Structural Effects of Steel Reinforcement Corrosion on Residual Load-Bearing Capacity

Charles Kennedy¹, Uebari Sunday Luton², Gloria Inipaitaribia F. Dan-Orawari³

¹Faculty of Engineering, Department of Civil Engineering, Rivers State University, Nkpolu, Port Harcourt, Nigeria.

^{2,3}School of Engineering, Department of Mechanical Engineering, Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria

Authors E-mail: ¹ken_charl@yahoo.co.uk, ²gloriad11@yahoo.com,

³Sunday.uebari@yahoo.com

ABSTRACT

This study critically examined the potency of the locally available materials in preventing the negative impact of corrosion attack on steel reinforcement in the highest salt concentration (sodium chloride) of the marine environment. The role of exudates/resins was examined due to their waterproofing and resistivity against adverse attacks on reinforcing steel thereby causing surface modification and effects on the fibre reduction. The viscous exudates/resin was then coated to the reinforcing steel directly to varying thicknesses for examinations on its potency and effectiveness and inserted into concrete beams and pooled into the harsh environment of the coastal marine zone's representation. The flexural strength test computed maximum value was 27.82% compared to the corroded and coated sample values of -20.72% and 27.83%, respectively. The calculated mean differential and percentile values obtained during and after the corrosion test were checked (0.02kN and 0.05%), corroded values (0.03kN and 0.2%), and coated values (0.01kN and 0.03%). The results showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in diameter as well as a decrease in the average value and the percentage recorded from the corrosion samples, while the controlled and coated samples showed a preserved state by coating at one increase in diameter resulted in different thicknesses of the exudates/resin layer. The cross-sectional area of reinforcing steel shows different mean and percentile values for corroded values (0.02 mm and -10.33%) and coated values (0.03 mm and 8.75%). The results obtained showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in the diameter of the reinforcement in the corroded sample, while the coated sample showed an increase due to the thickness of the exudates paste layer. The computational results of the maximum comparative values for yield strength and ultimate tensile strength for the controlled sample are 7.30% and 3.43% for the corroded values are -6.72% and -3.61%, coated values 7.31 % and 3.76%, respectively. From the data obtained and compared, the yield strength limit and tensile strength limit of the corroded sample take into account the average and percentile values for failure loads with low applications. The strain ratio results in comparative of the maximum calculated deformation ratio for the mean and percentile values for the control were -3.53% compared to the corroded and overlaid values of 3.42% and -3.23%, respectively. The mean differential and percentile values obtained for the controlled samples were (0.82% and 1.08%), corroded values (0.82% and 2.33%), and coated values (0.82% and 1.09%).

The maximum comparative values recorded after the corrosion test for the controlled sample remained the same, without any trace of the corrosive effect, because it was incorporated in freshwater, for the corroded and coated samples the values obtained were -4.92% and 5.52% respectively. The calculated data showed a decrease in the value of the corroded sample as a result of the corrosion attack, which led to a decrease in the registered weight, whereas the coated sample showed an increase in weight compared to the reference value of the controlled sample due to the different coating thickness.

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

INTRODUCTION

Corrosion of reinforcing steel embedded in concrete structures caused many side effects:, such as the potential for serious degradation and deterioration leading to loss of a cross-sectional area of steel which will decrease and reduction of both load carrying capacity and ductility.

The examination of concrete structures in the marine environment of the Niger Delta region, Nigeria revealed that many buildings needed major repairs to achieve their original life span. Because of this, in a good, well-designed structure and maintained with reinforced concrete structures, there should be some problems with the corrosion of the reinforcing steel over its service life. However, corrosion is the most common cause of reinforced concrete rust and can lead to catastrophic failure, leading to injury and death. However, research has not yet developed other methods of steel, which makes it economically and technically feasible to use to strengthen concrete. Composite aggregates and alloys used during construction are the main causes of reinforcing steel solidification; either from the introduction of chloride ions from the sea or from the salts of de-icing salt. The introduction of corrosion inhibitors organic or inorganic to reinforcing steel has curbed the rapid effect of structural collapse and service life durations. [2] Development of corrosion inhibitors depends on organic compounds [2] Nitrogen, oxygen, sulfur molecules, and multiple bonds in molecules adsorption on the reinforcing steel surface [3]. These can be taken at the lowest cost with simple procedures and are biodegradable in nature. Many authors ([4], [5], [6], [7], 8], [9], [10], [11]), use these natural products as compounds extracted from leaves or seeds as corrosion inhibitors. [12], [13], [14], [15], [16], [17], [18], [19], [20], [21].

[22] Investigated surface changes, diameter reduction, and weight loss of reinforcing steel from uncoated and exudate/resin-coated samples in aggressive environments. Uncoated and coated samples of different thicknesses are embedded in the concrete structure, exposed and monitored for 150 days. Corroded samples show a decrease in the mechanical properties of reinforcing steel due to corrosion attack, which led to higher yield strength, higher midspan deflection / deformation, while coated samples show that small curvature, low deformation in the center region, normal yield strength. Coated samples exhibit greater flexibility against failure due to higher yields and lower strains.

[23] Conducted an experimental study to establish the relationship between flexural loss and reinforced concrete beam cross-sectional loss due to reinforcement corrosion, and experimental results showed that flexure was significantly reduced at only 10% of the average corrosion penetration ratio to the reinforcing radius.

[24] proposed a correction factor that combines the effects of loss of bond strength and other factors associated with loss of flexural strength to achieve residual flexural strength.

[25] Evaluated the minimization of corrosion reduction in steel reinforcement that damages concrete structures in saltwater areas by introducing exudates/resin from *Invingia gabonesis*, coated with varying thicknesses to steel reinforcement, embedded into concrete beams and investigated the effect of corrosion on uncoated and coated samples. The detailed test results show the potential corrosion resistance of the coated samples on the mechanical properties of reinforcing steel the effects of weight loss, cracking and fracture, and weight loss. The experimental results show an indication of the potential for corrosion of uncoated samples with corrosive properties that reduced the thickness of the reinforcing steel surface, loss of reinforcing steel weight, and the presence of cracks. These properties failed in the case of variable load and high retention capacity with low average usage, high fright rate, elongation and deformation in the medium range.

[26] Evaluated the reinforcing behavior of reinforcing steel and samples coated with a Senegalese exudates/acacia resin with different layer thicknesses, embedded in a concrete carrier, which were immersed in a corrosive and harsh environment for 150 days. The results obtained after Lent confirm that uncoated samples have potential corrosion properties of weight loss and cross-section reduction. Higher failure loads. General experimental tests show that the presence of the reinforcing mechanical properties of steel is compromised by corrosion.

[27] Evaluated the effectiveness of applying exudates /resin olibanum embedded reinforcing steel on concrete immersed in a corrosive environment against possible corrosion by accelerating the process of embedded concrete samples from coated and uncoated samples for first crack and spalling. Corroded samples exhibit lower flexural loads and as well as high degree of midspan deflection, cross-sectional are reduction and weight loss.

[28] Examined the use of environmentally friendly inorganic exudates/resin products from *Artocarpus altilis* to prevent corrosion attacks on reinforcing steel embedded in concrete. The results of corroded samples on the mechanical properties of reinforcing steel embedded in concrete and exposed to a corrosive environment showed high flexural deflection, average span deformation, and exudates/resin coated, and maximum tensile strength against corroded samples. Controlled and coated samples result has higher tensile strengths, and lower deformation rates compared to corroded samples. Overall results show crack resistance and adhesion to corrosion attack on reinforcing steel samples of coated.

MATERIALS AND METHODS FOR EXPERINMENT

Aggregates

Fine and coarse are bought; both meet the requirements of [29]

Cement

Limestone cement grade 42.5 is the most common type of cement on the Nigerian market. It was used for all concrete mixes in this test. Cement meets the requirements of [30]

Water

The water samples were clean and free of impurities. The freshwater used was obtained from the Civil Engineering Departmental Laboratory, Kenpoly, Bori, Rivers State. Water meets the requirements of [31]

Structural steel reinforcement

Reinforcements are obtained directly from the market at Port Harcourt. Confirmed on [32]

Corrosion Inhibitors (Resins / Exudates) *Euphorbia tirucalli*

The exudates/latex has a caustic milky white sap that was obtained from the fleshy stems that ooze out on breaking. It was obtained from Bori Town, Khana Local Government of Rivers State

Methods

This research evaluates the use of resins derived from naturally occurring plant extracts with environmentally friendly characteristics of non-hazardous materials obtained from tree trunks. The viscous exudate/resin was then coated to the reinforcing steel directly to varying thicknesses for examinations on its potency and effectiveness and inserted into concrete beams and pooled into the harsh environment of the coastal marine zone's representation.

This study critically examined the potency of the locally available materials in preventing the negative impact of corrosion attack on steel reinforcement in the highest salt concentration (sodium chloride) of the marine environment. Beam specimens of 17 mm x 175 mm x 750 mm, thickness, width, and length, with four (4) numbers of diameter 16 mm reinforcing steel was embedded in the concrete beam for 360 days immersion in 5% sodium chloride (NaCl) after initial 28 days curing. Corrosion is a long-term natural process that spans many years to unfold, but the synthetic release of sodium chloride (NaCl) accelerates and stimulates the corrosion rate which represents the salt concentration in the coastal area and this process is soon to be achieved. The role of exudates/resins was examined due to their waterproofing and resistivity against adverse attacks on reinforcing steel thereby causing surface modification and effects on the fibre reduction.

Sample Preparation and Casting of Concrete Beams

The standard method of concrete mixing ratio was followed, manual manipulation by material weight. The mixing ratio of concrete is 1: 2: 4, the water-cement ratio is 0.65. Manual mixing was applied to clean the edges of the concrete, and the mixing was inspected and water was slowly added to obtain the perfect mixing design concrete. Continuous uniform color and consistency were achieved by adding cement, water, and aggregate. The test beams were cast in a steel mold of 175 mm x 175 mm x 750 mm and were fitted with inlet air and embedded reinforcing steel 4 numbers with a diameter of 16 mm. Samples were de-molded after 72 hours and treated for 28 days in standard procedure and in-room temperature for rapid corrosion acceleration test process in 360 days with 3 months interval and intensive monitoring on the crack occurrence and test conduct on the beam samples.

Flexural Beam Test

According to [33], the universal testing machine was used for flexural testing and a total of 36 beam models were tested. After 28 initial and standard cures of treatment, 12 beams (control samples) were controlled to prevent corrosion-related reinforcement, while 24 beam samples of non-coated and exudate/resin coated samples were completely immersed in 5% sodium chloride (surface). Investigating the effects of changes in mechanical properties for both non-coated (corroded) and coated samples for 360 days with regular testing at 90 days, 180 days, 270 days, and 360 days. Flexural testing was performed on an Instron Universal Testing Machine with a capacity of 100KN. Samples was placed on the specification in the machine, and flexural testing was performed on two supports in the third stage. Cracks and flexural strength loads, midspan deflection, and all corresponding checks of measured rebar diameter before testing by digitally recorded and computerized system, after rebar diameter-corrosion, cross-sectional area decrease/increase, yield strength, final tensile strength, stress ratio, elongation, rebar weight- before the test, rebar weight- 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	ET	ET1	ET2	ET3	ET4	ET5	ET6	ET7	ET8	ET9	ET10	ET11
Flexural Strength Load (KN)	83.39	82.58	82.09	84.31	82.51	80.53	83.33	82.65	83.58	83.52	81.53	82.62
Midspan Deflection (mm)	7.39	7.47	8.07	8.18	7.27	8.21	7.30	7.47	7.27	7.35	7.35	9.51
Nominal Bar Diameter (mm)	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Measured Rebar Diameter Before Test(mm)	16.00	15.99	15.97	16.00	15.99	15.94	16.00	15.98	15.90	15.97	15.96	15.98
Rebar Diameter 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, f_y (MPa)	409.77	409.28	407.38	403.40	402.02	405.10	409.99	403.51	405.39	406.21	407.30	407.32
Ultimate Tensile Strength, f_u (MPa)	583.42	578.37	570.05	575.83	579.36	569.78	569.58	570.38	568.98	581.53	574.03	582.89
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 (%)	15.90	15.97	16.10	15.30	17.10	17.44	14.90	15.47	14.40	17.00	15.94	15.23
Rebar Weights- Before Test	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.58	1.60	1.61	1.60
Rebar Weights- After at 28 days (Kg)	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.58	1.60	1.61	1.60
Weight Loss /Gain of Steel (Kg) at 28 days	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.2 : Flexural Strength of Beam Specimen (Corroded specimens)

	ET1A	ET1B	ET1C	ET1D	ET1E	ET1F	ET1G	ET1H	ET1I	ET1J	ET1K	ET1L
Flexural Strength Load (KN)	66.07	65.41	64.78	64.76	65.20	64.31	66.02	65.34	66.27	63.22	63.72	67.00
Midspan Deflection (mm)	11.70	11.78	12.38	12.49	11.58	12.52	11.61	11.78	11.58	11.66	11.66	13.82
Nominal Rebar Diameter	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Measured Rebar Diameter Before Test(mm)	15.76	15.87	15.86	15.86	15.68	15.90	15.99	15.98	15.93	15.83	15.57	15.68
Rebar Diameter- After Corrosion(mm)	15.64	15.62	15.78	15.81	15.63	15.83	15.94	15.90	15.85	15.81	15.50	15.59
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.12	0.25	0.08	0.05	0.05	0.07	0.05	0.08	0.08	0.02	0.07	0.09
Yield Strength, f_y (MPa)	382.30	381.81	379.91	375.93	374.55	377.63	382.52	376.04	377.92	378.74	379.83	379.85
Ultimate Tensile Strength, f_u (MPa)	564.34	559.29	550.97	556.75	560.28	550.70	550.50	551.30	549.90	562.45	554.95	563.81
Strain Ratio	1.48	1.46	1.45	1.48	1.50	1.46	1.44	1.47	1.46	1.49	1.46	1.48
Elongation (%)	23.18	23.25	23.38	22.58	24.38	24.72	22.18	22.75	21.68	24.28	23.22	22.51
Rebar Weights- Before Test(Kg)	1.59	1.59	1.59	1.58	1.60	1.59	1.60	1.60	1.60	1.59	1.59	1.60
Rebar Weights- After Corrosion(Kg)	1.55	1.55	1.55	1.53	1.55	1.54	1.55	1.55	1.55	1.55	1.55	1.55
Weight Loss /Gain of Steel (Kg)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

Table 3.3 : Flexural Strength of Euphorbia Tirucalli Exudate / Resin Coated Beam Specimens

	ET1A1	ET1B2	ET1C3	ET1D4	ET1E5	ET1F6	ET1G7	ET1H8	ET1I9	ET1J10	ET1K11	ET1L12
	150µm (Exudate/Resin) coated			300µm (Exudate/Resin) coated			450µm (Exudate/Resin) coated			600µm (Exudate/Resin) coated		
Flexural Strength Load (KN)	83.39	82.08	82.10	84.32	82.52	80.54	83.34	82.66	83.59	82.73	81.04	81.63
Midspan Deflection (mm)	7.45	7.53	8.13	8.24	7.33	8.27	7.36	7.53	7.33	7.41	7.41	9.57
Nominal Rebar Diameter	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Measured Rebar Diameter Before Test(mm)	15.99	15.95	15.93	15.96	15.98	15.97	15.99	15.96	15.98	15.98	15.89	15.99
Rebar Diameter- After Corrosion(mm)	16.06	16.06	16.04	16.07	16.07	16.07	16.07	16.06	16.07	16.04	16.03	16.05
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.08	0.09	0.09	0.10	0.08	0.07	0.08	0.10	0.07	0.06	0.09	0.07
Yield Strength, fy (MPa)	409.77	409.28	407.38	403.40	402.02	405.06	409.99	403.51	405.39	406.21	407.30	407.32
Ultimate Tensile Strength, fu (MPa)	585.22	580.17	571.85	577.63	581.16	571.58	571.38	572.18	570.78	583.33	575.83	584.69
Strain Ratio	1.43	1.42	1.40	1.43	1.45	1.41	1.39	1.42	1.41	1.44	1.41	1.44
Elongation (%)	15.83	15.90	16.03	15.23	17.03	17.37	14.83	15.40	14.33	16.93	15.87	15.16
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)	82.68	82.99	82.97	82.45	65.42	64.98	64.91	64.76	82.52	82.83	82.98	82.46
Midspan Deflection (mm)	7.64	7.90	7.84	7.88	11.95	12.22	12.15	12.20	7.71	7.97	7.90	7.95
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	15.83	15.86	15.80	15.81	15.95	15.95	15.96	15.97
Rebar Diameter- After Corrosion(mm)	15.99	15.99	15.99	15.97	15.91	15.88	15.89	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	-0.09	-0.08	-0.09	-0.10	0.09	0.09	0.10	0.07
Yield Strength, fy (MPa)	408.81	406.68	404.26	403.50	381.34	379.22	376.80	376.04	408.81	406.69	404.27	403.51
Ultimate Tensile Strength, fu (MPa)	577.28	574.75	575.08	574.99	558.20	555.67	556.00	555.91	579.08	576.55	576.88	576.79
Strain Ratio	1.41	1.41	1.42	1.43	1.46	1.47	1.48	1.48	1.42	1.42	1.43	1.43
Elongation (%)	15.99	15.79	16.17	16.61	23.27	23.07	23.44	23.89	15.92	15.72	16.09	16.54
Rebar Weights- Before Test(Kg)	1.60	1.60	1.60	1.60	1.59	1.59	1.59	1.59	1.56	1.56	1.56	1.56
Rebar Weights- After Corrosion(Kg)	1.60	1.60	1.60	1.60	1.55	1.54	1.54	1.54	1.63	1.63	1.63	1.63
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.04	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)	26.39	27.71	27.82	27.33	-20.72	-21.55	-21.77	-21.47	26.14	27.47	27.83	27.34
Midspan Deflection (mm)	-36.09	-35.31	-35.51	-35.37	55.06	53.25	53.70	53.38	-35.51	-34.75	-34.94	-34.80
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)	0.364	0.376	0.367	0.372	0.379	0.384	0.372	0.377	0.378	0.377	0.376	0.379
Rebar Diameter-After Corrosion(mm)	0.76	0.75	0.71	0.73	-0.88	-1.08	-1.05	-1.08	0.89	0.89	0.86	0.88
Cross- sectional Area Reduction/Increase (Diameter, mm)	0.00	0.00	0.00	0.00	-18.85	-12.96	-19.39	-23.29	28.23	21.13	29.88	22.11
Yield Strength, f_y (MPa)	7.20	7.24	7.29	7.30	-6.72	-6.75	-6.80	-6.81	7.20	7.24	7.29	7.31
Ultimate Tensile Strength, f_u (MPa)	3.42	3.43	3.43	3.43	-3.61	-3.62	-3.62	-3.62	3.74	3.76	3.75	3.76
Strain Ratio	-3.53	-3.55	-3.60	-3.61	3.34	3.36	3.41	3.42	-3.23	-3.25	-3.30	-3.31
Elongation (%)	-31.27	-31.54	-31.04	-30.46	46.18	46.77	45.67	44.44	-31.59	-31.86	-31.35	-30.77
Rebar Weights- Before Test(Kg)	0.0804	0.0834	0.0844	0.0814	0.0784	0.0834	0.0834	0.0844	0.0844	0.0844	0.0814	0.0854
Rebar Weights- After Corrosion(Kg)	3.38	3.77	3.57	3.57	-4.92	-5.23	-5.10	-5.19	5.18	5.52	5.37	5.48
Weight Loss /Gain of Steel (Kg)	0.00	0.00	0.00	0.00	-34.85	-32.69	-32.88	-32.85	53.49	48.57	48.98	48.92

EXPERIMENTAL RESULTS AND DISCUSSION

Results of Concrete Beam Members Flexural Strength Load and Midspan Deflection

Corrosion of reinforced concrete or concrete has led to the sudden collapse of many of the exposed structures in coastal areas with severe weather. The effect of corrosion on flexural forces has been investigated by a large number of investigators and is well understood. Many studies conducted in this area have been described by critical tests of their effectiveness in the effects of corrosion on the flexibility of reinforced concrete beams. Considering the effect of corrosion on reinforced concrete structures built within the coastal areas of Niger Delta, Nigeria, with high salinity, the application of Euphorbia Tirucalli 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. Reinforced concrete is used as the main material in the main structural system of various structures in several countries. Reinforced concrete is considered durable and can withstand a wide range of environmental conditions. However, premature corrosion of steel reinforcement causes structural damage. Corrosion of reinforcement in reinforced concrete worsens the strength of such structures. With reinforced concrete samples, the effect of corrosion is even more pronounced, since almost all of the tensile force is exerted on the steel reinforcement.

Experimental data for flexural tests on concrete beam samples are shown in Tables 3.1, 3.2, and 3.3, summarized in 3.4, mean and percentile values in 3.5, and the results are shown graphically in Figures 3.1 - 3.8b. The calculated mean and minimum and maximum percentile values of the flexural strength for controlled sample were 82.45kN and 82.45kN (26.39% and 27.82%), the value corroded samples were 64.76kN and 65.42kN (-21.77% and -20.72%), and coated were 82.46kN and 82.98kN (26.14% and 27.83%). The flexural strength test computed maximum value was 27.82% compared to the corroded and coated sample values of -20.72% and 27.83%, respectively. Mean differential and percentile range checked are (0.54kN and 1.43%), corroded (0.66kN and 1.05%), and coated (0.52kN and 1.69%). The results showed that the reference percentage of controlled samples according to [31] was placed in fresh water and no corrosion effect was observed and was therefore used as a reference value for controlled and coated samples immersed in a corrosive environment as described in the test program. Corroded specimens fail with a lower load, whereas coated specimens have a higher load failure. The results further confirmed that the flexural rupture load of the controlled and coated specimen maintains a narrow range of values over the corroded specimen at moderate, reduced, and lower loads.

The midspan deflection minimum and maximum mean yields and the percentage of deformation loads reported on the controlled samples were 7.64kN and 7.9kN (-36.09% and -35.31%), corroded samples were 11.95kN and 12.22kN (53.25% and 55.06%) and the coated samples were 7.71kN and 7.97kN (-35.51% and -34.75%). The comparative evaluated results show that the maximum value obtained for the controlled is -35.31% compared to 55.06% corroded and -34.75% coated. The recorded mean and percentile difference values were controlled (0.26kN and 0.78%), corroded (0.27kN and 1.81%) and coated (0.26kN and 0.76%). The midspan deflection results show lower elongation loads in the case of controlled and coated samples with reduced values over corroded samples with higher elongation loads and increased values compared to the reference range (controlled) and coated samples. The results of the comparative of flexural strength and midspan deflection of the corroded sample show the effect of corrosion on the mechanical properties of reinforcing steel with detached ribs, high surface modification, which causes low load bearing capacity and high deformation of reinforcing steel as confirmed in the previous works of ([22]; [25];[27]; [27];[28]). From the results obtained, the exudate/resin of ficus plane trees is proven to be a corrosion protection material in reinforced concrete structures exposed to corrosive environments, with high resistance and as a sealing membrane against the effects of corrosion.

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

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

Figure 3.1B: Average Percentile Failure Load versus Midspan Deflection of Beam Specimens

(Non-Corroded, Corrode and Resin Coated Specimens)

Results of Measured Rebar Diameter Before and After Corrosion Test

Corrosion of steel reinforcement in reinforced concrete beams reduces the cross-section of the steel surface and causes localized cracks in the steel surface. The tensile capacity of steel decreases in direct proportion to the loss of the steel surface. In addition, the loss of the steel surface causes the loss of the connection between the steel and the enclosed concrete. All these actions contribute to the loss of the hardness and ductility of the beam and thereby reduce the ultimate strength of the beam. It should be emphasized that reinforcing steel is provided in reinforced concrete to resist tensile forces and to produce controlled crack formation in these areas. However, corrosion not only affects the steel bar and its tensile stress transmission function but also damages the concrete by dropping the cover.

The results obtained from the minimum and maximum mean and percentage values for the nominal value size are 16 mm (100%) for all standards. The rebar diameters measured before corrosion testing for the controlled sample were 15.97 mm and 15.99 mm (0.364% and 0.376%), the corroded ones were 15.8 mm and 15.86 mm (0.372% and 0.384%) and the coated are 15.95 mm and 15.97 mm (0.376% and 0.379%). The results obtained indicate that the diameter of the reinforcing steel varies in the range of minute due to the production of

reinforcement by different companies, the production mold used produces an average value and the percentage difference is not significant.

The average value and the minimum and maximum percentage of the rebar diameter - after the controlled corrosion test is 15.97mm and 15.99 mm (0.71% and 0.76%), the corroded sample values were 15.88 mm and 15.91 mm (-1.08% and -0.88%), the sample values with the coated are 16.05 mm and 16.066 mm (0.86% and 0.89%).

The comparative results obtained during and after the corrosion test the maximum value of the controlled rebar diameter was 0.76% compared to the corroded - 0.88% and the sample with coated was 0.89%. The calculated mean differential and percentile values obtained during and after the corrosion test were checked (0.02kN and 0.05%), corroded values (0.03kN and 0.2%), and coated values (0.01kN and 0.03%). The results showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in diameter as well as a decrease in the average value and the percentage recorded from the corrosion samples, while the controlled and coated samples showed a preserved state by coating at one increase in diameter resulted in different thicknesses of the exudates/resin layer. The use of exudates/resin protects the reinforcing steel from severe corrosion damage. The mean and percentile values were determined after and before the corrosion test on the diameter of the reinforcing steel, which leads to a reduction and an increase in the cross-sectional area.

The minimum and maximum obtained “reduction/increase of cross-sectional area (diameter)” of the controlled sample is 0.00 mm, which indicates for all samples (100%) that the corroded samples are -0.1 mm and -0.08 mm (- 23.29% and -12.96%), and the coated samples were 0.07 mm and 0.1 mm (21.13% and 29.88%). The cross-sectional area of reinforcing steel shows different mean and percentile values for corroded values (0.02 mm and -10.33%) and coated values (0.03 mm and 8.75%).

The results obtained showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in the diameter of the reinforcement in the corroded sample, while the coated sample showed an increase due to the thickness of the exudates paste layer. The reduction in cross-sectional area is due to the corrosive effect on reinforced concrete structures constructed in marine coastal environments and the increased protective layer by work-related exudates/resins ([22]; [25]; [27]; [27]; [28]).

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 Reduction/Increase (Diameter)

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

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

Results of Ultimate Tensile Strength and Yield Strength

Reinforcement corrosion is known to be the main wear mechanism in reinforced concrete structures, which seriously affects the serviceability and safety of the structure.

Chloride ions from the external environment diffuse through the concrete onto the steel surface, leading to depassivation of the protective layer and ultimately the initiation of reinforcement corrosion. Corrosion gradually consumes the reinforcing steel, reducing the cross-sectional area. Corrosion increases its volume by 2 to 6 times more than real steel; causes volume expansion, which creates tensile stresses in the concrete [34].

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 at the sample-controlled value result points are 403.50MPa and 408.8MPa (7.20% and 7.30%), Corroded samples were 376.04MPa and 381.34MPa (-6.81% and -6.72%) and the coated samples were 403.51MPa and 408.85MPa (7.20% and 7.31%).

The ultimate tensile strength values of controlled samples were 574.75MPa and 577.28MPa (3.42% and 3.43%), corroded samples were 555.67MPa and 558.20MPa (-3.62% and -3.61%) and the coated samples were 576.55MPa and 579.08MPa (3.74% and 3.76%). The computational results of the maximum comparative values for yield strength and ultimate

tensile strength for the controlled sample are 7.30% and 3.43% for the corroded values are - 6.72% and -3.61%, coated values 7.31 % and 3.76%, respectively.

Differently calculated mean and percentage values of yield strength and tensile strength (5.30MPa and 0.10%) and (2.53MPa and 0.02%) were examined, the corroded value was (5.30MPa and 0.09%) and (2.53MPa and 0.02%), the values with coated were (5.3MPa and 0.10%) and (2.53MPa and 0.02%).

From the data obtained and compared, the yield strength limit and tensile strength limit of the corroded sample take into account the average and percentile values for failure loads with low applications. The damage caused a corrosive effect on the mechanical properties of reinforcing steel due to surface modifications affecting the ribs and fibers, whereas the coated samples recorded an increase in the mean values and percentages of the reference range (controlled samples) under higher loads ([22]; [25]; [27]; [27]; [28]). Exudates/resins have been proven to be effective and effective in protecting reinforced concrete structures exposed to corrosive media.

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

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

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

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

Corrosion of reinforcement has been carried out in the past, addressing various problems related to the corrosion process, its initiation, and its destructive effects. Evaluation of flexural strength of reinforced concrete samples damaged by corrosion investigated ([24]; [35]; [36]; [37]; [38]). The results of the minimum and maximum mean and percentile values calculated in Tables 3.4 and 3.5 are obtained from Tables 3.1 to 3.3 the strain ratio values of the controlled sample are 1.41 and 1.43 (-3.61%, and -3.53%), the corroded samples were reported as 1.46 and 1.48 (3.44% and 3.42%), the coated sample values were 1.42 and 1.43 (-3.31% and -3.23 %).

The strain ratio results in comparative of the maximum calculated deformation ratio for the mean and percentile values for the control were -3.53% compared to the corroded and overlaid values of 3.42% and -3.23%, respectively. The mean differential and percentile values obtained for the control were (0.02 and 0.08%), corrosion values (0.03 and 0.09%) and closed values (0.02 and 0.08%).

The results showed that the corroded samples had a higher percentage of elongation deformation as a result of lower failure loads and higher yields, whereas the coated had higher load application rates with lower yields. Lower loads and higher yield and deformation strengths are a result of the effect of corrosion on the mechanical properties of reinforcing steel, which has effects on the interface, surface modification, fiber reduction, and rib removal. The above factors have reduced the load bearing capacity of work-related reinforced concrete structures ([22]; [25]; [27]; [27]; [28]).

The results of the minimum and maximum elongation values (%) for the controlled sample were 15.79% and 16.61% (-31.54% and -30.46%), corroded values were 23.07%, and 23.89% (44.44% and 46.77%), coated sample values were 15.72% and 16.54% (-31.86% and -30.77%). The maximum comparative elongation values for the controlled sample was -30.46% compared to the corroded and coated sample of 46.77% and -30.77% respectively. The mean differential and percentile values obtained for the controlled samples were (0.82% and 1.08%), corroded values (0.82% and 2.33%), and coated values (0.82% and 1.09%). In comparative, the corroded samples showed higher stress values and higher elongation rates, whereas the failure state of coated samples was lower load and reduced elongation. The effect of corrosion impairs the mechanical properties of reinforcing steel, leading to a higher fracture state when the load is low; coated samples show a range of values closer to the

reference (controlled sample). The use of exudates material for rebar has reduced the scourge and tendency of corrosive attack to which reinforced concrete structures in marine coastal areas are heavily exposed in connection with work ([22]; [25]; [27]; [28]).

The unit weight - the minimum and maximum average and percentage values before the test, calculated in Tables 3.4 and 3.5 and obtained from Tables 3.1 - 3.3 parameters per unit weight before and after the corrosion test, the controlled sample values are 1.6 Kg and 1.6Kg (0.0804% and 0.0844%), the corroded values are 1.59Kg and 1.59Kg (0.0784% and 0.0844%), and the values covered are 1.56Kg and 1.58Kg (0.0814% and 0.0854%). and anchor weight - after corrosion (kg) the values of the minimum and maximum mean values and percentiles of 1.60 kg and 1.62 kg (3.38% and 3.77%) were checked, the corroded values were 1.54 kg and 1.55 kg (-5.23% and -4.92%), the values coated are 1.63 kg and 1.65 kg (5.18% and 5.52%). The difference values obtained for the mean and percentile of controlled samples are (0.02 kg and 0.14%), corrosion values (0.003 kg and 0.05%) and coated values (0.001 kg and 0.06%).

The results of the minimum and maximum steel loss/weight mean and controlled percentage values (100%) for the controlled sample, leading to their combination in freshwater without any trace of corrosion attack, the corroded sample values were 0.04 kg and 0.04 kg (- 34.85% and -32.69%), coated samples were 0.07 kg and 0.07 kg (48.57% and 53.49%).

The calculated data for the maximum percentage of reinforcement beam weight before corrosion test for controlled, corroded, and coated values were 0.5%, 0.04%, and 0.07%. The maximum comparative values recorded after the corrosion test for the controlled sample remained the same, without any trace of the corrosive effect, because it was incorporated in freshwater, for the corroded and coated samples the values obtained were -4.92% and 5.52% respectively.

The percentages of maximum weight loss/gain for corroded and coated samples were - 32.69% and 53.49%, respectively. The calculated data showed a decrease in the value of the corroded sample as a result of the corrosion attack, which led to a decrease in the registered weight, whereas the coated sample showed an increase in weight compared to the reference value of the controlled sample due to the different coating thickness in the works ([22]; [25]; [27]; [28]).

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

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

Figure 3.5B: Average percentile Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

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

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

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

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

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

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

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

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

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

CONCLUSION

The experimental results obtained are drawn:

1. The results showed that exudates/resin is a corrosion-resistant material in reinforced concrete structures exposed to a corrosive environment, with high resistance and as a waterproof membrane against the effects of corrosion.
2. The results obtained showed the effect of corrosion on the mechanical properties of reinforcing steel with a decrease in the diameter of the reinforcement in the corroded sample, while the coated sample showed an increase due to the thickness of the exudates paste layer.
3. Reduced cross-sectional area due to corrosive effects on reinforced concrete structures constructed in marine coastal environments and work-related increase in exudates/resin
4. Exudates / resins have been proven to be effective and efficient in protecting reinforced concrete structures exposed to corrosive environments.
5. Results show lower strain loads for controlled and coated samples with lower values than for corroded samples with higher strain loads and increased values compared to reference ranges (controlled) and coated samples.

6. The results of the comparative of flexural strength and elongation load in the center of the corroded sample show the effect of corrosion on the mechanical properties of reinforced steel with curved reinforcement, high surface modification, low load carrying capacity, tensile strength and high deformation of reinforcing steel.
7. The combined results of the controlled sample on the corroded sample show that the controlled sample replaces the corroded sample with low flexural elongation, low deviation in the mean elongation range, normal limits, high tensile strength, low elongation / elongation ratio.
8. Corrosion test results show high flexural stresses; the stretching speed is faster than the average range.

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