Global Scientific JOURNALS

GSJ: Volume 9, Issue 10, October 2021, Online: ISSN 2320-9186

www.globalscientificjournal.com

Evaluation of Interfacial Bond Strength of Reinforced Concrete Structures Degradation Exposed to Corrosive media

Akosubo Iwekumo Stevyn[1], Charles Kennedy[2], John A. TrustGod [3],

[1] Department of Civil Engineering, Faculty of Engineering, Nigeria Maritime University Okerenkoko, Delta State, Nigeria

[2]Department of Civil Engineering, Faculty of Engineering, Rivers State University, Port Harcourt - Rivers State, Nigeria

[3]Faculty of Engineering, Department of Civil Engineering, Niger Delta University, Wilberforce Island, Bayelsa State

Authors E-mail: stenyn.akosubo@nmu.edu.ng[1], ken_charl@yahoo.co.uk[2], johteskconzults@gmail.com[3],

Abstract

This study investigated the utility of tree trunk exudates from Vitellaria paradoxa as an inhibitor to limit corrosion attack on rebar embedded in concrete structures and to expose high salinity in coastal oceans. The applied resin exudates/paste is coated with rebar of various thicknesses, embedded in a concrete cube and simulated while accelerating the corrosion of sodium chloride (NaCl) to determine the environmental use of abundantly available materials to control the effects of general alteration institute in concrete structures in marine areas. In comparison, the maximum percentile attained controlled 86.543% versus -45.595% corroded and coated 99.43%. The results show relatively neared values for controlled coated samples having lower failure load applications. These results indicate that the samples coated with exudates/resin are protected from the effects of corrosion by the formation of a resistance layer. The maximum controlled bond strength value was 69.572% compared to -42.481% corroded and 98.031% coated. The results obtained show that the higher load failure of controlled samples while corroded recorded lower failure loads and maximum slip, the controlled peak value is 95.942%, compared to -43.076% corroded and 121.718% coated. The results obtained for maximum slip also show higher slip values for controlled and coated specimens compared to corroded specimens. The results showed an indication of the effect of corrosion on defects of bond strength and maximum slip. The presence of corrosion reduces the performance of the material that corrodes there and reduces the mechanical properties of the surface modifications that affect the bond and interaction between the concrete and the reinforcing steel. From the results obtained and shown in the figure, the effect of corrosion on uncoated and coated reinforcing steel, it can be seen from the diameter of the reinforcement that the diameter of the uncoated reinforcing steel is reduced to the maximum value of -0.872% and coated increased by 0.88%, for the cross-sectional area, the corroded has a maximum decrease value of -16.626% and coated increased by 20.042%. For the weight loss and gain, obtained values were corroded -18.848% (loss) and coated 20.042% increased (gain). The data analyzed from experimental work showed that the corrosion effect on uncoated concrete cubes resulted in a reduction in diameter and cross-sectional area and a reduction in weight, whereas coated concrete cubes resulted in diameter and cross-sectional increase in weight from different thicknesses encased with reinforcing steel.

Index Terms: Corrosion, Corrosion inhibitors, Pull-out Bond Strength, Concrete and Steel Reinforcement

1.0 INTRODUCTION

Reinforced concrete structures are mainly based on mechanisms of bonding between reinforcing steel bars and concrete. The interfacial properties of reinforced concrete are affected by a large number of parameters related to steel and concrete and their interactions which lead to heterogeneity of reinforced concrete boundaries, which among other things affect the bond of reinforced concrete [1]. In addition, as a phenomenon that is influenced by many variables, it is a challenge to know how reinforced concrete multiparty can be described in reinforced concrete construction standards. This property has been studied since the 1940s, as [2] investigated the factors affecting the relationship between steel bars and concrete. Other studies are those of ([3];[4]; [5];[6];[7];[8];[9];[10];[11]). All these basic tests are performed on reinforcement larger than 12.0 mm in diameter.

Corrosion has a significant effect on the behavior on the bond between the concrete and the reinforcement. It has been shown that the adhesive strength initially increases and then decreases with increasing corrosion rate ([12]; [13]).

[12] Observed a steep hop in free-end shear value when the longitudinal crack opened, indicating a sudden loss of reinforcement strength during tensile tests.

Corrosion of reinforcement embedded in concrete structures has caused many side effects such as ductility; ([14]); [15]). In addition, if corrosion occurs, either a larger volume is coated compared to the original steel, the corrosion products affect the surrounding concrete and thereby increase the mechanical stress on the reinforcement. Crack propagation and layer coating are the two main general physical characteristics of this phenomenon according to ([11]); [16]; [17]; [18]). The volumetric expansion of rust not only causes stress cracking, but also affects the adhesive properties of reinforced concrete; [11]; [19]; [20]). This effect should be taken into account especially in the static assessment if: corrosion occurs in the required area; [21]).

[11] Found that in the early stages of crack formation (corrosion (0-4%, measured as the gravimetric weight loss of reinforcement), the end bond stress increases, whereas the bond end slip stress increases with the degree of corrosion. Damage to the joint is the result of cracking of the concrete near the ends of the reinforcement. If the reinforcement corrodes in the 4-6% range, the joint disintegrates abruptly with very little slip at the free ends. At this corrosion rate, large slip is recorded as the ultimate failure of the bond due to specimen damage. Of the 6% rate of corrosion, mutual damage is the result of constant low slippage. The adhesive tension initially increases with the corrosion rate until the corrosion reaches a maximum value of 4%, after which a sharp decrease in the adhesive stress up to 6% corrosion on the rate can be observed. Beyond the level corrosion of reinforcement 6%, the final joint stress almost does not change, even corrosion up to 80%.

[12] confirmed that the bond strength increases with increasing corrosion rate to critical percentage (2% for normal concrete, 3.5% for polypropylene fiber concrete as additive and 4.5% for basalt fiber concrete as additive) and then decreasing.

Permeability of water into concrete causes crack formation due to its expansion when it freezes, and this in turn causes corrosion when it reaches the embedded reinforcements. This process in addition to abrasion enhances the weakness in the durability of the reinforced concrete, in order to reduce the permeability of concrete; the capillary porosity should be reduced as much as possible. In addition to other durability problems, the increase in the permeability of concrete also initiates and accelerates the corrosion of reinforcement steel [22]. However, the reinforcements in concrete resist corrosion for a long time; the electrical conductivity of concrete is rather low when it is dry. For justifying the methodology to measure the performance of reinforced concrete, the bonding between concrete and steel is the most relevant property, the mass loss of reinforced concrete does not only involve a decrease in the cross-sectional area of reinforcements due to corrosion but the more important thing is that the bond between the steel and concrete is weakened by the corrosion taking place between the concrete and un-corroded section of the steel. Consequently, in order to evaluate the performance of reinforced concrete subjected to corrosion, changes in the bond properties have been investigated ([23]; [24]).

Research on reinforced concrete composites has followed the development of materials such as high-strength concrete, auxiliary concrete and self-compacting concrete ([25]; [26]; [27];[28],;[29]).

Also in quality control of reinforced concrete structures ([30]; [31]; [32]), and the function of reinforced concrete under extreme conditions, such as high temperature environments) and corrosion [33] which is commonly used in reinforced concrete elements. In addition, the development of concrete allows the design and manufacture of thin reinforced concrete components, especially from the precast sector, especially with the help of thin reinforcement.

[34] Evaluated the adhesive strength of samples of corroded and exudates/resin coated reinforcing steel embedded into standard cubes of 150 mm x 150 mm x 150 mm and submerged in a corrosive media for 150 days. The combined results show that the corroded sample weakens during the high-stress separation test with low bond strength. Non-corroded and exudates/resin-coated samples have higher bond strengths and lower failure loads. The exudates/resin design exhibits high protective properties against the effects of

corrosion and acts as an inhibitor. Samples coated with exudates/resin exhibit higher resistance to adhesive properties and higher flow with less damage compared to their constituents.

[35] Investigated the presence of chloride pollution and carbonization in the marine region of the Niger Delta in Nigeria to identify the causes of the poor relationship between steel reinforcement and concrete, which has led to premature deterioration of reinforced concrete structures in harsh environments. The reinforcing steel bars are coated with different thicknesses against uncoated and embedded in concrete cubes, hardened in an accelerated corrosive environment and the tensile strength parameters are tested. The yield of the corroded sample was relatively decreased, while the control sample and cola acuminata resin inhibited steel rods increased due to the binding properties of the exudates layer. The overall results suggest that natural exudates/resin should be investigated as an inhibitor of the corrosion effect on steel reinforcement in concrete structures in the expected areas with chlorides.

[36] Investigated the effect of corrosion inhibitors on plated reinforced steel in an accelerated method to investigate the fracture toughness of embedded steels for 150 days. In comparison, the yield of the corroded sample decreased and the exudates-coated sample of the control sample increased. The overall results showed higher tensile bond strength values for the control elements and the coated exudates/resin compared to the corroded samples.

[37] Investigated the tensile strength of bonds between reinforcing steel and concrete with samples that were un-corroded, corroded, and with samples coated with khaya senegalensis resin. The results of the destructive bond showed a difference of -43.66% compared to 77.37% and 79.67% in the corroded and coated exudates/resin. The decrease in bond strength percentiles ranged from 57.0631% to 36.33% and 106.57% in the corroded and coated samples. The results obtained clearly show that the destructive junction stress on the corroded elements in the exudates/resin is higher in the non-aggressive samples. The adhesive strength of the un-corroded and coated samples showed a greater affinity for elongation than the corroded one.

[38] Investigated the bond strength between concrete and reinforcement, which leads to a reduction in diameter due to the subsidence effect of reinforcing steel from near-shore saltwater areas. The application of artocarpus altilis resin extract to reinforcing steel with a layer thickness of 150µm, 300µm and 450µm and uncoated reinforcing steel was inserted into a concrete cube dipped in sodium chloride and an accelerated corrosion process was carried out for 150 days. The comparison results show that the value of the corroded sample decreases and the exudates/resin coated sample increases. When checking. Overall results showed higher tensile strength values under control and exudates/resin coated compared to corroded samples.

[39] Investigated the use of acacia exudates/resin as a paste material on reinforcing steel with varying thicknesses. The experimental study examined coated and uncoated samples embedded in concrete cubes and dipped in sodium chloride and accelerated for 178 days. In comparison, the value of the uncoated samples decreased due to corrosion of the mechanical properties of the rebar, but the un-corroded and exudates/resin coated items increased, indicating a potential acacia exudates/resin from Senegalese steel reinforcement application process. The overall results show a high value of joint tensile strength and low stress at failure in the control and the corroded sample.

[40] Investigated the effect of olibanum exudates/ resins in limiting the corrosion tendency of reinforcing steel in coastal areas by the action of saltwater on concrete structures. Tests show that uncoated samples corrode and deteriorate with low maximum slip, while the exudates/resin showed higher maximum slip and high bond pullout strength.

[41] Investigated steel reinforcement coated with acacia exudates/resin paste and uncoated steel, embedded in concrete cubes, and accelerated for 178 days in sodium chloride (NaCl) solution. The results showed that corroded failure had a bond load value of -36.15% compared to 56.61% and 59.15% of the controlled and exuded/resin coated elements. The adhesive strength was 83.04% and 94.92% vs -45.36%, the results showed that the percentage was decreased compared to the elements that were corroded and coated with exudates/resin. In comparison, the value of the sample corroded was reduced but controlled and elements with an exudates/resin coating increased, indicating the exudates/resin potential of senegalese acacia in steel coated members exposed to corrosive media.

2.0 Test program

This study investigated the utility of tree trunk exudates from Vitellaria paradoxa as an inhibitor to limit corrosion attack on rebar embedded in concrete structures and to expose high salinity in coastal oceans. The applied resin exudates/paste is coated with rebar of various thicknesses, embedded in a concrete cube and simulated while accelerating the corrosion of sodium chloride (NaCl) to determine the environmental use of abundantly available materials to control the effects of general alteration institute in concrete structures in marine areas. The test sample relates to the solid acid content, which indicates the level of sea salt concentration in the ocean atmosphere in reinforced concrete structures. The built-in reinforcing steel is completely immersed and the samples for accelerated corrosion are stored in the aggregation tank. This sample consists of 36 cubes of reinforced concrete and the standard method for concrete mix ratio, manual dosing according to the weight of the material, has been adopted. Concrete mixing ratio 1:2:4, water-cement ratio 0.65 to weight of concrete. Manual mixing is used on clean concrete benches, the mixing is checked and water is added gradually to get the concrete mix completely. Standard color and uniform consistency achieved by adding cement, water and aggregate, concrete cubes with dimensions of 150 mm x 150 mm x 150 mm, with reinforcement diameter of 12 mm, built into the tensile test center, with 360 days of immersion in sodium chloride 28 days after treatment first cube The acid corrosive medium solution was modified monthly and solid samples were examined to investigate higher potency and change.

2.1 Materials and Testing Methods

2.1.1 Aggregate

Both aggregates (fine and coarse) were purchased. Both meet [42] requirements;

2.1.5 Cement

Grade 42.5 lime cement grade calcareous is the most common type of cement in the Nigerian market. It was used for all concrete mixes in this test. Meets requirements for cement [43]

2.1.3 Water

Water samples are clean and free from contamination. The water was obtained from civil engineering laboratory from Kenule Beeson Saro-wiwa Polytechnic, Bori, Rivers State. Water complies with requirements [44]

2.1.4 Steel Structure Reinforcement

Reinforcements obtained directly from the market in Port Harcourt [45]

2.1.5 Corrosion inhibitor (resin / exudates) Vitellaria paradoxa

The extruded exudates are extracted from the trunk of trees in Aaran village in the local district of Ifelodun in Kwara state, Nigeria.

2.3 Test Procedure

Accelerated corrosion was tested on high tensile steel with a diameter of 12 mm and a length of 650 mm. Coated with 150µm, 300µm, 450µm, and 600µm before corrosion test. The test cubes had a size of 150 mm x 150 mm x 150 mm and were placed in a metal mold and disassembled after 72 hours. Samples were processed and cured in tanks for 28 days prior to the first treatment time at room temperature, followed by regular 360-day monthly monitoring to confirm by corrosion test and fast accelerated test mode. Samples for accelerated corrosion were taken at intervals of about 3 months of 90 days, 180 days, 270 days and 360 days. Tests were carried out on failure, bond strength, maximum slip, reduction/increase in cross-sectional area, and weight lost of reinforcing steel.

2.3 Accelerated Corrosion Setting and Testing Method

In real and natural phenomena, the development of corrosion effects on reinforcement embedded in concrete elements is very slow and can take years; but the laboratory acceleration process will take less time to accelerate the marine environment. To test the surface and mechanical properties of the examiner and fingerprint, test the uncoated and exudates/resin samples and immerse them in 5% NaCl solution for 360 days.

2.4 Tensile strength test

Tensile tests were carried out on 36 concrete cubes laid 150 mm x 150 mm x 150 mm with built-in reinforcement with a diameter of 12 mm in the center on controlled, uncoated and coated samples from a universal testing machine with a compressive load of 50 KN according to BSEN 12390.2. , And the results of the adhesive tensile test, adhesive tensile strength, maximum slip, cross-section reduction/enlargement and weight loss/bone reduction were recorded.

2.5 Tensile Strength of Reinforcing bars

To determine the density and tensile strength of uncoated and uncoated reinforcing steel, they were tested and loaded directly on a universal testing machine (UTM) with a failure load. To ensure stability, the remaining pieces are used in subsequent tests of bonding and failure loads, bond strength, maximum slip, reduction/increase in cross-sectional area, and weight reduction/reinforcement of steel.

3.1 Experimental Results and Discussion

The interaction between concrete and reinforcing steel must be perfect to allow maximum bond to the surrounding concrete structure. The increase in deformed (rib) rebar and slip joints mainly depends on bearings or mechanical locks between the concrete around the ribs on the bar surface. The harmful effects of corrosive attack render many structures unusable and their intended life shortens.

The experimental data shown in Tables 3.2.3.2 and 3.3, summarized in Tables 3.4 and 3.5, were tested on 36 samples of concrete cubes from 12 controlled samples placed in fresh water for 360 days, 12 samples without coating and 12 samples with exudates coating. / Resin, all combined with reinforcement and immersed in 5% sodium chloride (NaCl) solution for 360 days and assessed for performance by inspection, monitoring, review, and 3-month intervals at 90 days, 180 days, 270 days, and 360 days. In fact, the manifestation of corrosion is a long-term process that takes decades to fully function, but the artificial introduction of sodium chloride causes the manifestation and occurrence of corrosion in a shorter time. Experimental work presents an ideal high salinity coastal marine area and the potential use of Vitellaria Paradoxa exudates/resin as an inhibitor to limit bullfighting and corrosion risk in reinforced concrete structures exposed to or constructed in such heavy and hard areas.

Table 3.1: Results of Pull-out Bond Strength Test (τu) (MPa)

	Non-corroded Control Cube Specimens											
Sample Numbers	VPC	VPC1	VPC2	VPC3	VPC4	VPC5	VPC6	VPC7	VPC8	VPC9	VPC10	VPC11
	Time Interval after 28 days curing											
Sampling g and Durations	Samples 1 (28 days)			Samples 2 (28 Days)			Samples 3 (28 Days)			Samples 4 (28 Days)		
Failure Bond Loads (kN)	29.899	27.810	28.374	28.970	29.785	29.486	30.010	29.827	29.892	31.703	30.827	31.029
Bond strength (MPa)	11.446	12.338	10.836	11.766	12.139	13.062	13.156	12.485	12.520	13.226	12.537	13.084
Max. slip (mm)	0.131	0.133	0.123	0.128	0.127	0.126	0.139	0.143	0.151	0.149	0.153	0.151
Nominal Rebar Diameter	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
Measured Rebar Diameter Before Test(mm)	12.031	12.028	12.032	12.023	12.032	12.031	12.028	12.032	12.031	12.032	12.022	12.022
Rebar Diameter- at 28 Days Nominal(mm)	12.031	12.028	12.032	12.023	12.032	12.031	12.028	12.032	12.031	12.032	12.022	12.022
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rebar Weights- Before Test (Kg)	0.567	0.568	0.568	0.574	0.568	0.567	0.568	0.567	0.568	0.568	0.566	0.566
Rebar Weights- at 28 Days Nominal (Kg)	0.567	0.568	0.568	0.574	0.568	0.567	0.568	0.567	0.568	0.568	0.566	0.566
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3.2: Results of Pull-out Bond Strength Test (τu) (MPa) Corroded Concrete Cube Specimen

	Corroded Concrete Cube Specimens											
Sampling g and Durations	Samples 1 (90 days)			Samples 2 (180 Days)			Samples 3 (270 Days)			Samples 4 (360 Days)		
Failure Bond Loads (kN)	15.888	15.201	15.491	14.933	14.181	15.049	14.628	14.936	14.634	15.869	14.748	15.482
Bond strength (MPa)	7.557	7.568	7.332	7.554	7.321	7.293	7.092	7.780	6.755	7.244	7.091	7.404
Max. slip (mm)	0.080	0.084	0.085	0.093	0.084	0.088	0.087	0.077	0.083	0.084	0.085	0.075
Nominal Rebar	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00

Diameter												
Measured Rebar Diameter Before Test(mm)	12.015	12.014	12.033	12.023	12.024	12.024	12.013	12.014	12.023	12.020	12.023	12.024
Rebar Diameter- After Corrosion(mm)	11.966	11.965	11.984	11.974	11.975	11.975	11.964	11.965	11.974	11.971	11.974	11.975
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049
Rebar Weights- Before Test (Kg)	0.569	0.570	0.569	0.569	0.569	0.569	0.570	0.569	0.576	0.569	0.568	0.570
Rebar Weights- After Corrosion (Kg)	0.527	0.527	0.527	0.534	0.527	0.527	0.527	0.527	0.527	0.525	0.534	0.527
Weight Loss /Gain of Steel (Kg)	0.043	0.043	0.042	0.036	0.042	0.042	0.043	0.042	0.048	0.044	0.034	0.043

Table 3.3: Results of Pull-out Bond Strength Test (τu) (MPa of vitellaria paradoxa Exudate / Resin (steel bar coated specimen)

Sampling g and Durations	Samples 1 (90 days)			Samples 2 (180 Days)			Samples 3 (270 Days)			Samples 4 (360 Days)		
Sample	**150µm (Exudate/Resin) coated**			**300µm (Exudate/Resin) coated**			**450µm (Exudate/Resin) coated**			**600µm (Exudate/Resin) coated**		
Failure Bond Loads (kN)	30.713	28.623	29.187	29.784	30.599	30.300	30.823	30.641	30.705	32.516	31.641	31.842
Bond strength (MPa)	13.089	13.982	12.479	13.410	13.783	14.706	14.799	14.129	14.164	14.869	14.181	14.727
Max. slip (mm)	0.123	0.124	0.115	0.120	0.119	0.118	0.131	0.135	0.143	0.140	0.145	0.143
Nominal Rebar Diameter	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
Measured Rebar Diameter Before Test(mm)	12.003	11.993	11.984	11.983	11.993	11.993	11.985	11.994	12.003	11.983	11.984	11.994
Rebar Diameter- After Corrosion(mm)	12.402	12.392	12.383	12.382	12.392	12.392	12.383	12.393	12.402	12.382	12.383	12.393
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399	0.399
Rebar Weights- Before Test (Kg)	0.569	0.569	0.576	0.576	0.569	0.569	0.570	0.569	0.576	0.569	0.576	0.569
Rebar Weights- After Corrosion (Kg)	0.630	0.630	0.629	0.630	0.629	0.630	0.630	0.629	0.630	0.629	0.628	0.629
Weight Loss /Gain of Steel (Kg)	0.054	0.061	0.058	0.058	0.058	0.059	0.060	0.060	0.054	0.060	0.052	0.060

Table 3.4: Results of Average Pull-out Bond Strength Test (τu) (MPa) Control, Corroded and Exudates/ Resin Coated Steel bar

	Control, Corroded and Resin Steel bar Coated											
Sample	Non-Corroded Specimens Average Values				Corroded Specimens Average Values				Coated Specimens Average Values of 150µm, 300µm, 450µm, 6000µm)			
Failure load (KN)	29.018	29.737	30.233	31.510	15.856	15.050	15.062	15.696	29.830	30.550	31.045	32.322
Bond strength (MPa)	11.530	12.313	12.711	12.939	7.796	7.699	7.519	7.556	12.995	13.778	14.176	14.404
Max. slip (mm)	0.142	0.140	0.158	0.149	0.083	0.088	0.082	0.081	0.131	0.129	0.147	0.153
Nominal Rebar Diameter	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000
Measured Rebar Diameter Before Test(mm)	11.998	11.993	11.998	11.998	11.990	11.996	11.989	11.990	11.960	11.963	11.962	11.959
Rebar Diameter- After Corrosion(mm)	11.998	11.993	11.998	11.998	11.941	11.947	11.940	11.941	12.013	12.017	12.016	12.013
Cross- Sectional Area Reduction/Increase	0.000	0.000	0.000	0.000	0.049	0.049	0.049	0.049	0.054	0.054	0.054	0.054

(Diameter, mm)												
Rebar Weights- Before Test (Kg)	0.580	0.581	0.581	0.581	0.583	0.583	0.587	0.582	0.584	0.582	0.583	0.581
Rebar Weights- After Corrosion (Kg)	0.580	0.581	0.581	0.581	0.539	0.540	0.540	0.542	0.642	0.643	0.643	0.645
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.043	0.043	0.047	0.040	0.060	0.061	0.060	0.064

Table 3.5: Results of Average Percentile Pull-out Bond Strength Test (τu) (MPa) of Control, Corroded and Exudate/ Resin Coated Steel bar

	Non-corroded Control Cube				Corroded Cube Specimens				Exudate / Resin steel bar coated specimens			
Failure load (KN)	83.007	97.586	100.725	100.754	-46.845	-50.73	-51.48	-51.43	88.129	102.983	106.118	105.928
Bond strength (MPa)	47.908	59.919	69.049	71.242	-40.011	-44.11	-46.95	-47.54	66.698	78.944	88.530	90.627
Max. slip (mm)	72.068	59.070	92.665	94.546	-37.062	-31.83	-44.24	-47.13	58.888	46.712	79.340	89.149
Nominal Rebar Diameter	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Measured Rebar Diameter Before Test(mm)	0.294	0.026	0.271	0.268	0.251	0.278	0.224	0.255	0.250	0.278	0.224	0.254
Rebar Diameter- After Corrosion(mm)	0.480	0.384	0.482	0.480	-0.607	-0.579	-0.634	-0.604	0.611	0.583	0.638	0.607
Cross- Sectional Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	-8.905	-8.905	-8.905	-8.905	9.776	9.776	9.776	9.776
Rebar Weights- Before Test (Kg)	0.336	0.360	0.323	0.376	0.356	0.369	0.321	0.333	0.366	0.369	0.316	0.353
Rebar Weights- After Corrosion (Kg)	7.567	7.479	7.516	7.202	-15.999	-15.96	-15.98	-16.02	19.047	18.993	19.030	19.077
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	-28.073	- 30.099	- 22.848	- 36.892	39.030	43.059	29.614	58.458

3.2 Failure load, Bond Strength, and Maximum slip

Investigation of the bonding forces of reinforcing bars revealed a three-component bonding mechanism: (1) chemical bond, (2) friction, and (3) mechanical interactions between concrete and steel ([46]; [47]). This is the bond strength originally obtained from the weak chemical bond between the steel and the hardened cement; however, this resistance is usually compromised at low levels of exercise. The loss of chemical bonds causes the appearance of radial micro-cracks in the concrete.

Corrosion is one of the main reasons for the limited durability of reinforced concrete [48]. The bond strength is a measure of the load transfer between concrete and reinforcement but the effect of corrosion on reinforced concrete structures exposed to the coastal areas with high salinity has called for the inclusion of coating materials to curb the negative effects of corrosion on steel which is studied in this research work and results obtained presented and discussed below.

The results of the failure load, bond strength, and maximum slip were carried out on 36 concrete cubes, as shown in tables 3.1, 3.2, 3.3, and averagely summarized in 3.4 and percentile in 3.5, shown graphically in figures 1 - 6b. The results obtained referred to 12 controlled, 12 corroded and 12 coated samples tested for failure using Instron Universal Testing Machines at 50kN as described in the test procedure.

The relationship between reinforcement and concrete is the most important parameter for the composite effect of reinforced concrete sections. The load is always transferred by transferring the bond stress to the interaction zone. The computed data of the minimum and maximum average and percentile values obtained from the failure load of controlled concrete cube samples were 28.25kN and 31.253kN representing percentile values of (70.041% and 86.543%), corroded concrete cube samples were 16.108kN and 16.914kN, and percentiles values were (-50.11% and -45.595%), with coated samples value of 31.089kN and 33.581kN and denoted percentile values of (93.03% and 99.43%). The bond strength values for control were 11.393MPa and

12.802MPa which were represented by percentiles of (46.27% and 69.572%), corroded 7.51MPa and 7.789MPa and percentile values of (-49.503% and -42.481%) and the coated samples were represented of 13.542MPa and 14.951MPa and percentile values of (73.854% and 98.031%). The maximum examples of concrete cubes with control slip are 0.14mm and 0.153mm and 0.152 mm with percentile values (61.195% and 95.942%), corroded 0.079 mm and 0.087 mm, and with percentile values (-54.889% and - 43.076%) and 0.176 mm and are indicated by percentiles (75.674% and 121.718%).

The results shown in Table 3.4 yielded the average values from Tables 3.1, 3.2, and 3.3, which are further summarized from 3.4 to 3.5, for the difference between the percentile values of failure load, bond strength, and maximum slip, all of which fail in applications with lower loads, compared with the reduced percentile values for the controlled and exudates/resin coated concrete cube samples. In comparison, the maximum percentile attained controlled 86.543% versus -45.595% corroded and coated 99.43%. The results show relatively neared values for controlled coated samples having lower failure load applications. These results indicate that the samples coated with exudates/resin are protected from the effects of corrosion by the formation of a resistance layer.

The maximum controlled bond strength value was 69.572% compared to -42.481% corroded and 98.031% coated. The results obtained show that the higher load failure of controlled samples while corroded recorded lower failure loads and maximum slip, the controlled peak value is 95.942%, compared to -43.076% corroded and 121.718% coated. The results obtained for maximum slip also show higher slip values for controlled and coated specimens compared to corroded specimens.

The results showed an indication of the effect of corrosion on defects on bond, bond strength, and maximum slip as related in the studies of ([38];[39];[40];[33];[37];[35]). The presence of corrosion reduces the performance of the material that corrodes there and reduces the mechanical properties of the surface modifications that affect the bond and interaction between the concrete and the reinforcing steel.

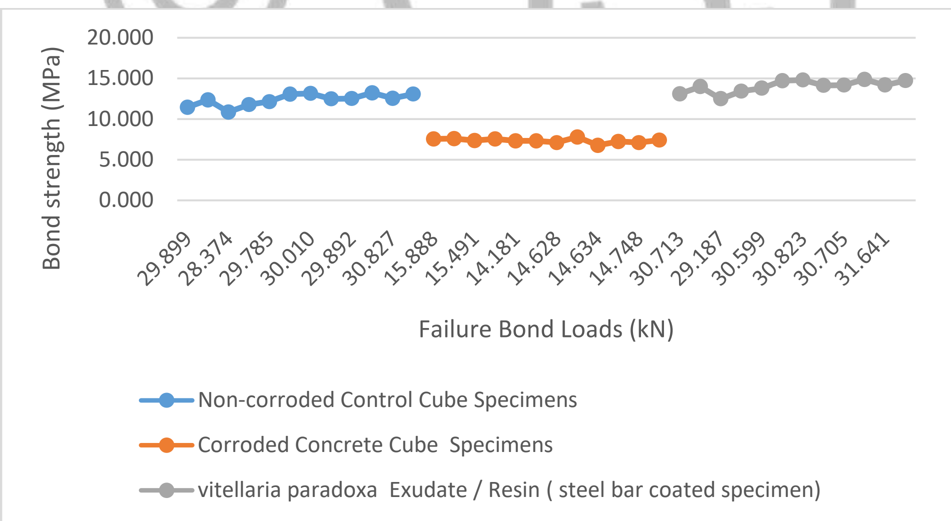

Figure 1. Failure Bond loads versus Bond Strengths

GSJ: Volume 9, Issue 10, October 2021
ISSN 2320-9186

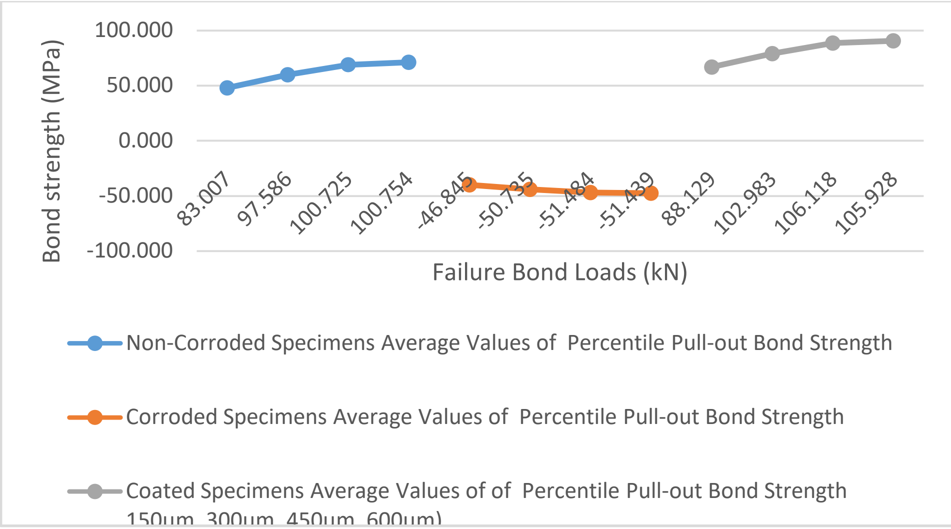

Figure 1a. Average Failure Bond loads versus Bond Strengths

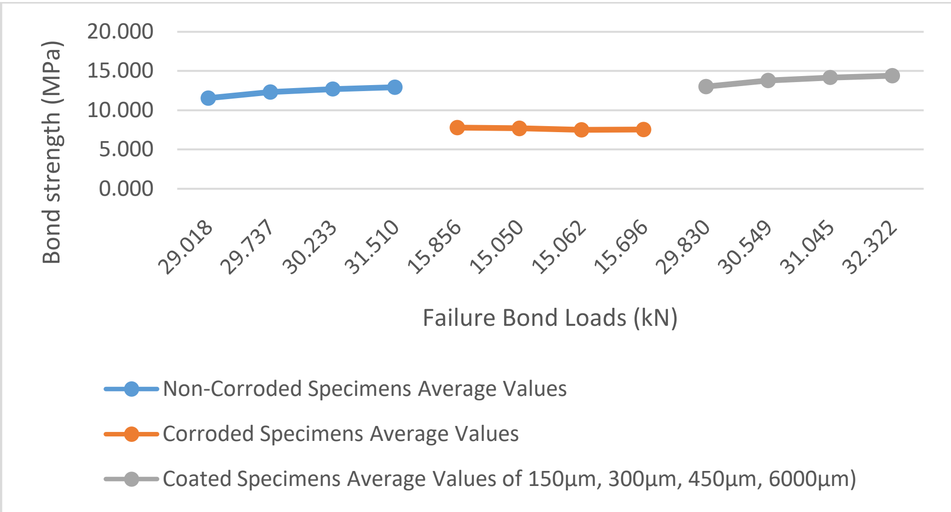

Figure 1b. Average Percentile Failure Bond loads versus Bond Strengths

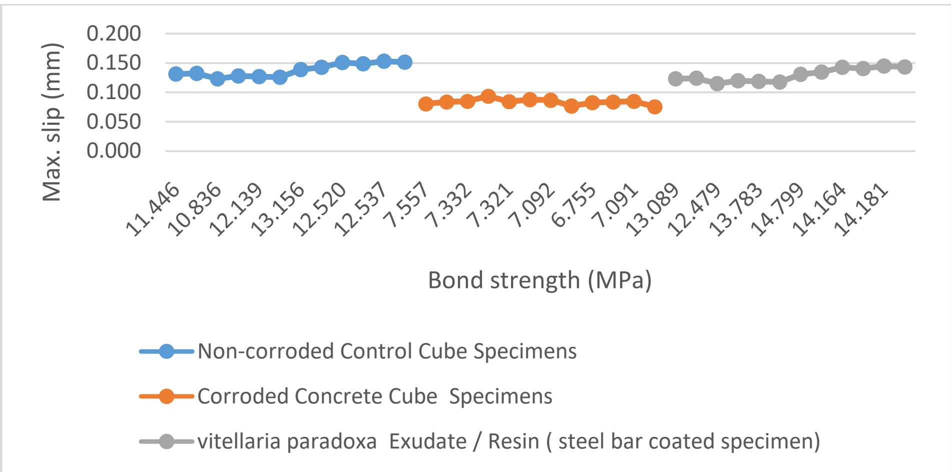

Figure 2. Bond Strengths versus Maximum Slip

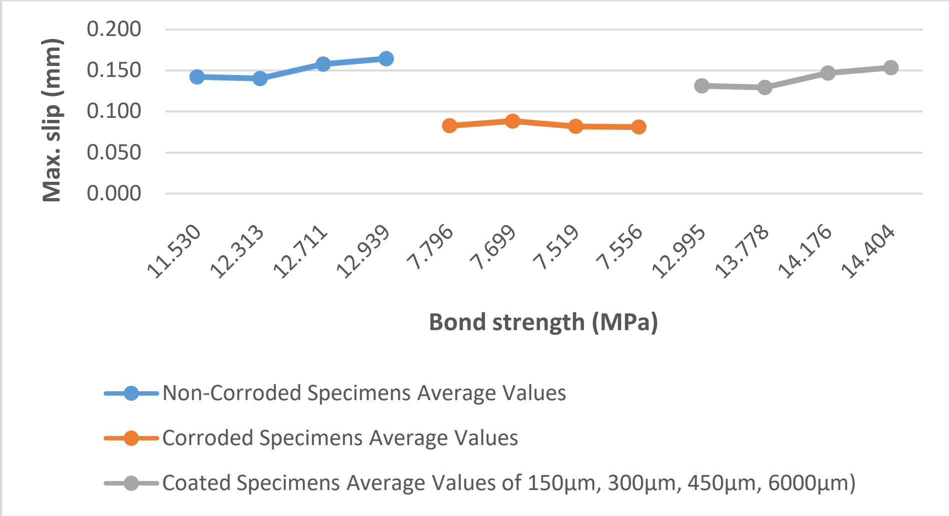

Figure 2a. Average Bond Strengths versus Maximum Slip

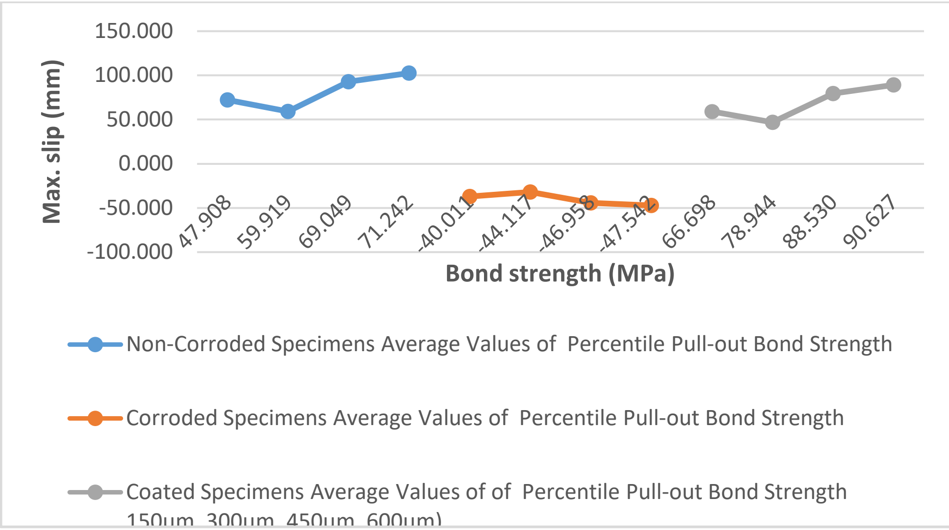

Figure 2b. Average Percentile Bond Strengths versus Maximum Slip

3.3 Mechanical Properties of Reinforcing Bars

The bond strength is mainly due to the weak chemical bond between the steel and the hardened cement, but this strength disintegrates at low pressure. As soon as slippage occurs, friction will help bond. With fine steel bars, friction is an important part of strength. Reinforced steel reinforcement with ribs under enlarged shear bond relies primarily on bearing or mechanical connections between the reinforcement and the surrounding concrete at the surface. This study describes the use of exudates/resins to improve slip problems in fine/smooth and weakened ribs reinforcement.

The effect of corrosion on the mechanical properties of reinforcement has been studied by many researchers, for example by ([49]; [50]; [51]; [52]; [53]). According to [54], corrosion can be divided into two categories: generalized and localized corrosion. The relationship between reinforcement and concrete is the most important parameter for the composite effect of reinforced concrete sections. The load is always transferred by transferring the connection voltage to the interaction zone.

Investigation of the bonding forces of reinforcement revealed a three-component bonding mechanism: (1) chemical bond, (2) friction, and (3) mechanical interactions between concrete and steel ([46]; [47]). It is the bond strength that initially results from the weak chemical bond between the steel and the hardened cement; however, this resistance is usually compromised with light loads. The loss of chemical bonds causes the appearance of radial micro-cracks in the concrete.

The data are presented in Tables 3.1, 3.2, and 3.3 and summarized in Table 3.4 and Figures 1 to 6b. The result of the controlled sample is a value of 100% because it is pooled and obtained from a freshwater tank according to the requirements (BS 3148).

The results are summarized in the minimum and maximum values, which are taken from Tables 3.4A and 3.5.

Steel bars with nominal diameters of all samples were 100%, and the minimum and maximum diameters of steel bars measured before the tests were in the range of 11.955 mm and 11.595 mm. The diameter of the specimens for reinforcement uncoated (corroded) were 11.908mm and 11.911mm and percentile values of (-0.872% and -0.872%) after the corrosion test, and 12.013 mm and 12.016 mm with percentile values range of(0.879% and 0.88%) after coated.

The cross-section results for uncoated (corroded) were 0.048mm and 0.048mm, with percentiles values of (-16.776% and -16.626%), for coated were 0.057 mm and 0.057 mm (20.042% and 20.042%). The results for the weight of reinforcement before testing were 0.589 kg and 0.59 kg (0.039% and 0.059%) for all samples, the weight after corrosion testing for corroded was 0.533 kg and 0.535 kg (-18.886% and -18.848%), coated were 0.657 kg and 0.659 kg (23.226% and 23.283 %) and weight loss/weight gain of corroded steel 0.056 kg and 0.056 kg (-19.759% and -19.165%), as well as coating values 0.069 kg and 0.069 kg (23.709% and 24.625%).

From the results obtained and shown in the figure, the effect of corrosion on uncoated and coated reinforcing steel, in Figures 3 and 6b, it can be seen from the diameter of the reinforcement that the diameter of the uncoated reinforcing steel is reduced to the maximum value of -0.872% and coated increased by 0.88%, for the cross-sectional area, the corroded has a maximum decrease value of -16.626% and coated increased by 20.042%. For the weight loss and gain, obtained values were corroded -18.848% (loss) and coated 20.042% increased (gain) as related in the studies of ([38];[39];[40];[33];[37];[35]). The data analyzed from experimental work showed that the corrosion effect on uncoated concrete cubes resulted in a reduction in diameter and cross-sectional area and a reduction in weight, whereas coated concrete cubes resulted in diameter and cross-sectional area and an increase in weight of different thicknesses encased with reinforcing steel.

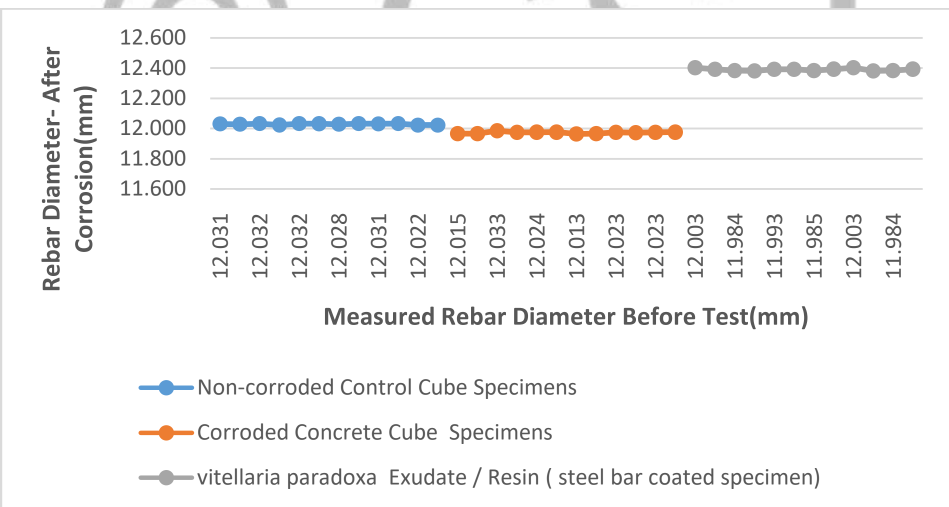

Figure 3. Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion)

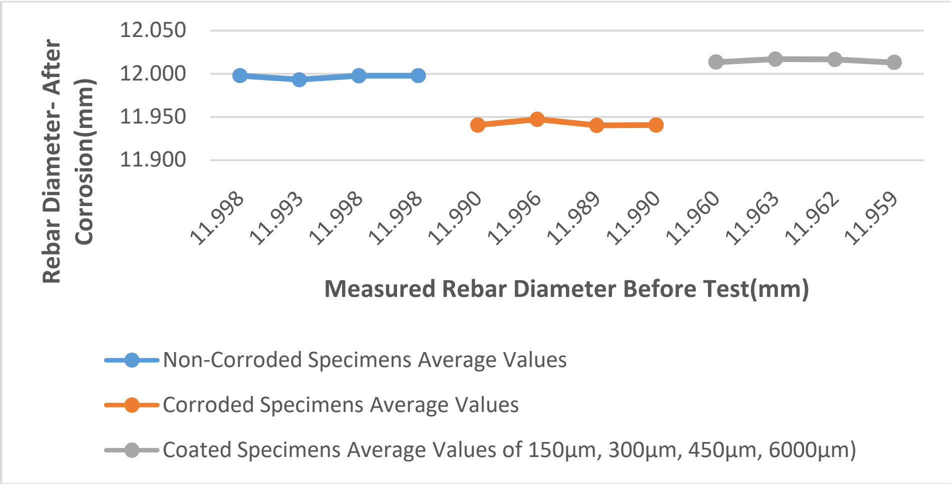

Figure 3a. Average Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion)

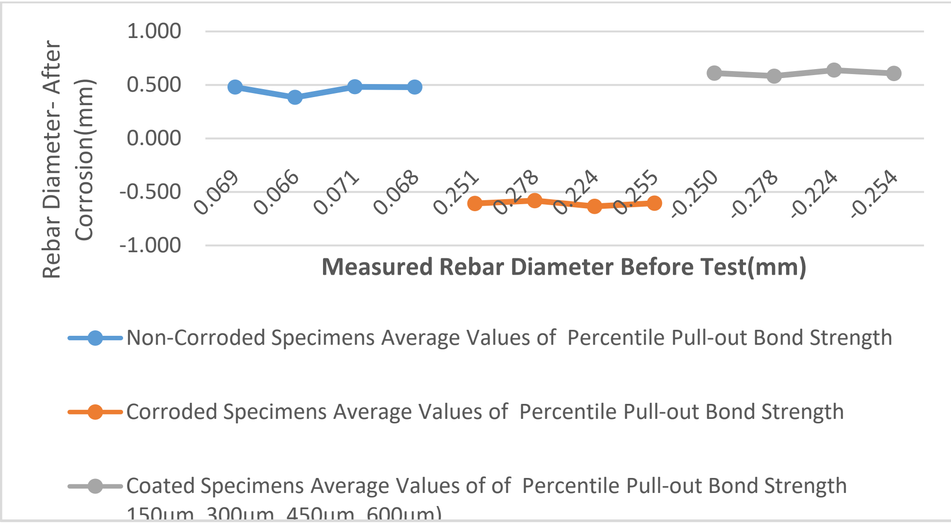

Figure 3b. Average Percentile Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion

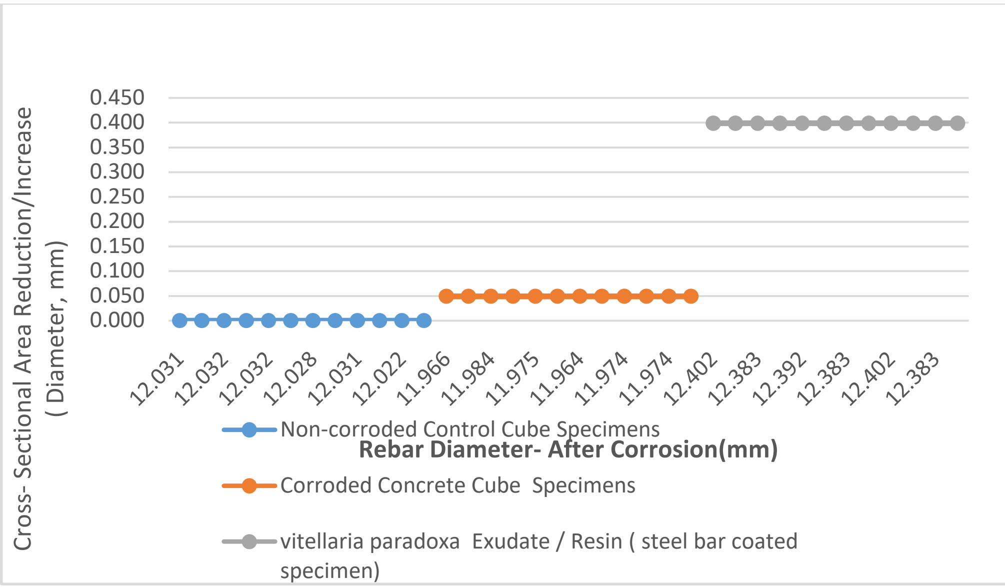

Figure 4. Rebar Diameter- After Corrosion versus Cross – Sectional Area Reduction/Increase

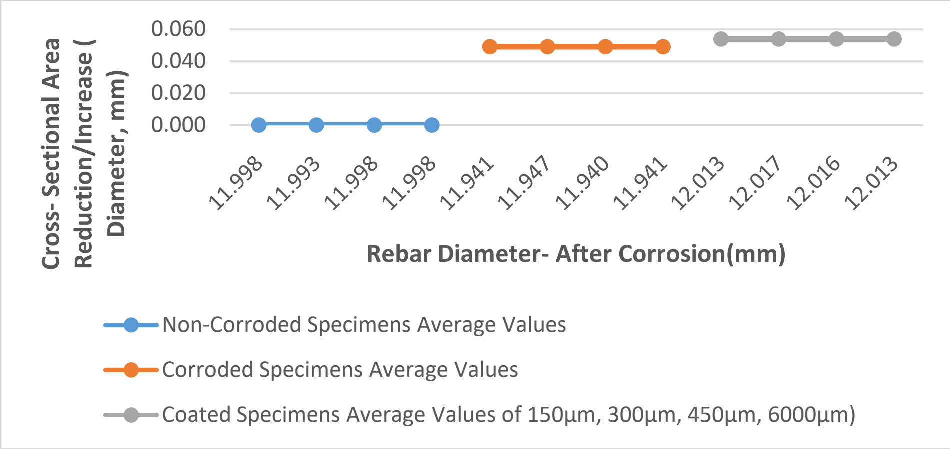

Figure4a. Average Rebar Diameter- After Corrosion versus Cross – Sectional Area Reduction/Increase

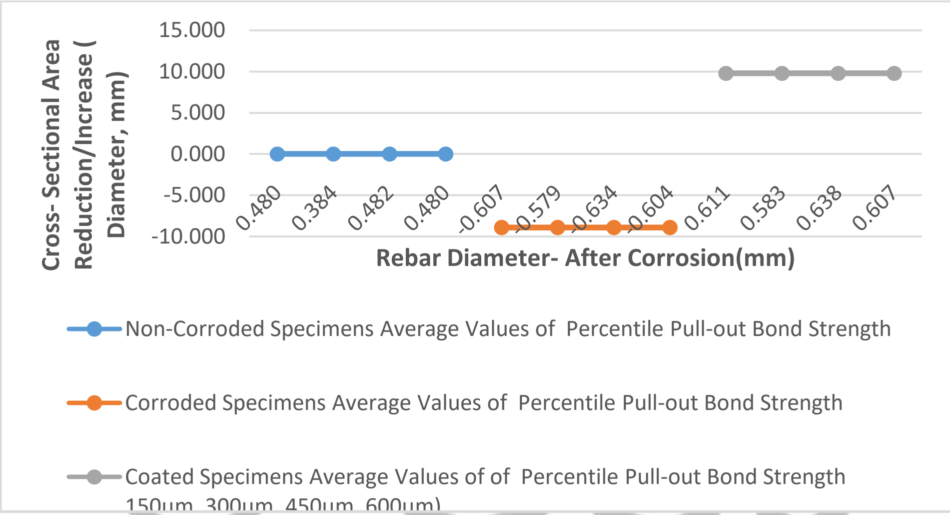

Figure 4b. Average percentile Rebar Diameter- After Corrosion versus Cross - sectional Area Reduction/Increase

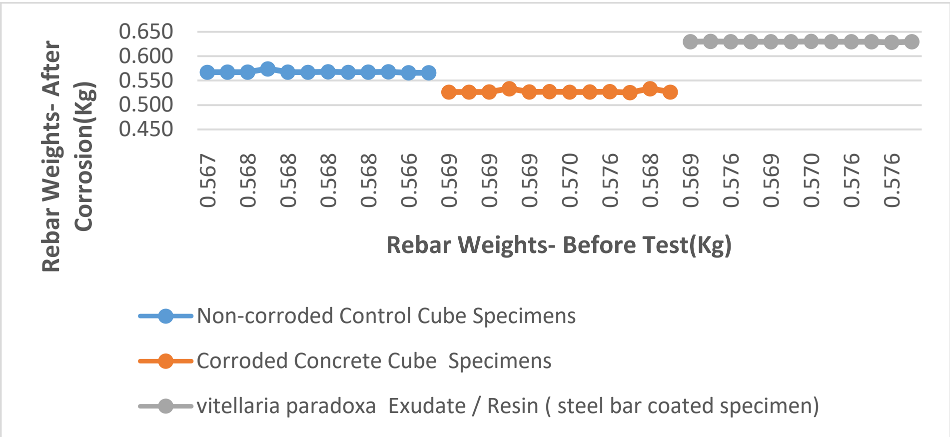

Figure 5. Rebar Weights- Before Test versus Rebar Weights- After Corrosion

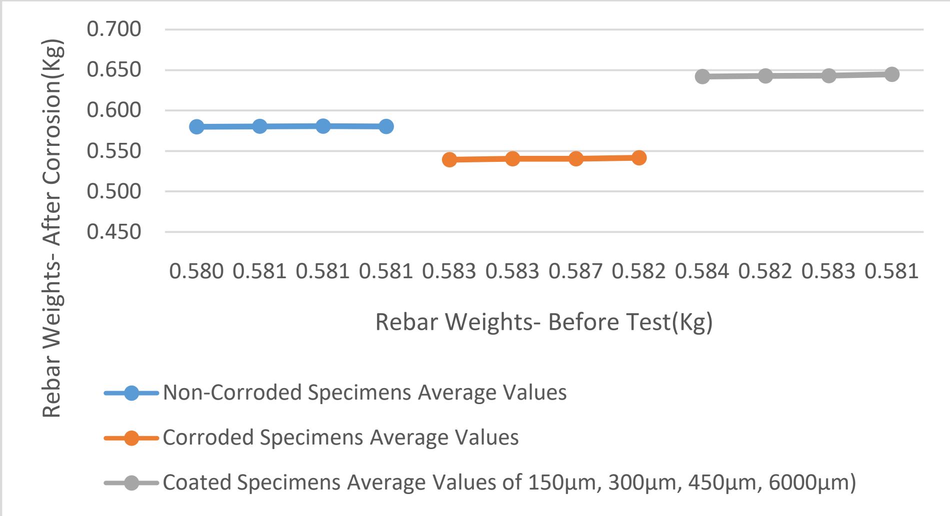

Figure 5a. Average Rebar Weights- Before Test versus Rebar Weights- After Corrosion

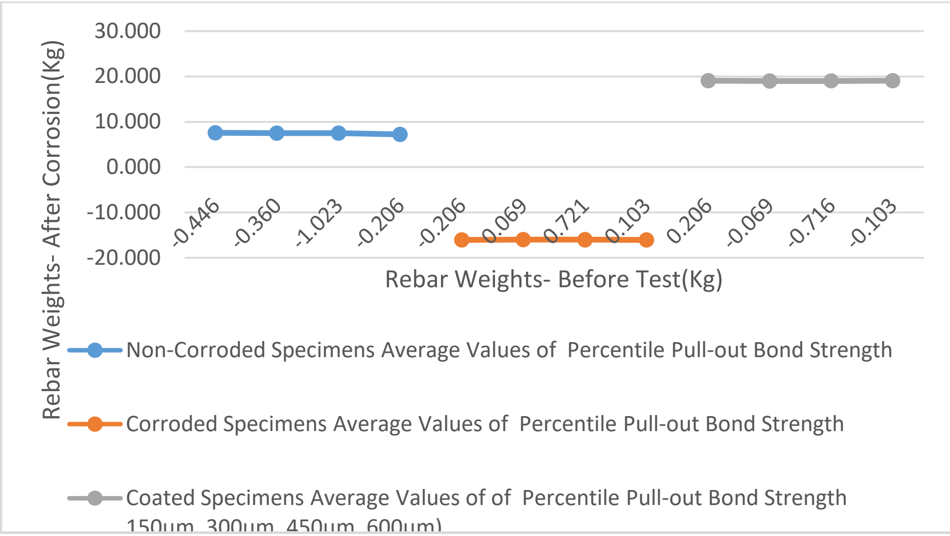

Figure 5b. Average Percentile Rebar Weights- Before Test versus Rebar Weights- After Corrosion

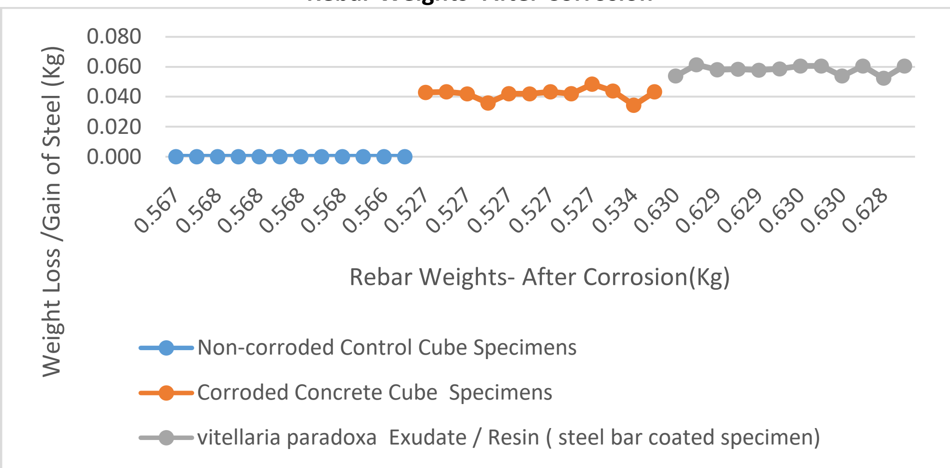

Figure 6. Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

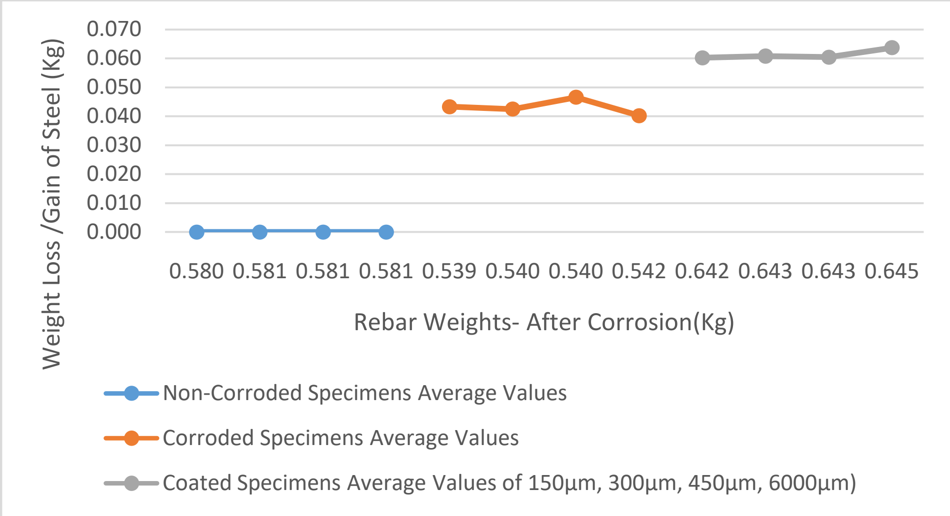

Figure 6a. Average Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

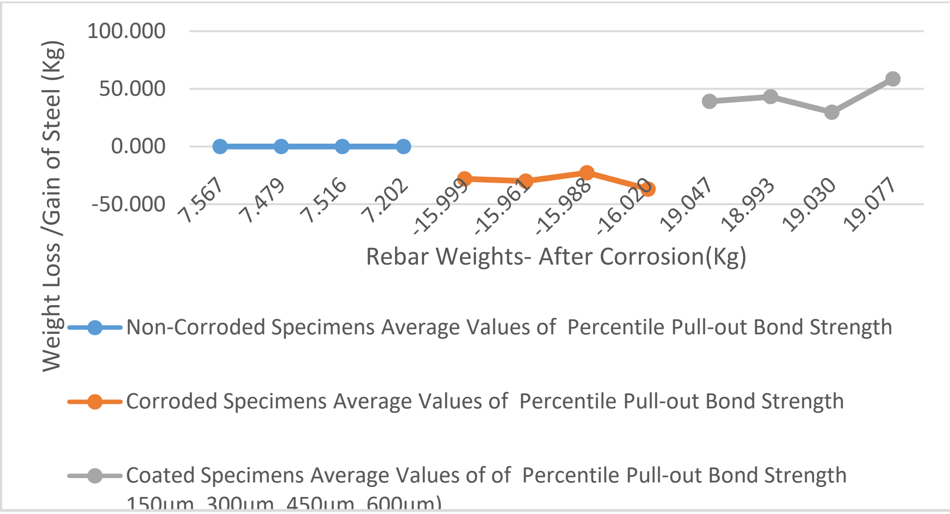

Figure 6b. Average percentile Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

3.3 Comparison of Control, Corroded, and Coated Concrete Cube Members

For comparison of the data in Tables 3.1, 3.2 and 3.3 and Figures 3, 4.5 and 6 for 12 controlled samples collected for 360 days in freshwater tanks, 12 uncoated and 12 coated, collected in 5% Sodium chloride (NaCl). Solutions for the 360 day ad, are described in 3.1 - 3.3 and summarized in Tables 3.4 - 3.5 and Figures 3a, 3b, 4a, 4b, 5a, 5b, 6a and 6b for the mean and percentage values for failure, bonding and maximum loads Slip, reduction/gain of cross-section, diameter of reinforcement before/after corrosion, weight loss/increase. The results obtained for comparison show that the load on the fracture joint in the controlled and coated area maintains a slight range of values, while the corroded element is subjected to a lower load; similar factors apply to bond strength and maximum slip. Regarding the mechanical properties of reinforcing steel, the corrosion effect of reinforcing steel shows a decrease in the cross-sectional diameter of the bar compared to the nominal diameter before the test, a decrease in weight is also observed, while the coated elements have an increase in cross-section. The cross-sectional area, diameter increase and weight increase compared to nominal reinforcement, this increase was caused by differences in the thickness of the roof covering. From this it can be concluded that the exudates/resin examined showed the effectiveness of its inhibitory properties against corrosion attack and could be used as a corrosion inhibitor.

4.0 Conclusion

In the experiment, the results obtained are plotted as follows:

1. The results show relatively slight values for controlled samples with coated with lower failure loads.
2. These results indicate that the samples coated with exudates/resin were protected from corrosion by the formation of a resistant layer.
3. The exudates/resin has a corrosion-inhibiting effect because it is water-resistant, resistant to penetration and corrosion attack.
4. The interaction between concrete and steel in the coated component is greater than that of the corroded sample
5. Coated and control samples showed higher values for bond strength
6. Weight loss and area reduction were noted mainly in the corroded layer and in controlled samples
7. Corrosive effect of uncoated concrete cubes causes a reduction in diameter and cross-sectional area and a reduction in weight, whereas coated concrete cubes cause an increase in diameter and cross-sectional area and weight in various thicknesses which are coated with reinforced steel.
8. The presence of corrosion reduces the yield strength of material and reduces the mechanical properties of the surface modifications that affect the bond and interaction between the concrete and the reinforcing steel.
9.

REFERENCES

1. Angst, U.M., Geiker, M.R., Michel, A., Gehlen C., Wong, H., Isgor, B., Elsener, B., Hansson, C.M., François, R., Hornbostel.K., Polder, R., Alonso, M.C., Sanchez, M., Correia, M.J., Criando, M., Sagues, A., Buenfeld, N. (2017). The Steel-concrete interface. Materials and Structures, 50,143.
2. Rehm, G. (1968). The Basic Principles of the Bond between Steel and Concrete. C&CA Library Translation n.134 (Uber die Grundlagem des Verbundes Zwischen Stahl und Beton. Deutscher Ausschuss Fur Stahlbeton, Heft 138, 59, 1961).
3. Watstein, D. (1941). Bond stress in concrete pull-out specimens; ACI Journal, Proc. Vol. 38, September, 37-50.
4. Mains, R. Measurement of distribution of tensile and bond stress along reinforcing bars (1951). Journal of ACI, 225-252
5. Perry, E. S.; Thompson, J. N. (1966). Bond stress distribution on reinforcing steel in beams and pull-out specimens; ACI Journal. Proc. 63, 865-875.
6. Goto, Y (1971). Cracks Formed in Concrete around Deformed Tension Bars. Journal of the ACI, (Apr), 244-251.
7. Mirza, S. M., Houde, J. (1979) Study bond stress-slip relationship in reinforced concrete. Journal of the ACI. 76(1), 19-46.
8. Kemp, E. L. (1986). Bond in reinforced concrete: behavior and design criteria. ACI Journal. Proc. Vol. 83, January-February, 50-57.
9. Jiang, D. H., Shah S., P.; Andonian A. T. (1984). Study of the transfer of tensile forces by bond. ACI Journal.
10. Ferguson, P. M.; Turpin, R. D.; Thompson, J. N. (1954). Minimum bar spacing as a function of bond and shear strength. ACI Journal. Proc. 50, 869-887.
11. Al-Sulaimani, G. J., Kaleemullah, M., Basunbul, I. A., and Rasheeduzzafar, (1990). Influence of corrosion and cracking on bond behavior and strength of reinforced concrete members." *ACI Struct. J.,* 87(2), 220–231. DOI: 10.14359/2732
12. Bajaj, S. (2012). Effect of corrosion on physical and mechanical properties of reinforced concrete. M.S. thesis, Univ. of Akron, Akron, OH.
13. Almusallam, A. A., Al-Gahtani, A. S., Aziz, A. R., and Rasheeduzzafar, (1996). Effect of reinforcement corrosion on bond strength. *Constr. Build. Mater.,* 10(2), 123–129. DOI: 10.1016/0950-0618(95)00077-1
14. Du, Y. G., Clark, L. A., and Chan, A. H. C. (2005a). Effect of Corrosion on Ductility of Reinforcing Bars." *Magazine of Concrete Research*, Vol. 57(7), 407–419.
15. Fernandez, I., Bairán J. M., and Marí A. R. (2015). Corrosion Effects on the Mechanical Properties of Reinforcing Steel Bars. Fatigue and σ–ε Behavior. *Construction and Building Materials*, 101(2015), 772–783.
16. Dang, V. H., and François R. (2013). Influence of Long-Term Corrosion in Chloride Environment on Mechanical Behavior of RC Beam. Engineering Structures, 48(2013), 558–568.
17. Sæther, I. (2010). Structural Behavior of Deteriorated and Retrofitted Concrete Structures. Ph.D. Thesis, Norwegian University of Science and Technology, Trondheim, Norway.
18. Val, D. V., Stewart, M. G., and Melchers, R. E. (1998). Effect of Reinforcement Corrosion on Reliability of Highway Bridges." Engineering Structures, 20(11), 1010–1019.
19. Lundgren, K. (2007). Effect of Corrosion on the Bond between Steel and Concrete: An Overview. Magazine of Concrete Research, 59(6), 447–461.
20. Imbsen, R. A., Liu, W. D., Schamber, R. A., and Nutt, R. V. (1987). Strength Evaluation of Existing Reinforced Concrete Bridges. No. 292, Washington D.C., USA.
21. Almusallam, A. A. (2001). Effect of Degree of Corrosion on the Properties of Reinforcing Steel Bars." Construction and Building Materials, 15(8), 361–368
22. Binici, H., Zengin, H., Zengin, G., and Yasarer, F. (2008). Use of pumice as a coating for the reinforcement of steel against corrosion and concrete abrasions, Corrosion Science, 50(8), 2140–2148,.
23. Feng, Q., (2016). A mechanics simulation of the influence of reinforcement corrosion on RC beam behaviour, Ph.D. thesis, University of Adelaide, Adelaide, Australia,
24. Feng, Q., Visintin, P., and. Oehlers, D. J. (2015). Deterioration of bond–slip due to corrosion of steel reinforcement in reinforced concrete, Magazine of Concrete Research, 68(15), 768–781,
25. Barbosa, Maria Teresa Gomes (2001). Avaliação do Comportamento da Aderência em Concretos de Diferentes Classes de Resistência [Evaluation of the Bonding Behavior of Concretes]. 144 f. Thesis (Doctor of Science in Civil Engineering) - Rio de Janeiro, 2001 [in portuguese].
26. Barbosa, Mônica Pinto; Costa, Odair José; Silva, Leonardo Moisés; Salles, Flavio Moreira (2004).

27. Michael, I.K. and Catherine G.P. (2016). Bond behavior of reinforcement in lightweight aggregate self-compacting concrete. Construction and Building Materials, 113, 641-652.
28. Almeida Filho, F.M., El Debs, M.K., El Debs, A.L. (2008). Bond-Slip behavior of self-compacting concrete and vibrated concrete using pull-out and beam tests. Materials and Structures, 41, 1073-1089.
29. Araujo, D. L.; Danin, A. R.; Melo, M. B.; Rodrigues, P. F. (2013). Influence of steel fibers on the reinforcement bond of straight steel bars. IBRACON Structures and Materials Journal. 6(2), 307-338.
30. Lorrain, Michel; Barbosa, Mônica Pinto; Silva Filho, Luiz Carlos (2011). Estimation of compressive strength based on Pull-Out bond test results for on-site concrete quality control, Ibracon Structures and Materials Journal, e 4(4), 582-591.
31. Silva, B.V.; Barbosa, M.P.; Silva Filho, L.C.P; Lorrain M. S. (2013). Experimental investigation on the use of steel concrete bond tests for estimating axial compressive strength of concrete: Part 1. IBRACON Structures and Materials Journal. 6(5), 715-736.
32. Jacintho, A. E. P. G. De Avila; Pimentel, L. L.; Barbosa, M. P.; Fontanini, P. S. P. (2014). Steel and concrete bond stress: a contribution to the study of Apulot tests using concrete with rubber addition. IBRACON Structures and Materials Journal. 7(5), 817-844
33. Charles, K., Ogunjiofor, E. I., Terence, T. T.W. (2019). Pullout Bond Splitting Effects of Corroded And Inhibited Reinforcement In Corrosive Media,Journal of Multidisciplinary Engineering Science and Technology, 6(9), 10747 -10753,
34. Toscanini, D. S., Gede, T. E., Charles, K. (2019). Pullout Bond Failure Load of Corroded and Coated Members in Corrosive Media, International Journal of Advanced Scientific and Technical Research, 5(9), 38-46.
35. Terence, T. T. W., Charles, K., Branly, E. Y. (2019). Bond Strength Characteristics of Reinforcements Embedded in Reinforced Concrete Structures in Corrosive Marine Environment, "American Journal of Engineering Research. 8(10)128-134.
36. Charles, E. N., Charles, K., Terence, T. T. W. (2019). Corrosion Degree on the Mechanical Properties of Reinforcing Steel Embedded in Concrete, Global Scientific Journal, 7(10) 688 -696.
37. Toscanini, D. S., Gede, T. E., Charles, K. (2019). Pullout Bond Failure Load of Corroded and Coated Members in Corrosive Media, International Journal of Advanced Scientific and Technical Research, 5(9), 38 – 46.
38. Gede, T. E., Charles, K., Geofrey, B. (2019). Reinforcement Bond Strength Interface Behavior of Corroded and Coated in Concrete Members, European Academic Research. Vii, (7), 3399 – 3412.
39. Charles, K., Geofrey, B., Gede, T. E. (2019). Corrosion Effect on Reinforcement Pull-Out Bond Strength Characteristics of Corroded and Coated Members in Concrete, American Journal of Sustainable Cities and Society, 1(8), 61-69.
40. Charles, K., John, A. T., John, C. O. (2019). Reinforcing Steel Mechanical Properties Influence on Bond Strength of Corroded and Coated Members in Concrete Structures, Global Scientific Journal, 7(9), 1168 – 1178..
41. Charles, K., Geofrey, B., Gede, T. E. (2019). Corrosion Effect on Reinforcement Pull-Out Bond Strength Characteristics of Corroded and Coated Members in Concrete, American Journal of Sustainable Cities and Society 1(6), 61 – 69.
42. BS. 882; 1992- Specification for Aggregates from natural sources for concrete. British Standards Institute. London, United Kingdom.
43. BS EN 196-6; 2010 - Methods of Testing Cement. Determination of fineness, British Standards Institute. London, United Kingdom.
44. BS 3148; 1980– Methods of test for water for making concrete. British Standards Institute. London, United Kingdom.
45. BS 4449:2005+A3; 2010 – Steel for reinforcement of concrete. British Standards Institute. London, United Kingdom
46. Lutz, L. A., and Gergely P. (1967). Mechanics of Bond and Slip of Deformed Bars in Concrete." In ACI Journal Proceedings, 64(11).
47. Tepfers, R. (1979). Cracking of Concrete Cover along Anchored Deformed Reinforcing Bars. Magazine of Concrete Research, 31(106), 3–12
48. Fu, X.., and Chung, D. D. L. (1997). Effect of corrosion on the bond between concrete and steel Rebar. Cement and Concrete Research, 27(12), 1811-181.
49. Apostolopoulos, C. A., and Papadakis, V. G. (2008). Consequences of Steel Corrosion on the Ductility Properties of Reinforcement Bar. Construction and Building Materials, 22(12), 2316–2324.
50. Apostolopoulos, C. A., and Papadopoulos, M. P. (2007). Tensile and Low Cycle Fatigue Behavior of Corroded Reinforcing Steel Bars S400. Construction and Building Materials, 21(4), 855–864.
51. Apostolopoulos, C. A. (2007). Mechanical Behavior of Corroded Reinforcing Steel Bars S500s Tempcore under Low Cycle Fatigue." Construction and Building Materials, 21(7), 1447–1456.
52. Apostolopoulos, C. A., Papadopoulos, M. P., and Pantelakis, S. G. (2006). Tensile Behavior of Corroded Reinforcing Steel Bars BSt 500s.Construction and Building Materials, 20(9), 782–789.
53. Zhang, W., Song X., Gu X., and Li S. (2012). Tensile and Fatigue Behavior of Corroded Rebars." Construction and Building Materials 34409–417
54. CEB-fib. (2000). Bond of Reinforcement in Concrete. State-of-Art Report, Fédération internationale du béton, Bulletin 10, prepared by Task Group Bond Models, Lausanne, Swetzerland.