90 days, 180 days, 270 days and 360 days under rapid corrosion acceleration test.

2.2.2 Flexure Testing of Beam Specimens

According to BS EN 12390-2, a universal testing machine is used for bending tests and a total of 36 beam models are tested. After 28 pre-treatments and standards, 12 (restricted ones) were controlled to prevent corrosion-related reinforcement, while 24 unbound and exudate/resin coated samples were fully immersed in 5% sodium chloride (surface) NaCl for 360 days after 90 days with routine trials, 180 days, 270 days, and 360 days and investigations of changes in mechanical properties in uncoated (corroded) and coated specimens. The bending test was carried out on an Instron Universal Testing Machine with a capacity of 100 kN. The bending test is carried out on the machine according to the sample specifications. Digitally recorded and computerized system, all tests related to average midspan deformation and pre-tested reinforcement diameter, Reinforcement diameter - reduction/increase in cross-sectional area after erosion, tensile strength deformation rate, extension, the weight of reinforcement - before the test, weight of reinforcement - corrosion and weight loss/steel gain are recorded.

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

Samples	**Samples A**			**Samples B**			**Samples C**			**Samples D**		
Items	TT	TT1	TT2	TT3	TT4	TT5	TT6	TT7	TT8	TT9	TT10	TT11
Flexural Strength Load (KN)	83.30	82.49	82.00	84.23	82.42	80.44	83.25	82.56	83.49	83.43	81.45	82.53
Midspan Deflection (mm)	6.35	6.43	7.03	7.14	6.23	7.17	6.26	6.43	6.23	6.31	6.31	7.16
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)	411.73	410.84	410.34	410.36	4090.98	410.97	411.56	410.47	411.35	410.17	411.26	411.28
Ultimate Tensile Strength, fu (MPa)	582.38	577.33	569.01	574.79	578.32	568.74	568.54	569.34	567.94	580.49	572.99	581.85
Strain Ratio	1.41	1.41	1.39	1.40	0.14	1.38	1.38	1.39	1.38	1.42	1.39	1.41
Elongation (%)	12.08	12.15	12.28	11.48	13.28	13.62	11.08	11.65	10.58	13.18	12.12	11.41
Rebar Weights- Before Test	1.56	1.56	1.54	1.56	1.56	1.56	1.56	1.56	1.56	1.57	1.56	1.56
Rebar Weights- After at 28 days (Kg)	1.56	1.56	1.54	1.56	1.56	1.56	1.56	1.56	1.56	1.57	1.56	1.56
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)

	TT 1A	TT 1B	TT 1C	TT 1D	TT1 E	TT 1F	TT 1G	TT 1H	TT 1I	TT 1J	TT 1K	TT 1L
Flexural Strength Load (KN)	65.98	65.32	64.69	64.67	65.11	64.22	65.93	65.25	66.18	63.13	63.63	66.91
Midspan Deflection (mm)	10.66	10.74	11.34	11.45	10.54	11.48	10.57	10.74	10.54	10.62	10.62	11.47
Nominal Rebar Diameter	16	16	16	16	16	16	16	16	16	16	16	16
Measured Rebar Diameter Before Test(mm)	15.96	16	16	15.98	15.99	15.99	16	15.99	15.93	15.98	15.98	15.99
Rebar Diameter- After Corrosion(mm)	15.93	15.93	15.94	15.93	15.93	15.87	15.93	15.94	15.91	15.95	15.93	15.94
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.03	0.07	0.06	0.06	0.06	0.11	0.07	0.06	0.02	0.04	0.06	0.05
Yield Strength, fy (MPa)	384.26	383.37	382.87	382.89	4063.51	383.5	384.09	383	383.88	382.7	383.79	383.81
Ultimate Tensile Strength, fu (MPa)	563.31	558.26	549.94	555.72	559.25	549.67	549.47	550.27	548.87	561.42	553.92	562.78
Strain Ratio	1.47	1.46	1.44	1.45	0.14	1.43	1.43	1.44	1.43	1.47	1.44	1.47
Elongation (%)	19.35	19.42	19.55	18.75	20.55	20.89	18.35	18.92	17.85	20.45	19.39	18.68
Rebar Weights- Before Test(Kg)	1.57	1.55	1.57	1.57	1.56	1.56	1.57	1.57	1.57	1.57	1.57	1.57
Rebar Weights- After Corrosion(Kg)	1.52	1.5	1.52	1.52	1.51	1.51	1.52	1.52	1.52	1.52	1.52	1.52
Weight Loss /Gain of Steel (Kg)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table-3.3: Flexural Strength of Terminalia tomentosa Exudate / resin Coated Beam Specimens

	TT1 A1	TT1 B2	TT1 C3	TT1 D4	TT1 E5	TT1 F6	TT1 G7	TT1 H8	TT 1I9	TT1 J10	TT1 K11	TT1 L12
	150µm (Exudate/Resin) coated			**300µm (Exudate/Resin) coated**			**450µm (Exudate/Resin) coated**			**600µm (Exudate/Resin) coated**		
Flexural Strength Load (KN)	83.30	81.99	82.01	84.23	82.43	80.45	83.25	82.57	83.50	82.64	80.95	81.54
Midspan Deflection (mm)	6.42	6.50	7.10	7.21	6.30	7.24	6.33	6.50	6.30	6.38	6.38	7.23
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)	15.96	15.98	15.98	15.98	16.00	15.98	15.99	15.98	15.92	15.99	15.99	15.99
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)	0.11	0.08	0.06	0.09	0.07	0.03	0.07	0.08	0.05	0.04	0.04	0.07
Yield Strength, fy (MPa)	411.74	410.85	410.35	410.37	4090.99	410.97	411.56	410.48	411.36	410.18	411.27	411.29
Ultimate Tensile Strength, fu (MPa)	584.19	579.14	570.82	576.60	580.13	570.55	570.35	571.15	569.75	582.30	574.80	583.66
Strain Ratio	1.42	1.41	1.39	1.41	0.14	1.39	1.39	1.39	1.39	1.42	1.40	1.42
Elongation (%)	12.00	12.07	12.20	11.40	13.20	13.54	11.00	11.57	10.50	13.10	12.04	11.33
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)	82.60	82.91	82.88	82.36	65.33	64.90	64.83	64.67	82.43	82.74	82.89	82.37
Midspan Deflection (mm)	6.60	6.87	6.80	6.85	10.92	11.18	11.11	11.16	6.67	6.94	6.87	6.92
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	15.99	16.00	15.99	15.99	15.97	15.98	15.99	15.99
Rebar Diameter- After Corrosion(mm)	15.99	15.99	15.99	15.97	15.94	15.93	15.93	15.91	16.05	16.06	16.06	16.05
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	0.05	0.06	0.06	0.07	0.08	0.07	0.07	0.06
Yield Strength, fy (MPa)	410.97	410.51	413.23	417.44	387.18	387.62	388.39	385.58	412.29	409.58	413.56	411.33
Ultimate Tensile Strength, fu (MPa)	576.24	573.71	574.04	573.95	557.17	554.64	554.97	554.88	578.05	575.52	575.85	575.76
Strain Ratio	1.40	1.40	1.40	1.40	1.45	1.45	1.43	1.43	1.41	1.40	1.41	1.41
Elongation (%)	12.17	11.97	12.35	12.79	19.44	19.24	19.62	20.07	12.09	11.89	12.27	12.72
Rebar Weights- Before Test(Kg)	1.56	1.56	1.56	1.56	1.56	1.56	1.57	1.57	1.56	1.56	1.56	1.56
Rebar Weights- After Corrosion(Kg)	1.56	1.56	1.56	1.56	1.51	1.51	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)	26.43	27.75	27.86	27.36	-20.75	-21.57	-21.79	-21.49	26.18	27.50	27.87	27.37
Midspan Deflection (mm)	-39.51	-38.58	-38.81	-38.65	63.61	61.19	61.79	61.37	-38.88	-37.96	-38.19	-38.03
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)	0.388	0.400	0.391	0.396	0.403	0.408	0.396	0.401	0.402	0.401	0.400	0.39
Rebar Diameter- After Corrosion(mm)	0.51	0.52	0.53	0.50	-0.74	-0.75	-0.77	-0.85	0.74	0.76	0.78	0.85
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-35.17	-18.98	-22.27	-22.43	24.24	23.43	28.64	28.32
Yield Strength, fy (MPa)	7.16	7.17	1.71	1.71	-6.68	-6.69	-1.68	-1.68	7.16	7.17	1.71	1.71
Ultimate Tensile Strength, fu (MPa)	3.42	3.44	3.44	3.44	-3.61	-3.63	-3.63	-3.63	3.75	3.76	3.76	3.76
Strain Ratio	-3.49	-3.48	-3.19	-3.19	3.29	3.28	2.97	2.97	-3.19	-3.18	-2.89	-2.88
Elongation (%)	-37.42	-37.81	-37.08	-36.25	60.77	61.79	59.89	57.79	-37.80	-38.19	-37.46	-36.62
Rebar Weights- Before Test(Kg)	0.062	0.065	0.065	0.063	0.060	0.064	0.065	0.066	0.065	0.065	0.063	0.066
Rebar Weights- After Corrosion(Kg)	2.94	2.99	2.60	3.00	-7.20	-7.11	-6.82	-6.91	7.76	7.66	7.31	7.42
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	-25.54	-23.26	-23.77	-23.57	34.30	30.31	31.18	30.85

3.1 Results and Discussion of Concrete Beam Members and Midspan Deflection

Corrosion of reinforced concrete or concrete has caused the sudden collapse of many exposed structures in coastal areas with inclement weather. 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. These corrosion factors and associated damage conditions by [10] investigated the loss of strength of steel due to corrosion of embedded steel in concrete elements with cross sections of 100 mm × 150 mm and 1500 mm.

Also investigated the effect of corrosion inhibitors on flexural strength under load, average spring deflection, tensile strength and steel reinforcement resin coated with mangifera indica extract as a corrosion inhibitor. The complete results show the effect of corrosion on the flexural strength of the reinforcement, which causes low loads and high deviations over the average span in the case of broken joints and bending at breaking loads and the lower center area of the concrete girder without a pipe and joint, which causes an attack of facial stiffness. In view of the corrosive effect on reinforced concrete structures built in the coastal area of the Niger Delta, Nigeria, with high salinity, the application of Terminalia tomentosa exudates / extract of resin from wood sources with environmentally friendly materials was applied directly to the reinforcement in concrete beams and evaluates their effectiveness as corrosion protection [14].

3.2 Results Flexural Strength Load and Midspan Deflection

Due to the influence of the natural and industrial environment, a decrease in the structural strength of corroded reinforced concrete is often observed, especially in corrosion-prone shipbuilding, road and bridge construction and construction in saline areas, corrosion of steel [34]. The human loss and corrosion properties of steel cannot be ignored. Steel corrosion has a very negative influence on the structural properties of concrete: effective cross-sectional area, nominal yield strength, ultimate strength and elongation rate are reduced by corrosion products; With increasing corrosion of steel and the influence of environmental influences, the bonding properties between corroded steel bars and concrete deteriorate, leading to a decrease in the load-bearing capacity and hardness of the elements.

The experimental data for the flexural test of concrete beams are shown in Tables 3.1, 3.2 and 3.3, the mean in table 3.4 and percentile values in 3.5, and the results are shown graphically in Figures 3.1 - 3.7b. The average values, the minimum and maximum percentages computed of the flexural strength using an Instron Universal Testing Machine with compression load of 100kN under pressure until failures.

The results obtained of the controlled samples as 82.36kN and 82.91kN with percentile representation as (26.43% and 27.86%), the corroded samples recorded 64.67kN and 65.33kN and with percentile values of (-21.79% and -20.75%), and the samples of coated with exudates/resin were 82.37kN and 82.89kN and percentile values of (26.18% and 27.87%) respectively. In comparison, the results of the flexural strength exhibited at the maximum for the controlled sample is 27.86% compared to the corroded with -20.75% and coated sample of 27.87%, respectively. Differential mean values and percentile ranges were checked to be (0.55kN and 1.43%) for the controlled, (0.66kN and 1.04%) corroded and (0.52kN and 1.69%) coated.

The results show that the reference percentage of the controlled sample was placed in fresh water according to BS 3148 and the corrosion effect was not observed and was therefore used as a reference value for the non-coated (corroded) and coated immersed in a corrosive medium as described in the test program. Corroded specimens fail with a lower load applications and high yielding, whereas coated specimens have a higher load to failure and lower yield occurrence. The results further confirmed that the flexural failure loads of the controlled and coated specimens maintain a narrow range of values over the corroded specimens at moderate, reduced and lower loads. The mean yields and percentages of minimum and maximum loads with midspan deflection (deviations from the middle) range, obtained for the non-coated (controlled) were 6.6kN and 6.87kN and percentile values of (-39.51% and -38.58%), corroded samples were 10.92kN and 11.18kN (61.19% and 63.61%) and the coated samples were 6.67kN and 6.94kN and percentile values of (-38.88% and -37.96%).

The comparative results showed that the maximum value of the controlled state is -38.58% compared to 63.61% corroded and controlled -37.96%. The recorded mean and percentage difference values were examined and computed to be (0.26kN and 0.93%), corroded (0.26kN and 2.42%) and coated (0.27kN and 0.92%). The results showed a lower failure deflection load in the controlled and coated samples with a reduced value over the corroded sample with a higher failure deflection load and an increasing value compared to the reference range (controlled) and the layered (coated) sample. The computed comparative results obtained for flexural strength and midspan deflection (deviations in the middle range) of corroded samples show the effect of corrosion on the mechanical properties of reinforcing steel with detached and peeled ribs, high surface modification with severe pits, which leads to low load bearing capacity and large deviations from the middle spring, as validated by the works of

[29, 28, 24, 26]. From the results obtained, Terminalia tomentosa exudates/resin is proven as a corrosion protection agent in reinforced concrete structures exposed to corrosive media with high resistance and as an insulating membrane against the effects of corrosion.

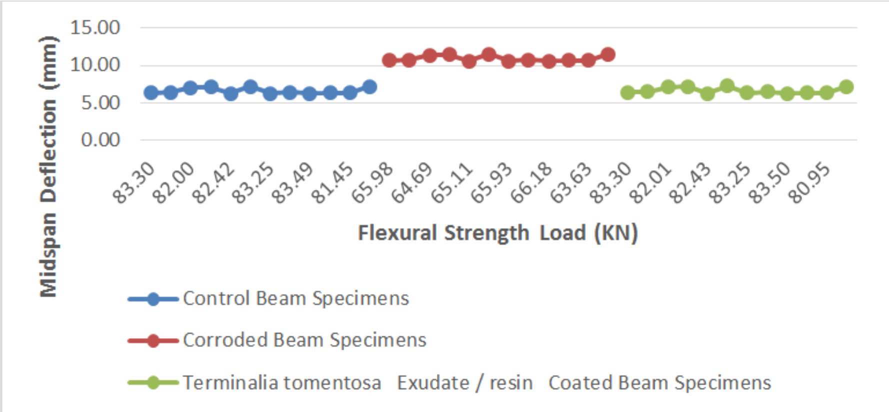

Fig-3.1: Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

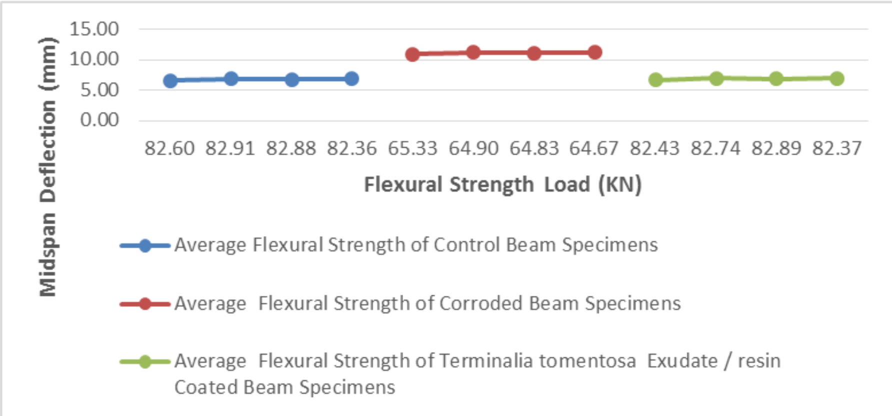

Fig-3.1A: Average Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

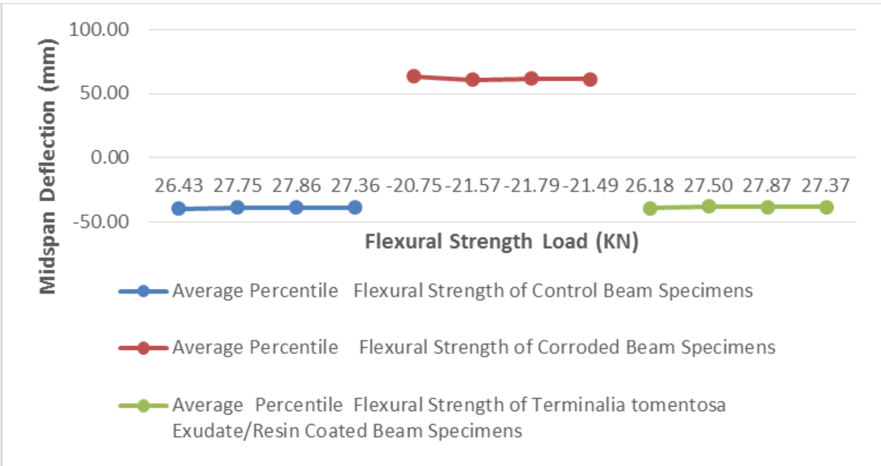

Fig-3.1B: Average Percentile Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

3.3 Results of Measured Rebar Diameter Before and After Corrosion Test

The tensile behavior of corroded reinforcement is very important to assess the load bearing capacity of corroded reinforced concrete structures.The reduction of the effective diameter of steel bars has a significant impact on the tensile strength of reinforced concrete structures. The results show an inverse relationship between the corrosion rate and the true tensile strength.

According to research by [7], the degree of corrosion does not affect the tensile strength of steel bars.

The results obtained for the minimum and maximum mean and percentile values for the nominal value diameter are 16 mm (100%) for all standard references. The rebar diameters measured before testing for the controlled sample were 15.97mm and 15.99mm with percentile computed values of (0.388% and 0.4%), the corroded were 15.99mm and 16mm and percentile represented values of (0.396% and 0.408%), and the coatings are 15.97 mm and 15.99 mm (0.39% and 0.402%). The results obtained indicate that the diameter of the reinforcing steel varies minimally due to the manufacture of reinforcement by different companies, the production form used leads to an average value and the percentile difference is not significant.

The average value and the minimum and maximum percentage of the rebar diameter - after the corrosion test, the controlled were 15.97 mm and 15.99mm with percentile values of (0.5% and 0.53%), the corroded samples were 15.91mm and 15.94mm and perecntile (-0.85% and -0.74%), the values of the coated samples were 16.05 mm and 16.06 mm and (0.74% and 0.85%) percentile values.

The comparative obtained results during and after the corrosion test for the maximum value of the rebar diameter is 0.53% compared to the corroded -0.74% and the coated sample 0.85%. The computed mean differential and percentile values were (0.02% and 0.03%), the corroded values were (0.03kN and 0.11%) and the coated values were (0.01kN and 0.11%).

The results showed the effect of corrosion on the mechanical properties of reinforcing steel with a smaller diameter, where the average value and the percentage of corroded samples decreased, while the controlled and coated samples showed a preserved condition, with an increase in the diameter of the coating emanating from the varying coating thicknesses from the exuates /resin. The use of exudates/resins protects reinforcing steel from severe corrosion damage. The mean and percentile values determined after and before the correction test adversely affect the diameter of the reinforcing steel, leading to a decrease and increase in the cross-sectional area.

The minimum and maximum "decrease/increase in cross-sectional area (diameter)" of the controlled samples was 0.00mm, which (100%) for all samples indicated that the corroded samples were 0.05mm and 0.07mm respectively. was 35.17% and -18.98%) and coated samples were 0.06mm and 0.08mm (23.43% and 28.64%). The cross-sectional area of the reinforcing steel mean and percentile values calculated from the corroded values are (0.02 and 6.19%) and the coated values (0.02 mm and 5.21%).

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 in the thickness of the exudate paste layer. The reduction in cross-sectional area is due to the corrosive effect on reinforced concrete structures built in marine coastal environments and the increased protective layer provided as validated by the works of [29, 28, 24, 26].

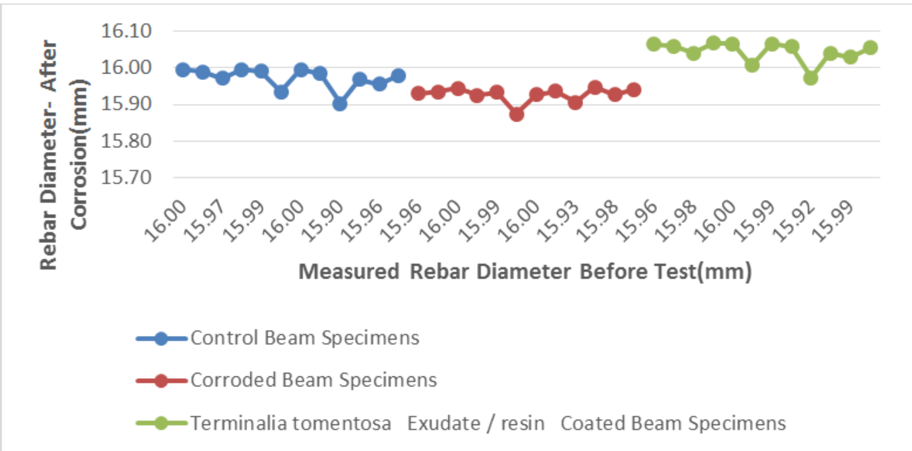

Fig-3.2: Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

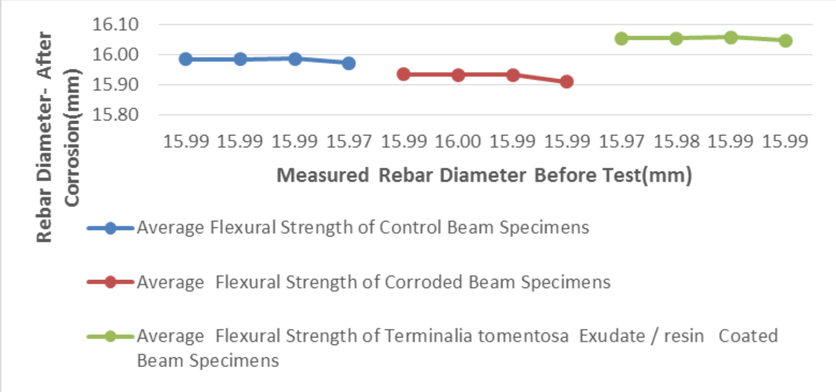

Fig-3.2A: Average Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

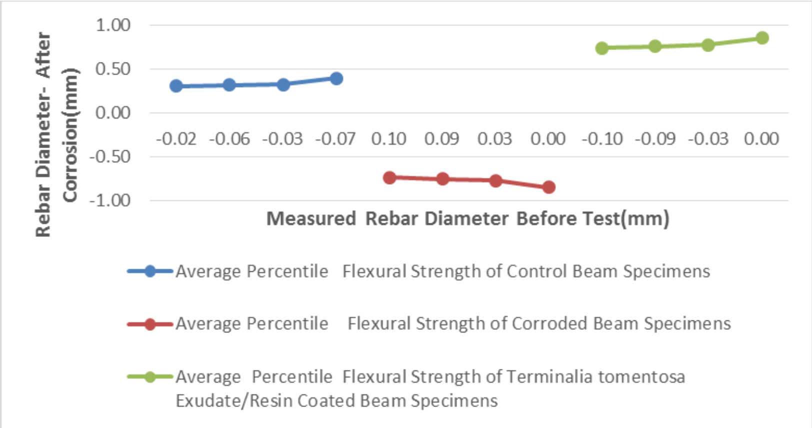

Fig-3.2B: Average Percentile Measured Rebar Diameter Before Test versus Rebar Diameter- After Corrosion

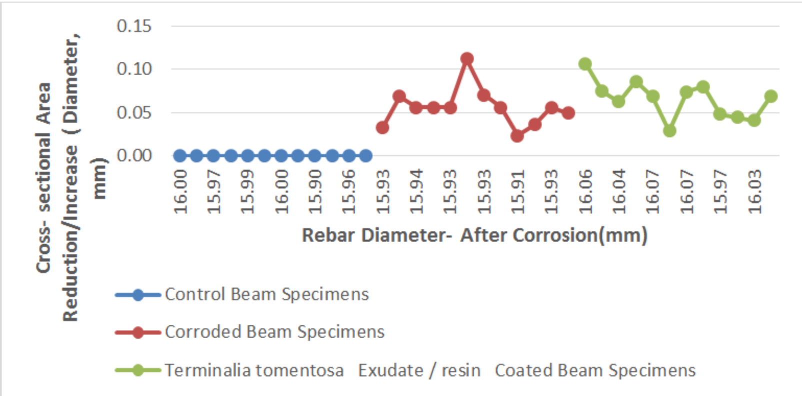

Fig-3.3: Rebar Diameter- After Corrosion versus Cross- sectional Reduction/Increase (Diameter

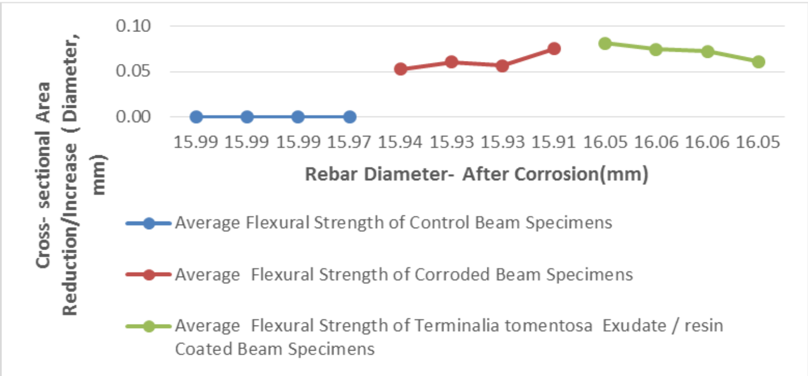

Fig-3.3A: Average Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase(Diameter)

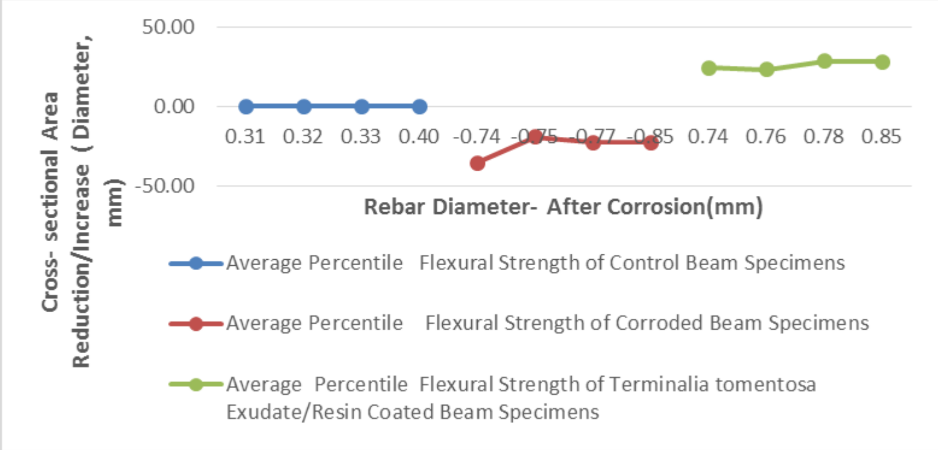

Fig-3.3B: Average Percentile Rebar Diameter- After Corrosion versus Cross- sectional Area Reduction/Increase(Diameter)

3.4. Results of Ultimate Tensile Strength and Yield Strength

The strength limit ratio ratio fy/fu reflects the deformability of the steel bar and warns of most of the desired damage to the reinforcing bar. Usually the deformation increases with increasing fy/fu, the corroded capacity of the steel bar decreases. The smaller diameter of the reinforcement (16 mm) results in a significant reduction in cross-section. It has a higher fy/fu ratio compared to larger diameter reinforcement (20 and 25mm) and has less reduction in steel cross-sectional area and lower fy/fu values. 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 at the point of the sample-controlled value results are 410.51MPa and 417.44MPa with percentile values of (1.71% and 7.17%), the corroded samples were 385.58MPa and 388.39Mpa and percentile values of (-6.69% and -1.68%) and the coated samples were 409.58 MPa and 413.56Mpa with percentile values of (1.71% and 7.17%).

The ultimate tensile strength values of controlled samples were 573.71MPa and 576.24MPa (3.42% and 3.44%), corroded samples were 554.64MPa and 557.17 MPa -3.63% and -3.61%) and coated samples of 575.52 MPa and 578.05MPa (3.75% and 3.76%). The calculation results of the maximum comparative value for both yield point and tear strength for the controlled sample were 7.17% and 3.44% in relation to the corroded and coated values of -1.68% and -3.61% were closed respectively. values of 7.17% and 3.76%.

The differential calculated average and percentage yield strength and ultimate tensile strength (6.93MPa and 5.46%) and (2.53MPa and 0.02%), the corrosion value was (2.81 MPa and 5.01%) and (2.53 MPa and 0.02%). the values covered are (3.98MPa and 5.46%) and (2.56MPa and 0.01%). From the data obtained and compared, the yield strength and tensile strength values of the corroded sample take into account the mean and percentile values reduced with load damage with low application. The damage caused caused a corrosive effect on the mechanical properties of reinforcing steel through surface modifications affecting the ribs and fibers, whereas the coated samples at higher loads recorded an increase in the mean and percentage values of the reference range (controlled sample) in relation to the studies of [29, 28, 24, 26]. Exudates / resins exhibit efficiency and strength in protecting reinforced concrete structures exposed to corrosive media

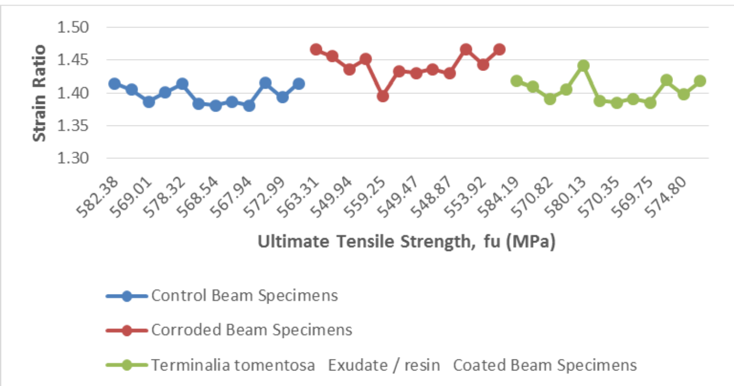

Fig-3.4: Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

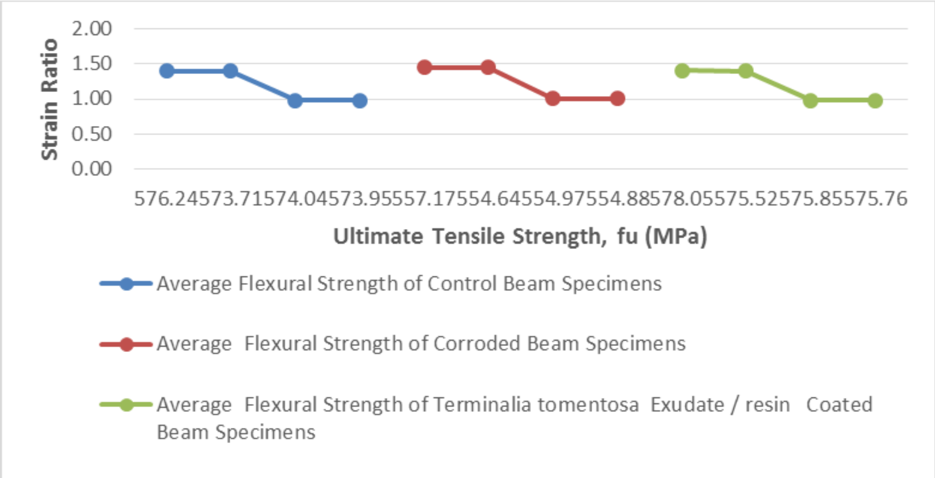

Fig-3.4A: Average Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

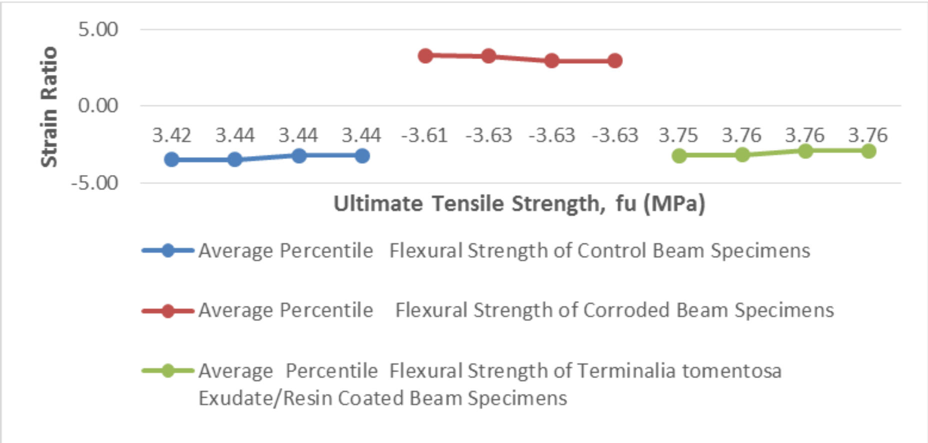

Fig-3.4B: Average percentile Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

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

The elongation and ductility of corroded reinforcement is significantly reduced compared to its maximum weight and strength limits. Elongation and ductility decrease exponentially with increasing corrosion losses [35]. Although the parameters of elongation, maximum strength and corroded plastic area are reduced more in the case of small diameter and/or ordinary rods than in the case of large diameter and/or ribbed rods, these differences are not significant and can be neglected [36]. The coefficient of expansion increases as the corrosion rate decreases; that is, as the corrosion rate increases, the elongation decreases until the steel reinforcement collapses. This corrosion rate is inversely proportional to elongation at break. The results agree with [37] investigated that the expansion of the corrosion damage point in the damaged samples increased with decreasing the corrosion rate.

The results of the minimum and maximum mean and percentile values calculated in Tables 3.4 and 3.5 obtained from Tables 3.1-3.3 the elongation ratio values obtained from the controlled sample are 1.40 and 1.41 (-3.49% and -3.19%), the samples that corroded were 1.45 and 1.45 (2.97% and 3.29%), the values of the coated samples were 1.40 and 1.40 (-3.19% and -2.88%).

The comparative strainn ratio obtained from the calculated maximum values for the mean and percentile values for the control was -3.19% compared to the corroded and overlaid values of 3.29% and -2.88%, respectively. The mean differential and percentile values obtained for the control were (0.42 and 0.3%), corroded values (0.42 and 0.32%) and closed values (0.43 and 0.31%).

The results showed that the corroded sample had a higher percentage of deformation due to lower breaking load and higher yield strength, while the coating had a higher breaking load with lower yield strength. The lower stress and yield strength and higher stress are the result of a corrosive effect on the mechanical properties of reinforcing steel, which has affected the interface, surface modification, reduction of fibers and loose ribs. The above factors have reduced the load bearing capacity of work-related reinforced concrete structures in relation to the studies of [29, 28, 24, 26].

The results of the mean and percent of minimum and maximum elongation (%) for controlled samples were 11.97% and 12.79% (-37.81% and -36.25%), corrosion values were 19.24% and 20.07 % (57.79% and 61.79%), recorded sample values were 11.89% and 12.72% (-38.19% and -36.62%). The maximum comparison value for controlled samples was -36.25% compared to corroded and coated samples of 61.79% and -36.62%, respectively. The mean differentials and percentages obtained for the controlled samples were (0.82% and 1.56%), corrosion values (0.83% and 4.28%), and closed values (0.83% and 1.57% respectively). In comparison, the corroded samples showed higher stress values as well as higher elongation rates, whereas the coating state of the coated samples showed less stress and reduced elongation. Corrosion effect affects the mechanical properties of reinforcing steel, leading to low loads leading to higher failure states; closed samples show a range of values closer to the reference (controlled sample). The application of exudates materials to reinforcing steel has reduced the scourge and tendency of corrosion attack that occurs in reinforced concrete structures in rough coastal areas in relation to the studies of [29, 28, 24, 26].

The values of rebar weight - the minimum and maximum mean and percentage values before the test, calculated in Tables 3.4 and 3.5 and obtained from Tables 3.1 - 3.3, the unit weight parameters before and after the corrosion test value of the control sample 1.56kg and 1.56kg (0.0615% and 0.0655%), corrosion values 1.56kg and 1.57kg (0.059% and 0.065%) and coating values 1.56 kg and 1.56 kg (0.0625% and 0.066%), the weight of reinforcement - the average values and the minimum and maximum percentages obtained after corrosion (kg) were 1.56 kg and 1.56kg (2.6% and 3.05%) were controlled, the corroded values were 1.51 kg and 1.52kg (-7.2% and -6.82%), coated values were 1.63kg and 1.63kg (7.31% and 7.76%). The difference values obtained for the mean and percentile of the controlled sample are (0.01 and 0.4%), the corroded values are (0.03Kg and 0.38%) and the covered values are (0.004Kg and 0.47%).

The results of the weight loss/gain of the average minimum and maximum steel and controlled percentage values (100%) for the controlled sample, which leads to their combination in fresh water without any trace of corrosion attack, corroded sample values of 0.05 kg and 0.05 kg (- 25.54% and -23.26%, coated samples were 0.07 kg and 0.07kg (30.31% and 34.3%).

The calculated data for the maximum percentage of reinforcement weight before corrosion test for controlled, corroded and coated values were 0.05%, 0.05% and 0.07%. The maximum comparison values recorded after the corrosion test for the controlled sample remained the same, with no trace of a corrosive effect, as it was collected in fresh water, for the corroded and coated samples the values obtained were -6.82% and 7.76%, respectively.

The maximum weight loss/gain percentages for corroded and coated samples were -23.26% and 34.3%, respectively. The calculated data showed a decrease in the values of the samples that were corroded due to corrosive attack, which led to a loss of weight, whereas the coated samples, due to different coating thicknesses, showed an increase in weight compared to the reference range values of the controlled samples, in relation to the studies of [29, 28, 24, 26].

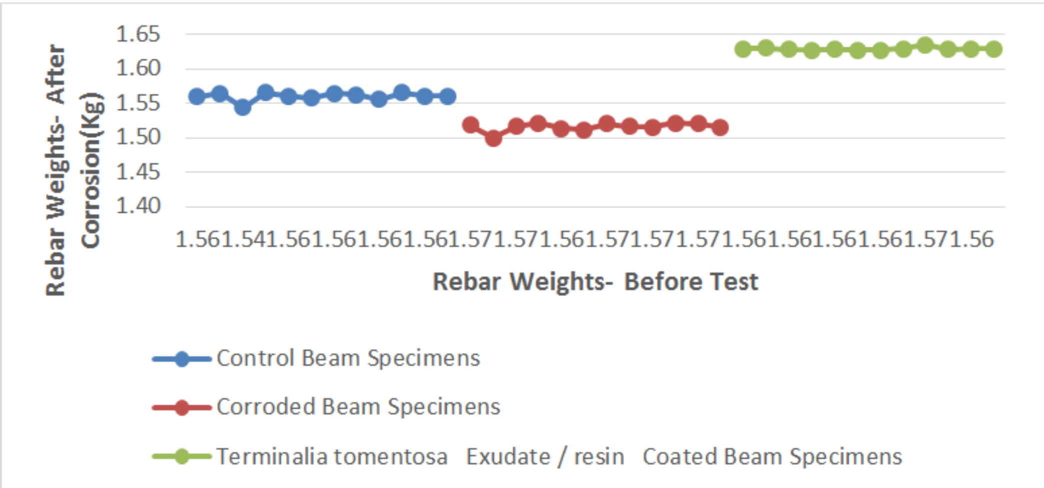

Fig-3.5: Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

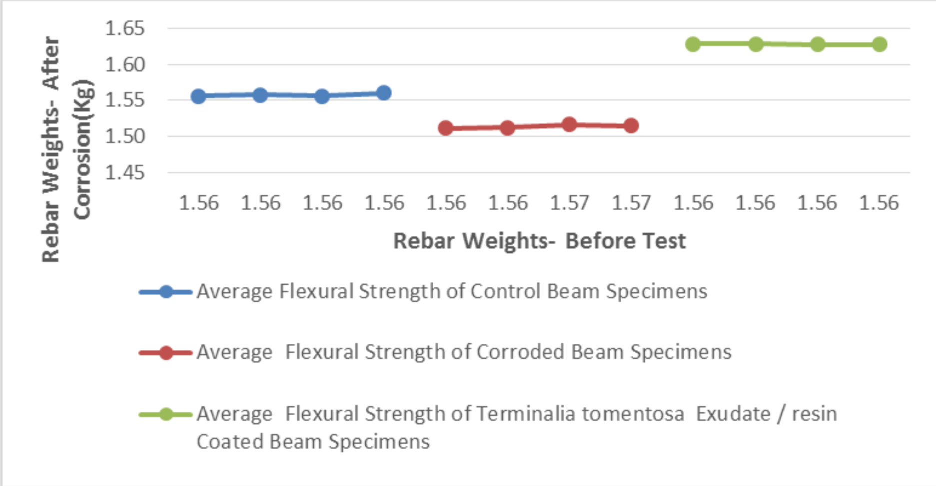

Fig-3.5A: Average Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

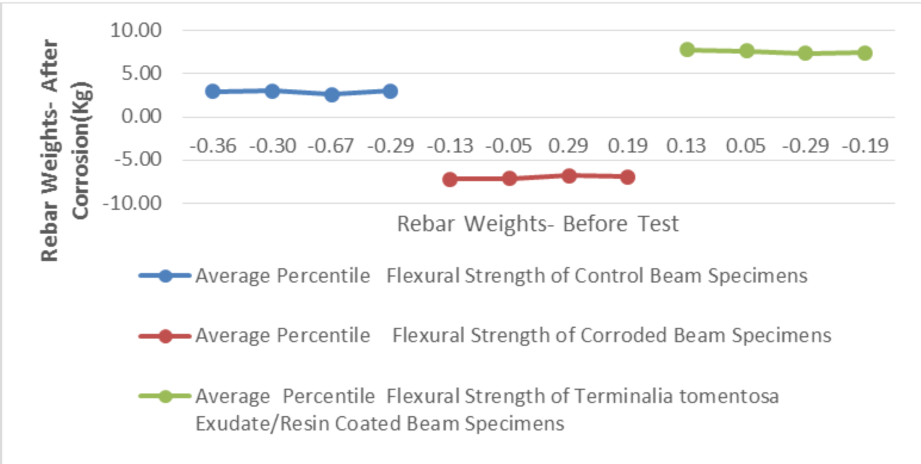

Fig-3.5B:Average Percentile Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

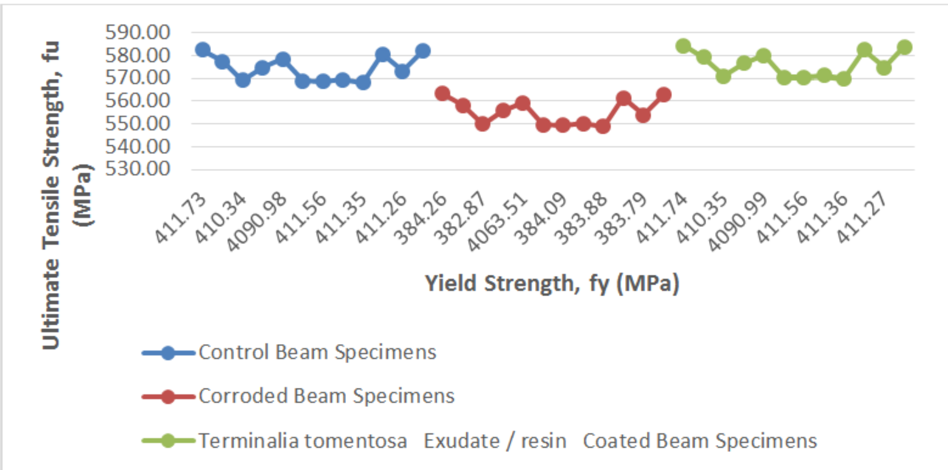

Fig-3.6: Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

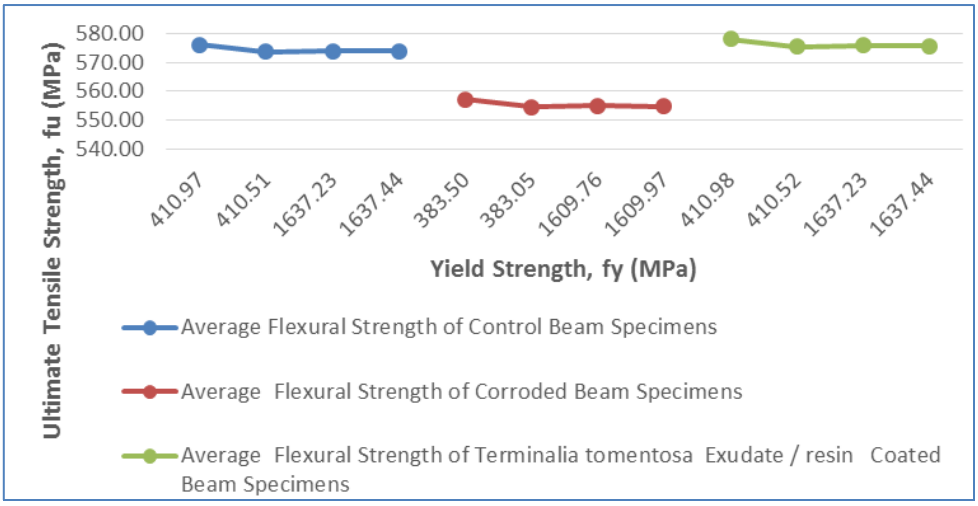

Fig-3.6A: Average Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

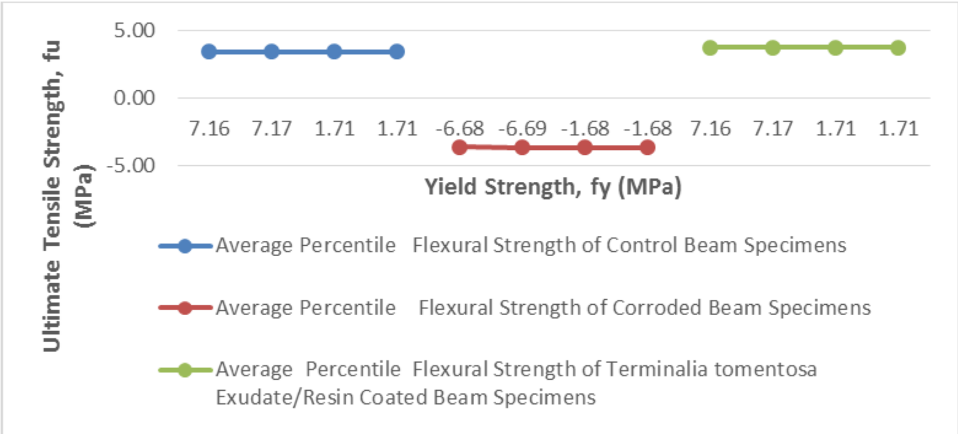

Fig-3.6B: Average Percentile Ultimate Tensile Strength versus Strain Ratioof Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

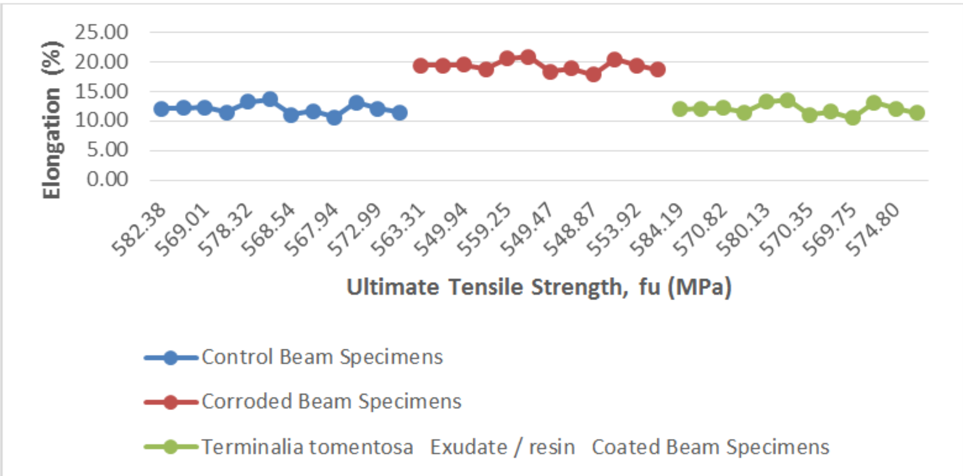

Fig-3.7: Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

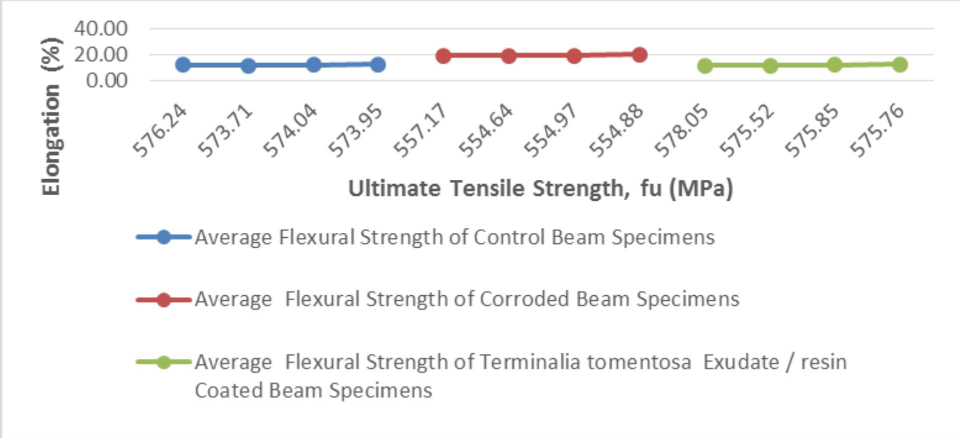

Fig-3.7A: Average Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

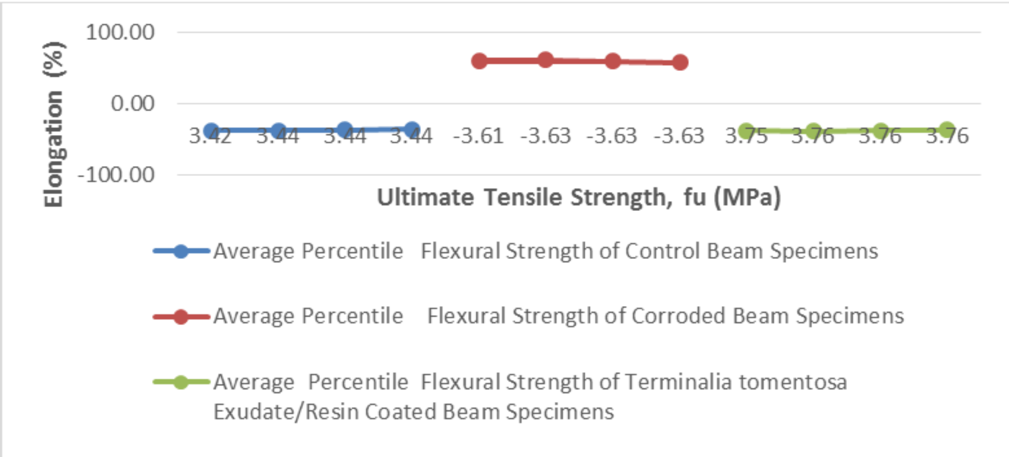

Fig-3.7B: Average Percentile Rebar Weights- Before Test versus Rebar Weights- After Corrosion (Non-Corroded, Corrode and Resin Coated Specimens

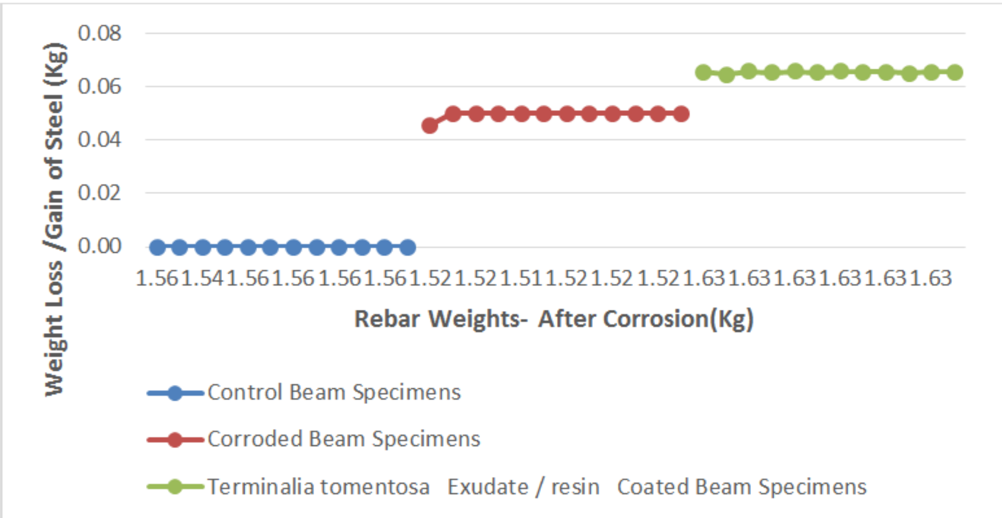

Fig-3.8: Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

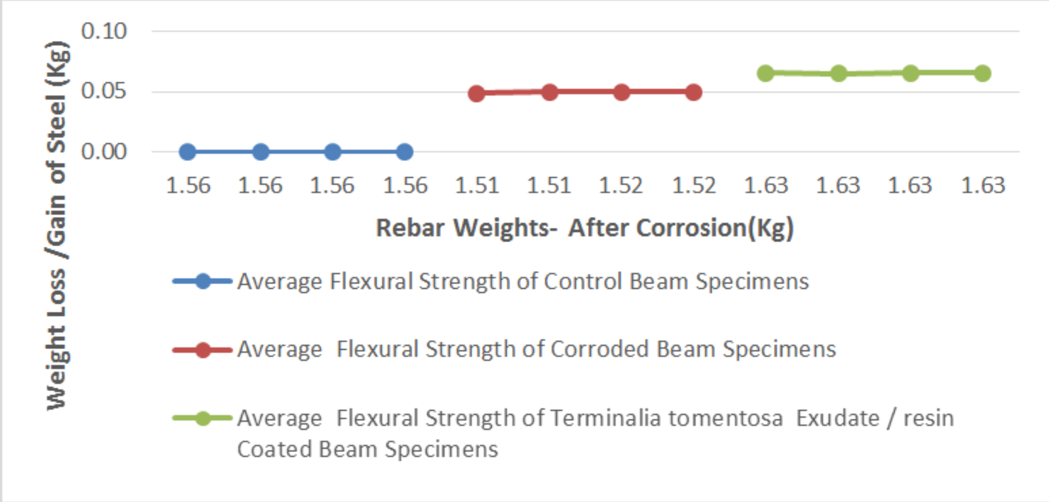

Fig-3.8A: Average Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

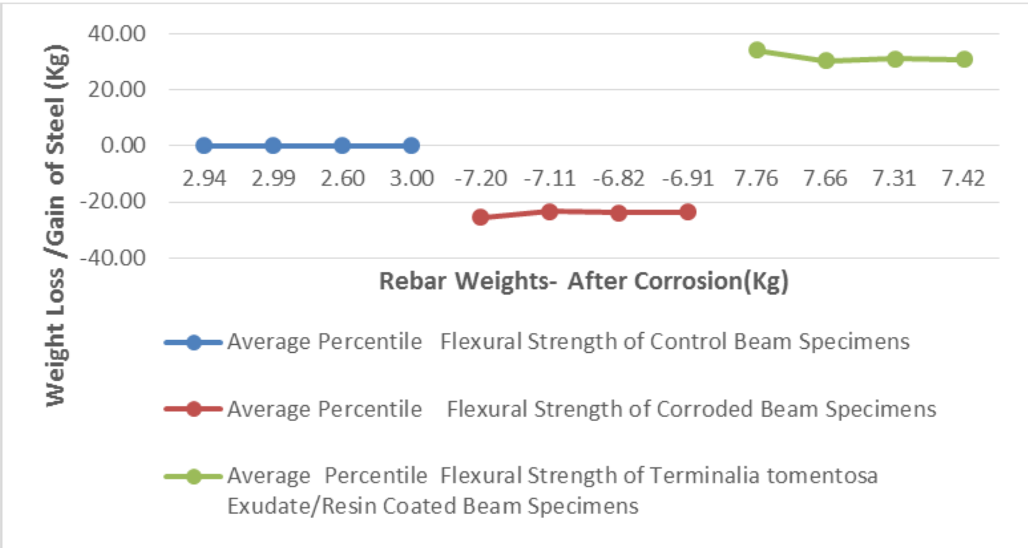

Fig-3.8B: Average Percentile Weights- After Corrosion versus Weight Loss /Gain of Steel (Kg) (Non-Corroded, Corrode and Resin Coated Specimens

4.0 CONCLUSION

The experimental results obtained are summarized as follows:

i. Results show lower elongation loads for controlled and coated samples with lower values than for corroded samples with higher elongation loads and increased values compared to reference ranges (controlled) and coated samples.
ii. 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.
iii. The results of the comparison of flexural strength and elongation load in the center of the corroded sample show the effect of corrosion on the mechanical properties of reinforcing steel with bent reinforcement, high surface modification, low load carrying capacity, high tensile strength and deformation of reinforcing steel.
iv. Reduced cross-sectional area due to corrosive effects on reinforced concrete structures built in marine coastal environments and work-related increase in exudates/resins
v. The combined results of the controlled sample on the corroded sample show that the controlled sample replaces the corroded sample with low flexural elongation, low deviation in the medium elongation range, normal limits, high tensile strength, low elongation / elongation ratio
vi. Exudates / resins have been proven to be effective and efficient in protecting reinforced concrete structures exposed to corrosive environments.
vii. The results showed that exudates/resin is a corrosion-resistant material in reinforced concrete structures exposed to a corrosive environment,

with high resistance and as a waterproof membrane against corrosion.

viii. Corrosion test results show high flexural stresses; stretching speed is faster than the average range.

REFERENCES

1. Elsener, B. (2000). Corrosion Inhibitors for Steel in Concrete, Keynote lecture presented at Materials Week, Int. Congress on Avanced Materials, ICM International Congress Centre Munich. *Session E1 Corrosion of Steel in Concrete*, 25.-28.
2. Baluch, M. H., Rahman, M. K., & Al-Gadhib, A. H. (2002). Risks of cracking and delamination in patch repair. *Journal of Materials in Civil Engineering*, *14*(4), 294-302.
3. Li, L. Y., Xia, J., & Lin, S. S. (2012). A multi-phase model for predicting the effective diffusion coefficient of chlorides in concrete. *Construction and Building Materials*, *26*(1), 295-301.
4. Bertolini, L. (2008). Steel corrosion and service life of reinforced concrete structures. *Structure and Infrastructure Engineering*, *4*(2), 123-137.
5. Abdulrahman, A. S., & Ismail, M. (2012). Evaluation of corrosion inhibiting admixtures for steel reinforcement in concrete. *International Journal of Physical Sciences*, *7*(1), 139-143.
6. Ali, S. A., Al-Muallem, H. A., Rahman, S. U., & Saeed, M. T. (2008). Bis-isoxazolidines: A new class of corrosion inhibitors of mild steel in acidic media. *Corrosion Science*, *50*(11), 3070-3077.
7. Almusallam, A. A. (2001). Effect of degree of corrosion on the properties of reinforcing steel bars. *Construction and building materials*, *15*(8), 361-368.
8. Du, Y. G., Clark, L. A., & Chan, A. H. C. (2005). Residual capacity of corroded reinforcing bars. *Magazine of Concrete Research*, *57*(3), 135-147.
9. Malumbela, G., Moyo, P., & Alexander, M. (2008). Structural behaviour of beams under simultaneous load and steel corrosion. In *Concrete Repair, Rehabilitation and Retrofitting II* (pp. 271-272). CRC Press.
10. Torres-Acosta, A. A., Navarro-Gutierrez, S., & Terán-Guillén, J. (2007). Residual flexure capacity of corroded reinforced concrete beams. *Engineering structures*, *29*(6), 1145-1152.
11. Ell-Maaddawy, T. E., Soudki, K. & Topper, T. (2005). Analytical Model to Predict Nonlinear Flexural Behavior of Corroded Reinforced Concrete Beams. *American Concrete Institute Structural Journal*, 102 (4), 550-559.
12. Broomfield, J.G. (1997). Corrosion of Steel in Concrete: Understanding, Repair and Investigation, (1st Edition), UK: E and FN Spon.
13. Rengaswamy, N.S., Srinivasan, S., & Balasubramanian, T.M. (1988). Inhibited and Sealed Cement Slurry Coating of Steel Rebar-A State of Art Report. *Transactions of the SAEST*, *23*(2-3), 163-173.
14. Charles, K., Ishmael, O., Akatah, B, M., & Akpan, P, P. (2018). Comparative Residual Yield Strength Structural Capacity of Non-corroded, Corroded and Inhibited Reinforcement Embedded in Reinforced Concrete Structure and Exposed to Severely Medium. *International Journal of Scientific and Engineering Research*, *9*(4), 1135-1149.
15. Charles, K., Terence, T, T, W., Kelechi, O., & Okabi, I., S. (2018). Investigation on Comparative Flexural Residual Yield Strength Capacity of Uncoated and Coated Reinforcement Embedded in Concrete and Exposed to Corrosive Medium. *International Journal of Scientific & Engineering Research*, *9*(4), 655-670.
16. Charles, K., Gbinu, S, K., & Ugo, K. (2018). Load Carrying Capacity of Coated Reinforcement with Exudates of Concrete Beam in Corrosion Solution Ponding. *International Journal of Civil and Structural Engineering Research*, *6*(1), 5-12.
17. Charles, K., Ogunjiofor, E, I., Latam, L, P. (2018). Yield Strength Capacity of Corrosion Inhibited (Resins / Exudates) Coated Reinforcement Embedded in Reinforced Concrete Beam and Accelerated in Corrosive Medium. *European International Journal of Science and Technology*,*7*(3), 25-33.
18. Charles, K., Akpan, P, P., & Gbinu, S, K. (2018). Corrosion Effects on Residual Structural Capacity of Resins / Exudates Inhibited Steel Reinforcement Flexural Beam. *European Journal of Engineering Research and Science*, *3*(5), 31-35.
19. Otunyo, A. W., & Charles, K. (2018). Effect of Corrosion on Flexural Residual Strength and Mid-Span Deflection of Steel (Coated with Resins/Exudates of Trees) Reinforced Concrete Beams under Sodium Chloride Medium. *European International Journal of Science and Technology*, *6*(7), 77-87.
20. Charles, K., Ogunjiofor, E, I., Letam, L, P. (2018). Residual Flexural Strength of Corrosion Inhibited Resin Coated Beam in Corrosion Accelerated Media. *Global Scientific Journal*, *6*(5), 84-96.
21. Charles, K., Letam, L, P., & Gbinu, S. K. (2018). Effect of Resins / Exudates Inhibited Steel on the Flexural strength of Reinforced Concrete Beam under Corrosive Environment. International Journal of Advances in Scientific Research and Engineering, 4(4), 52-61.
22. Ballim, Y., & Reid, J.C. (2003). Reinforcement Corrosion and the Deflection of RC Beams, An Experimental Critique of Current Test Methods. *Cement and Concrete Composites*, *25*(6), 625-632
23. Rasheeduzzafar, F.H., Dakhil, M. A., & Mohammed, M. K. (1992). Performance of Corrosion Resisting Steels in Chloride-Bearing Concrete, *American Concrete Institute Materials Journal*, *89*(5), 439-448.
24. Kanee, S., Petaba, L. D., Charles, K. “Inhibitory Action of Exudates / Resins Extracts on the Corrosion of Steel bar Yield Strength in Corrosive

Media Embedded in Concrete, "European Academic Research – 7(7), 3381 – 3398

25. Gilbert D. G., Nelson, T. A., & Charles, K. (2019). Evaluation of Residual Yield Strength Capacity of Corroded and Exudates / Resins Coated Reinforcing Bars Embedded in Concrete, "*European Journal of Advances in Engineering and Technology*, *6*(9), 48-56.
26. TrustGod, J. A., Kennedy, C., and Gilbert, D. R. (2019). Flexural Residual Capacity and Ultimate Yield Strength of Corroded and Inhibitive Reinforced Concrete Beams in Corrosive Environment. *International Journal of Science and Engineering Investigations*, *8*(9), 121–12
27. Daso, D., Kanee, S., Charles, K. (2019). Mechanical Properties Behavior of Corroded and Coated Reinforced Concrete structures in Coastal Marine Environment, "*International Journal of Scientific & Engineering Research*, *10*(9), 1154 – 1168.
28. Charles, K., Letam, L. P., & Nzidee, L. F. (2019). Flexural Strength of Non-coated and Coated Reinforcement Embedded in Concrete Beam and pooled in Corrosive Solution. *Journal of Multidisciplinary Engineering Science and Technology*, *6*(9), 10736–10746.
29. Charles, K., Ukeamezhim, C. F., & Daso, D. (2019). Corrosion Effect on Flexural Mechanical Property of Concrete Reinforcement Steel in Corrosive Environment. *International Journal of Advanced Scientific and Technical Research*, *5*(9), 26-37.
30. BS EN 196-6; 2010- Methods of Testing Cement Determination of Fineness, British Standards Institute. London, United Kingdom.
31. BS 12390-5; 2005 – Testing Hardened Concrete: Flexural Strength Test of Specimens, British Standards Institute. London, United Kingdom.
32. BS 12390-5; 2005 – Testing Hardened Concrete: Flexural Strength Test of Specimens, British Standards Institute. London, United Kingdom.
33. BS 882; 1992- Specification for aggregates from natural sources for concrete, British Standards Institute. London, United Kingdom.
34. Lin, Z.S., & Hui, Y. L. (1997). Result of Macro-investigation on Durability of Concrete Structure for Industrial Mill Buildings in China (Industrial Construction, China).
35. Tang, F., Lin, Z., Chen, G., & Yi, W. (2014). Three-dimensional corrosion pit measurement and statistical mechanical degradation analysis of deformed steel bars subjected to accelerated corrosion. *Construction and Building Materials*, *70*, 104-117.
36. Du, Y. G., Clark, L. A., & Chan, A. H. C. (2005). Effect of corrosion on ductility of reinforcing bars. *Magazine of Concrete Research*, *57*(7), 407-419.
37. Chen, H., Zhang, J., Yang, J., & Ye, F. (2018). Experimental investigation into corrosion effect on mechanical properties of high strength steel bars under dynamic loadings. *International Journal of Corrosion*, *2018*.