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Original Research Article

Induced – Corrosion Mechanism on Splitting and Pullout Failures of Corroded and Coated Reinforced Concrete Members

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Abstract

Corrosion of reinforcement embedded in concrete is considered as one of the main reasons for the degradation and deterioration of many existing reinforced concrete structures and this degradation effects has been seen as major challenges in structures founded in region with high concentration of salt as in the case of the Niger Delta region of Nigeria. This study involves the coating of ficus sycomorus exudates/resin paste of plant trunks extract known as inhibitors directly on the reinforcing steel. The experiment aimed at determining the effectiveness in the use of eco-friendly and abundantly available materials in curbing the negative effect of corrosion attacks on reinforcing steel embedded in concrete structures and immersed in Sodium Chloride (NaCl) solutions by coating steel reinforcement with different thicknesses and experimentally tested to prevent corrosion attacks in the laboratory. The test specimens reflect the acute acidic level indicating the sea salt concentration level of the marine environment on reinforced concrete structures. The result showed that the decreased value in uncoated (corroded) represent the degree of corrosion that has to affect the bonding interaction between concrete and reinforcing steel, also, the negative values obtained in bond strength versus maximum slip showed that the reduction in slip was due to the effect of corrosion. The higher values obtained from coated members showed the potential and the effective interaction process in steel and concrete, results showed that the values of coated members are similar to that of controlled indicating the virtuous bonding characteristics. The result of weight loss for controlled samples are 100% indicating no weight loss, uncoated (corroded) samples negative values showed tremendous weight loss resulting from corrosion presence, and for coated samples, there are weight gain resulting from coating materials. Also, the effect of corrosive medial reduces the diameter of reinforcing steel after corrosion, the effect of corrosion formed pits which resulted to swollen rebar surface whereas coated and controlled maintained perfect diameter with an increasing diameter from coating thicknesses. Reduction in cross–sectional properties, weight loss was all seen in corroded samples resulting from damaging and destructive effect from corrosion manifestation while coated gained weight and as well as increased in cross-sectional properties. Clear examinations on the study and investigations, coated exudate/resin has demonstrated and shown to be good inhibitive material against corrosion.

Keywords: Corrosion, Corrosion inhibitors, Pull-out Bond Strength, Concrete and Steel Reinforcement.

1.0 INTRODUCTION

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

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

Has shown that calcium nitrate is not harmful to concrete properties as seen in the problem of inhibition based on sodium or potassium. Subsequent studies by Schottink (2000) and Slater (2000) have shown that calcium nitrate has a good quality in terms of strength when considering long-term rapid testing [2].

Investigated the relationship between corrosion and load-bearing capacity of reinforced concrete beams. Their results showed a significant reduction in load-bearing capacity with an increase in corrosion in beams with low w / c or predetermined fractures (mix B or type K). They conclude that this behavior is caused by the easier access of reinforcing steel in cracked beams than chloride ions [3].

Experimental work examined the bond strength of non-corroded, corroded, and exudates/resin coated samples of reinforced concrete structures of 150 mm x 150 mm x150 mm standard cubes, immersed in a corrosive medium for 150 days. Collective results demonstrated that corroded specimens exhibited weak maximum slip during split separation testing and high failure load with lower bond strength. Non-corroded and exudates/resin-coated models have high bond strength and low failure load. Exudate/resin members showed high protective properties against corrosion effects, thereby acting as inhibitors. Exudates/resins coated specimens exhibit high-performance resistance properties for bond strength, and maximum slip with minimal failure compared to corroded specimens [4].

Emphasized that the issue of chloride and carbonation contamination in marine zones of the Niger Delta, Nigeria are the main reasons for the lack of the bond between steel reinforcement and concrete, leading to premature deterioration in reinforced concrete structures in rough weather. Steel bars were coated with 150µm, 300µm, and 450µm thicknesses and embedded in concrete cubes, treated with corrosive medium, and investigated the pull-out bond strength parameters against non-coated. Relatively, the results of corroded specimens decreased whereas control and cola acuminate exudates/resins coated increased. The overall results showed that natural exudates/resins should be explored as inhibitors for the corrosion effects of steel reinforcement in concrete construction in marine areas [5].

Studied reinforcing steel bond strength using corroded and khaya senegalensis exudates/adhesive coated specimens. The results of the failure bond loads showed a difference of -43.622% against 77.37%, and 79.6743% for the members of the controlled and coated exudates/resin. The reduced mean percentage bond strength load varies from 57.06% to 36.33% and 106.57% in the corroded and coated samples. The obtained results clearly showed that the corrosive bond loads were higher for the corroded than for the exudates/adhesive coated members. The bond strength of the corroded and coated specimens showed a higher affinity for coated compared to corroded ones [6].

Investigated the strength of the bond between concrete and reinforcement that led to diameter reduction due to the diminishing effect of reinforcing steel from the coastal area with saltwater. The application of Artocarpus altilis resin extracts on reinforcing steel with a coating thickness of 150µm, 300µm, and 450µm, and non-coated reinforcing steel was embedded into a concrete cube, immersed in sodium chloride, and accelerated corrosion process implored for 150 days. Comparative results show that the values of the corroded samples decreased and the exudates/resins coated samples increased. Overall results showed higher values of pull-out bond strength under control and coated exudates/resins against corroded specimens [7].

Studied the use of acacia Senegal exudates/resins as paste materials in reinforcing steel coatings of 150µm, 300µm, and 450µm thickness. The test specimens were inhibited and uninhibited and embedded in concrete cubes and immersed in sodium chloride for 178 days for corrosion evaluation results. In comparison, the values of uninhibited samples are reduced due to the corrosion attack on steel reinforcing mechanical properties, but with the increased strength of corrosion and exudates/resins coated members, which indicates the ability of Acacia Senegal to be used as exudates/resins to strengthen steel coating operations. The overall results showed high values of pull-out binding strength and low failure load in the control and coated against the stained samples [8].

Studied the effect of olibanum exudates/resins in curbing the corrosion tendency of reinforcing steel in the coastal zones with the impact of saltwater on concrete structures. Tests have shown that non-coated specimens are corroded and showed deterioration. The mean percentile bond strength load was 331.34% compared to the control difference and coated members of 45% and 71.84%. The mean maximum slip values are 0.083567mm and represented 33.878% and 75.30% compared to the control and coated sample of -25.30%. The test results reviewed that the corroded models had low bond strength and high failure bond load and low maximum slip, whereas exudates/resins coated models had lower experimental models have shown that exudates/resins members have higher percentages values compared to corroded samples [9].

Explored the effectiveness of reinforced steel coated inhibitors in rapid process testing of embedded steel foil bond strength over 150 days. Overall results showed high values of control pull-out bond strength and exudates/adhesive coating members over corroded specimens [10].

2.1 MATERIALS

This study involves the coating of exudates/resin paste of plant trunks extract known as inhibitors directly on the reinforcing steel. The experiment aimed at determining the effectiveness in the use of eco-friendly and abundantly available materials in curbing the negative effect of corrosion attacks on reinforcing steel embedded in concrete structures and immersed in Sodium Chloride (NaCl) solutions by coating steel reinforcement with different thicknesses and experimentally tested to prevent corrosion attacks in the laboratory. The test specimens reflect the acute acidic level indicating the sea salt concentration level of the marine environment on reinforced concrete structures. The embedded reinforcement steel is completely submerged in water and the samples are maintained in the pooling tank for the corrosion acceleration process. The specimens were designed with 36 reinforced concrete cubes of dimensions 150 mm × 150 mm x 150 mm, with a 12 mm diameter reinforcement, embedded in the center for pullout bond testing for all controlled, uncoated, and coated specimens and immersed in sodium chloride between 1 - 360 days after the initial 28 days of curing of the cubes. Acid media samples were replaced monthly and samples were inspected for high-efficiency performance.

2.1.1 Aggregates

Aggregates (fine and coarse) were purchased. Both meet the requirements of [11].

2.1.2 Cement

Portland Lime Cement Grade 42.5 is the most common type of cement in the Nigerian market. It was used for all concrete mixes in this test. Meets Cement Requirements [12].

2.1.3 Water

The water samples were clean and free of impurities. Freshwater was obtained from Bori, Rivers, Sinul Engineering Laboratory, Kenul Besan Polytechnic, State Taps. Meets water [13] requirements.

2.1.4 Structural Steel Reinforcement

Reinforcements are obtained directly from the market at Port Harcourt [14].

2.1.5 Corrosion Inhibitors (Resins / Exudates) Ficus sycomorus

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

2.2 Methods

Corrosion acceleration was tested on high-yielding steel (reinforcement) with a diameter of 12 mm and a length of 650 mm. Paste with 150µm, 300µm, 450µm, and 600µm coatings before corrosion testing. The test cubes were cast with a 150 mm x 150 mm x 150 mm metal mold and dismantled after 72 hours. Samples were treated at room temperature in tanks 28 days prior to the initial treatment period, followed by a trial procedure allowing rapid acceleration corrosion testing and routine monthly monitoring of a procedure for 360 days. The cubes for corrosion-acceleration samples were taken for 90 days, 180 days, 270 days, and 360 days at 3 months intervals, and failure bond loads, bond strength, maximum slip, decrease/increase in cross-sectional area, and weight loss/steel reinforcement.

2.3 Accelerated Corrosion set-up and Testing Method

In real and natural phenomena, the expression of corrosion effects on reinforcement embedded in concrete members is very slow and can take many years to achieve; but the laboratory accelerated process will take less and less time with accelerating media representing the saltwater of the sea area. To test the surface and mechanical properties of the changes and effects and to test both non-coated and exudate/resin coated samples were immersed in 5% NaCl solution for 360 days.

2.4 Pull-out Bond Strength Test

The tensile-bond strength test of concrete cubes was carried out on a total of 36 samples of each of the 12 samples with filter water, non-coating, and coated members, and was subjected to a 50 kN universal testing machine as per BSEN12390-2. 36 cubes size 150 mm × 150 mm × 150 mm, embedded in the center of a single 12 mm diameter concrete cube.

2.5 Tensile Strength of Reinforcement Bars

To determine the yield and tensile strength of the bar, the reinforced, non-coated, and reinforced steel strip with a diameter of 12 mm was tested under stress in the Universal Test Machine (UTM) and subjected to direct stress until failure load is recorded. To ensure stability, the remaining cut pieces were used in subsequent bonding testing.

3.1 EXPERIMENTAL RESULTS AND DISCUSSIONS

The degradation of reinforced concrete structures caused by corrosion effects has been seen major challenges in structures founded on this region, and experimental results shown in tables 1–3 and represented graphically in figures 3.1-3.6b enumerated the behavioral performance of controlled, non-coated, and coated concrete members (cubes) cured under control conditions and as well as under induced corrosion accelerated processes. Experimental work was performed on 36 samples, 12 controlled cubes, 12 uncoated (corroded) cubes, and 12 Ficus sycomorus (exudate /resin) coated cubes. The experimental studies investigated the pullout bond characteristics of uncoated and coated samples in comparison to control samples. The use of exudate/resin was examined as a way of curbing the trend of corrosion attacks and the results in tables were obtained after 360 days induced process.

Table 1: Results of Pull-out Bond Strength Test (τu) (MPa) of Non-corroded Control Cube Specimens

	Non-corroded Control Cube Specimens											
Sample Numbers	FS C	FS C1	FS C2	FS C3	FS C4	FS C5	FS C6	FS C7	FS C8	FS C9	FSC 10	FSC 11
	Time Interval after 28 days curing											
Sampling and Durations	**Samples 1 (28 days)**			**Samples 2 (28 Days)**			**Samples 3 (28 Days)**			**Samples 4 (28 Days)**		
Failure Bond Loads (kN)	29.394	28.916	28.939	30.018	28.744	29.752	29.448	28.566	29.768	28.883	29.926	29.387
Bond strength (MPa)	9.676	9.909	9.209	8.995	9.709	10.026	10.364	10.740	9.916	9.936	10.855	11.006
Max. slip (mm)	0.100	0.106	0.100	0.100	0.115	0.999	0.102	0.104	0.108	0.115	0.118	0.103
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)	11.898	11.890	11.900	11.898	11.890	11.908	11.895	11.884	11.896	11.898	11.886	11.896
Rebar Diameter- at 28 Days Nominal(mm)	11.898	11.890	11.900	11.898	11.890	11.908	11.895	11.884	11.896	11.898	11.886	11.896
Cross- section 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)	0.562	0.559	0.565	0.559	0.561	0.561	0.560	0.568	0.558	0.559	0.564	0.560
Rebar Weights- at 28 Days Nominal(Kg)	0.559	0.559	0.560	0.559	0.568	0.565	0.561	0.562	0.560	0.558	0.564	0.561
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 2: Results of Pull-out Bond Strength Test (τu) (MPa) of Corroded Concrete Cubes Specimens

Sampling and Durations	**Samples 1 (90 days)**			**Samples 2 (180 Days)**			**Samples 3 (270 Days)**			**Samples 4 (360 Days)**		
Failure Bond Loads (kN)	17.935	17.248	17.538	16.980	16.228	17.095	16.675	16.983	16.680	17.916	16.795	17.529
Bond strength (MPa)	6.196	6.206	5.970	6.192	5.959	5.931	5.730	6.418	5.393	5.882	5.729	6.042
Max. slip (mm)	0.077	0.081	0.082	0.090	0.081	0.085	0.084	0.074	0.080	0.081	0.082	0.072
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)	11.899	11.889	11.899	11.898	11.889	11.909	11.899	11.888	11.898	11.896	11.889	11.899
Rebar Diameter- After Corrosion(mm)	11.852	11.843	11.853	11.852	11.846	11.862	11.853	11.842	11.852	11.849	11.843	11.853
Cross- section Area Reduction/Increase (Diameter, mm)	0.047	0.047	0.046	0.047	0.044	0.047	0.046	0.047	0.046	0.047	0.046	0.047
Rebar Weights- Before Test(Kg)	0.559	0.560	0.560	0.558	0.560	0.560	0.561	0.561	0.560	0.562	0.559	0.559
Rebar Weights- After Corrosion(Kg)	0.514	0.515	0.515	0.513	0.515	0.515	0.516	0.516	0.515	0.517	0.514	0.514
Weight Loss /Gain of Steel (Kg)	0.045	0.045	0.045	0.045	0.046	0.046	0.045	0.045	0.045	0.045	0.045	0.045

Table 3: Results of Pull-out Bond Strength Test (τu) (MPa) of Ficus sycomorus Exudate / Resin (Steel Bar Coated Specimen)

Samplin 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)	29.966	27.876	28.440	29.037	29.852	29.553	30.076	29.894	29.958	31.769	30.894	31.095
Bond strength (MPa)	11.299	12.192	10.689	11.620	11.993	12.916	13.009	12.339	12.374	13.079	12.391	12.937
Max. slip (mm)	0.144	0.145	0.136	0.141	0.140	0.139	0.152	0.156	0.164	0.161	0.166	0.164
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)	11.898	11.890	11.899	11.899	11.889	11.909	11.899	11.888	11.899	11.896	11.889	11.900
Rebar Diamete r- After Corrosion(mm)	11.988	11.979	11.989	11.988	11.979	11.998	11.989	11.978	11.988	11.985	11.980	11.989
Cross- section Area Reduction/Increase (Diameter, mm)	0.090	0.089	0.090	0.089	0.090	0.089	0.090	0.090	0.089	0.090	0.091	0.089
Rebar Weights- Before Test(Kg)	0.566	0.567	0.567	0.565	0.567	0.567	0.568	0.568	0.567	0.569	0.566	0.566
Rebar Weights- After Corrosion(Kg)	0.645	0.646	0.646	0.644	0.646	0.646	0.647	0.647	0.646	0.648	0.645	0.645
Weight Loss /Gain of Steel (Kg)	0.079	0.079	0.079	0.076	0.077	0.079	0.080	0.080	0.079	0.082	0.080	0.079

Table 4: Average Pull-out Bond Strength Test (τu) (MPa)

	Non-corroded Control Cube				**Corroded Control Cube**				**Exudate/ Resin steel bar coated specimens**			
Sample	**Non-Corroded Specimens Average Values**				**Corroded Specimens Average Values**				**Coated Specimens Average Values of 150µm, 300µm, 450µm, 600µm)**			
Failure load (KN)	29.083	29.291	29.234	29.505	17.573	17.255	16.915	16.768	28.761	28.451	29.110	29.480
Bond strength (MPa)	9.598	9.371	9.304	9.576	6.124	6.123	6.040	6.027	11.393	11.500	11.434	12.176
Max. slip (mm)	0.102	0.102	0.105	0.100	0.080	0.084	0.084	0.085	0.142	0.140	0.139	0.140
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)	11.896	11.896	11.896	11.899	11.896	11.896	11.896	11.899	11.896	11.896	11.896	11.899
Rebar Diamete r- After Corrosion(mm)	11.896	11.896	11.896	11.899	11.849	11.849	11.850	11.853	11.985	11.985	11.985	11.988
Cross- section Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.047	0.047	0.046	0.046	0.089	0.089	0.090	0.089
Rebar Weights- Before Test(Kg)	0.562	0.561	0.562	0.560	0.559	0.559	0.559	0.559	0.566	0.566	0.566	0.566
Rebar Weights- After Corrosion(Kg)	0.559	0.559	0.562	0.564	0.514	0.514	0.514	0.514	0.627	0.626	0.626	0.626
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.045	0.045	0.045	0.045	0.060	0.059	0.059	0.058

Table 5: Results of Average Percentile Pull-out Bond Strength Test (τu) (MPa)

	Non-Corroded Control Cube				Corroded Cube Specimens				Exudate / Resin steel bar coated specimens			
Failure load (KN)	65.494	69.755	72.827	75.961	-38.898	-39.352	-41.892	-43.123	63.662	64.887	72.093	75.818
Bond strength (MPa)	56.731	53.049	54.031	58.876	-46.253	-46.762	-47.172	-50.497	86.057	87.835	89.294	102.009
Max. slip (mm)	27.676	21.133	24.742	17.911	-43.678	-40.152	-39.235	-38.925	77.551	67.089	64.569	63.732
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)	0.001	0.002	0.003	0.001	-0.001	-0.003	-0.002	-0.002	0.001	0.003	0.002	0.002
Rebar Diamete r- After Corrosion(mm)	0.394	0.395	0.387	0.386	-1.136	-1.137	-1.129	-1.129	1.149	1.150	1.142	1.141
Cross- section Area Reduction/Increase (Diameter, mm)	-100	-100	-100	-100	-47.992	-47.879	-49.108	-49.018	92.277	91.861	96.495	96.147
Rebar Weights- Before Test(Kg)	0.458	0.334	0.419	0.162	-1.215	-1.215	-1.215	-1.215	1.230	1.230	1.230	1.230
Rebar Weights- After Corrosion(Kg)	8.743	8.811	9.403	9.730	-17.917	-17.927	-17.929	-17.931	21.828	21.843	21.845	21.848
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	-25.461	-24.147	-22.622	-22.214	34.159	31.833	29.236	28.559

3.2 Failure load, Bond Strength, and Maximum slip

The performance of reinforced concrete (R C) structures, as in other composite members, depends on the bond between the steel and the concrete which ensures that load is transferred safely between the two materials . The bond mechanism which is described by Park and Paulay [15] as a continuous stress field that develops in the vicinity of the concrete - steel interface ensures that the structure remains in equilibrium under any given load. In structures subjected to loads beyond its bond strength capacity, high deformation in the form of slip occurs between the rebar and the concrete.

The presented results from tables 1-5 and figures 1–1b and 2-2b are the results of the general summary results of failure bond load, bond strength, and maximum slip conducted on 12 controlled cubes samples 24 for uncoated and coated samples subjected to failure in an Instron Universal Testing Machine of 50 kN (UTM). The results are summarized into average and percentile values shown in the random test conducted for 360 days at 3 months intervals as shown in the tables. The controlled samples have average percentile values range of 65.50% to 77.95%, uncoated (corroded) has -38.89% to - 41.98 and coated has 63.66% to 75.82% at failure load and bond strength of -56.731% to 58.876% controlled, -46.76% to -50.497 uncoated and 86.057% to 102.009%, while maximum slip vales for controlled are 27.676% to 17.911%, uncoated are -43.678% to -38.925% and 77.551% to 63.732%. The result presented in tables 3.1 -3.5 and represented in figure 1–2b showed that the decreased value in uncoated (corroded) represent the degree of corrosion that has affected the bonding interaction between concrete and reinforcing steel, also, the negative values obtained in bond strength versus maximum slip showed that the reduction in slip was due to the effect of corrosion. The higher values obtained from coated members showed the potential and the effective interaction process in steel and concrete, results showed that the values of coated members are similar to that of controlled indicating the virtuous bonding characteristics [7, 10, 9].

Summary result obtained of failure bond load showed that the controlled samples were at stable state of no change, the corroded samples has destructive effect due to corrosion that has reduced the percentile maximum value to -38.89% against coated value of 77.95%. These results showed that corrosion of reinforcing steel has significant effect on the load carrying capacity of steel bar embedded in concrete. The bond strength maximum parameters of controlled 75.82%, corroded-46.76% and coated 102.009%. The results showed that corrosion causes decreased in bond due to the surface modification that affect reduction in rib while recorded increased in coated resulted from the gummy and sticky characteristics exhibited by exudates / resin, same factor affected negative and positively in maximum slippage with recorded values of corroded -38.925% and 77.551% respectively.

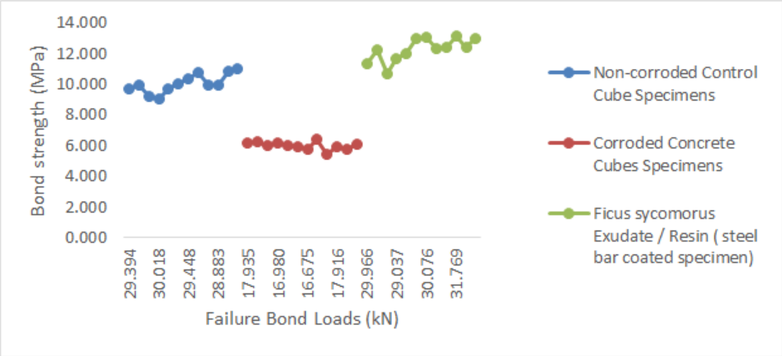

Figure 1: Failure Bond loads versus Bond Strengths

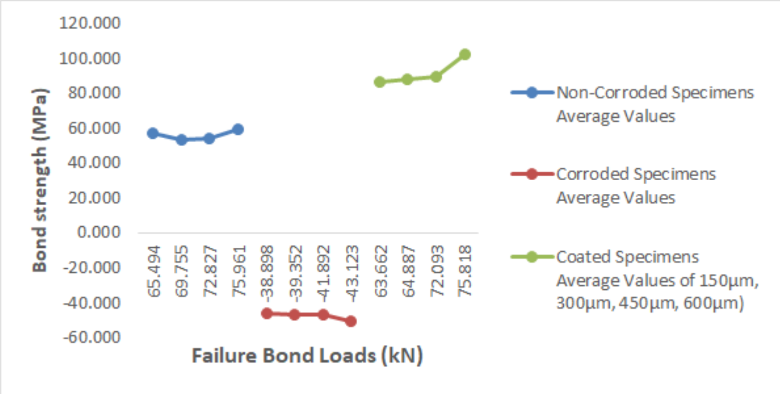

Figure 1a: Average Failure Bond loads versus Bond Strengths

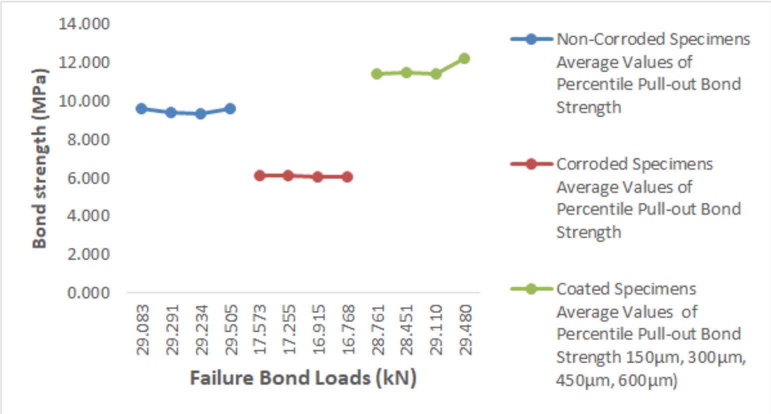

Figure 1b: Average Percentile Failure Bond loads versus Bond Strengths

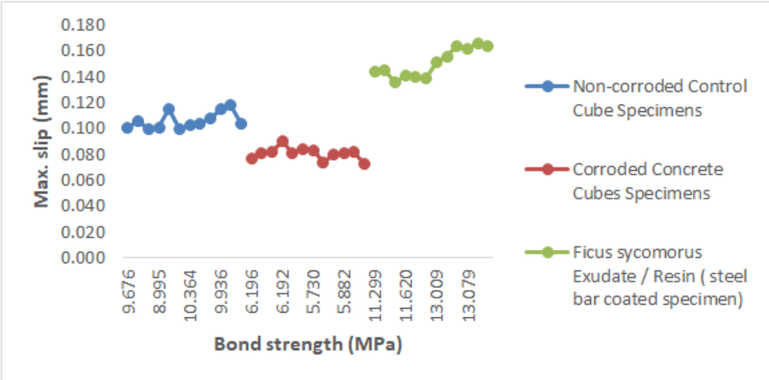

Figure 2: Bond Strengths versus Maximum Slip

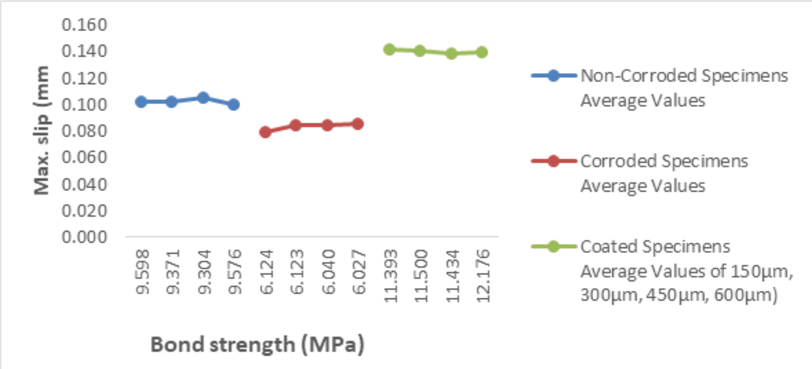

Figure 2a: Average Bond Strengths versus Maximum Slip

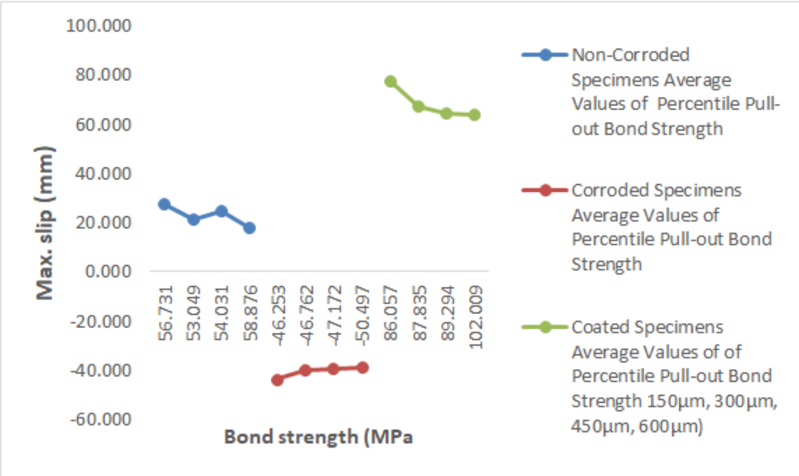

Figure 2b: Average Percentile Bond Strengths versus Maximum Slip

3.3 Mechanical Properties of Reinforcing Bars (Cross-Sectional Reduction and Weight loss / Gain)

Many considerable factors that affected and causes heterogeneity at the steel-concrete interface, which among other things impairs steel-concrete adhesion has been researched by [17]. In addition, as a phenomenon that is influenced by many variables, it is a challenge to know how steel-concrete bonding can be explained in reinforced concrete construction standards. This property has been studied since the 1940s, such as [18], who investigated the factors influencing the relationship between steel bars and concrete. The results contained in tables 1–5 and represented graphically in figures 3–6b presented the results of reinforcing steel bars nominal diameter, measured diameter before and after corrosion test, cross-sectional reduction, the weight of rebars (before and after corrosion test), and weight loss/gain) for controlled (non-corrosive), uncoated (corroded) and coated concrete cubes for 360 days in an induced rapid corrosion accelerated process. The nominal diameter represents 100% for all samples, rebar measured diameter average percentile value has the range of 0.395% to 0.387%, the range of value obtained for all reinforcing steel was as a result of production deficiencies in not maintaining standard gauging and more so due to different products in the market, obtained values of rebar after corrosion test for controlled is 100%, corroded -1.136% to -1.129%, this is an indication that corrosion affected the uncoated samples that led to the reduction in weight and coated 1.149% to 1.150% this an indication that coating material contributed to an increase in weight, results from the weight of indicating that there was no weight loss in the controlled samples since it was immersed and cured freshwater standard conformity to (BS 3148) requirements, for corroded sample. The results of cross-sectional area reduction/increase are of the range, uncoated (corroded) -47.992% to -49.018% and coated 91.861% to 96.495%;, weight before test 1.215% to 1.304% for all samples and weight after corrosion test controlled 8.74% to 9.730%, uncoated -17.917% to -17.931% and coated 21.828% to 21.848% and weight loss / gain are 100%, uncoated -22.622% to -25.46%, the coated values are 128.559% to 134.159%. The result of weight loss for controlled samples are 100% indicating no weight loss, uncoated (corroded) samples negative values showed tremendous weight loss resulting from corrosion presence, and for coated samples, there are weight gain resulting from coating materials as confirmed in the various studies of [5, 7, 10, 9]. From the experimental work, exudates has proven good bonding between the interface of concrete and reinforcing steel and serves as an inhibitor to corrosion attacks on reinforced concrete structures built with the coastal areas with high concentration of salt.

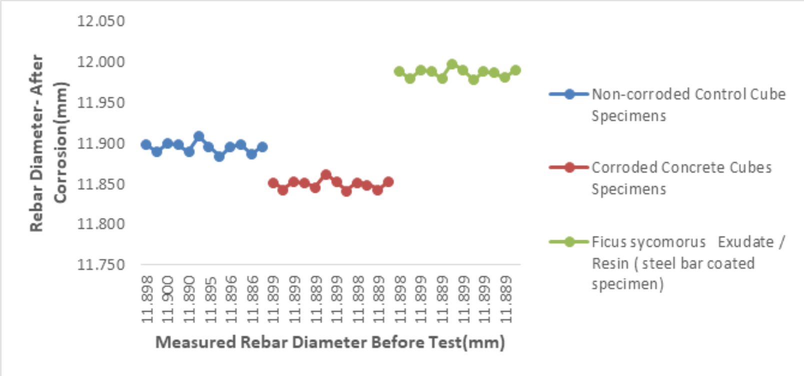

Figure 3: Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion)

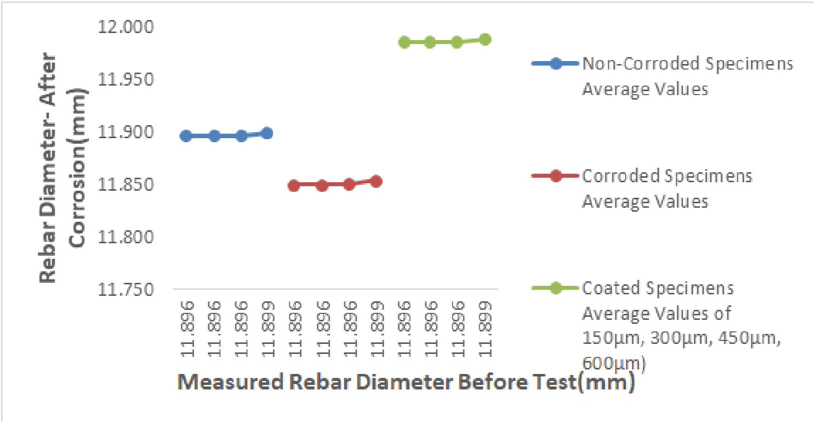

Figure 3a: Average Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion)

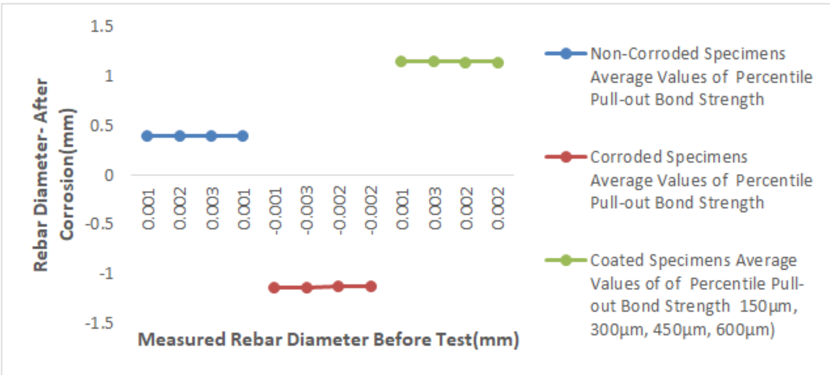

Figure 3b: Average Percentile Measured (Rebar Diameter before Test vs Rebar Diameter- after Corrosion)

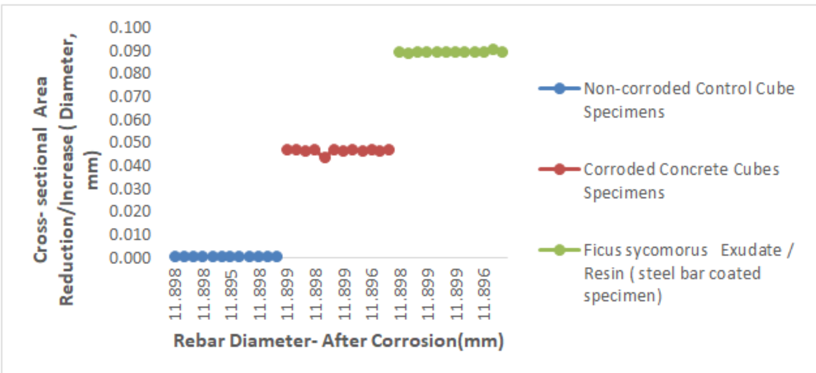

Figure 4: Rebar Diameter- After Corrosion versus Cross - Sectional Area Reduction/Increase

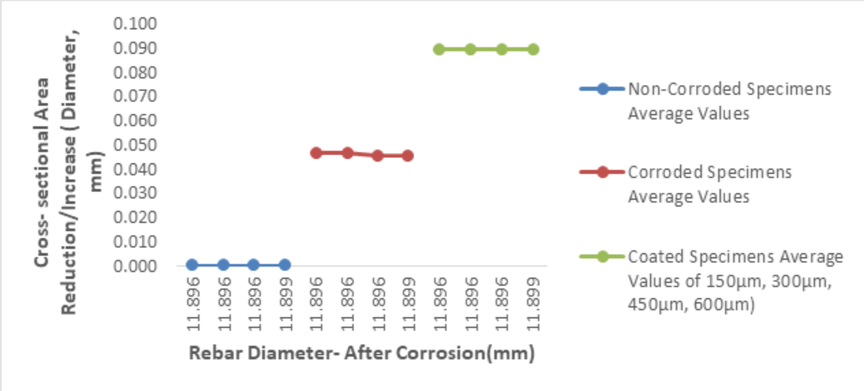

Figure 4: Average Rebar Diameter- After Corrosion versus Cross – Sectional Area Reduction/Increase

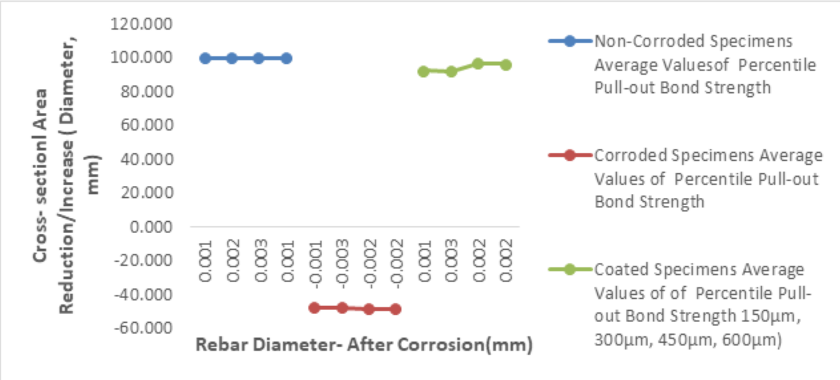

Figure 4b: Average percentile Rebar Diameter- After Corrosion versus Cross - sectional l Area Reduction/Increase

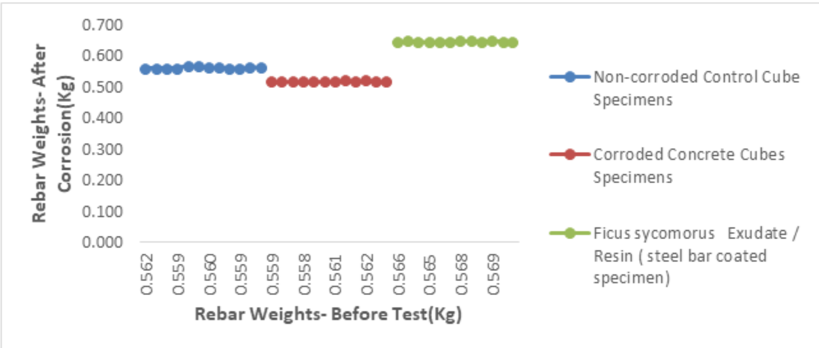

Figure 5: Rebar Weights- Before Test versus Rebar Weights- After Corrosion

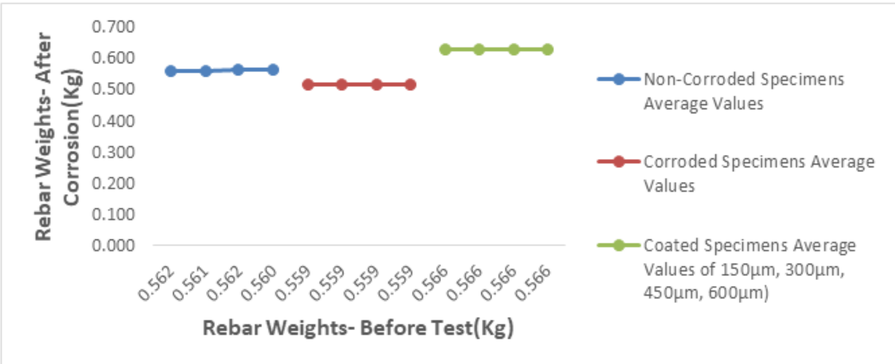

Figure 5a: Average Rebar Weights- Before Test versus Rebar Weights- After Corrosion

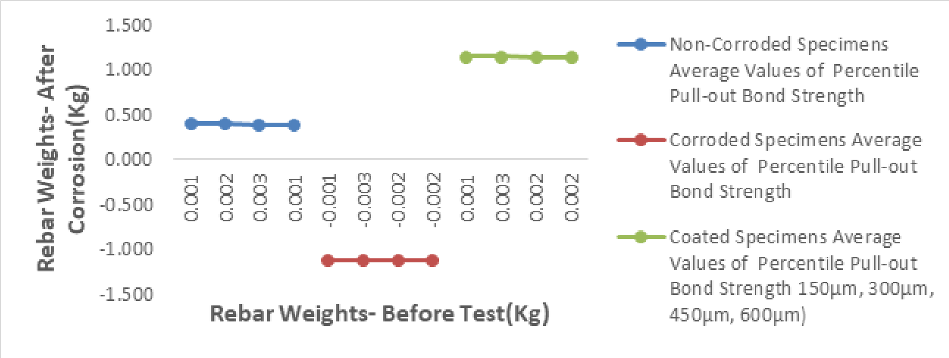

Figure 5b: Average Percentile Rebar Weights- Before Test versus Rebar Weights- After Corrosion

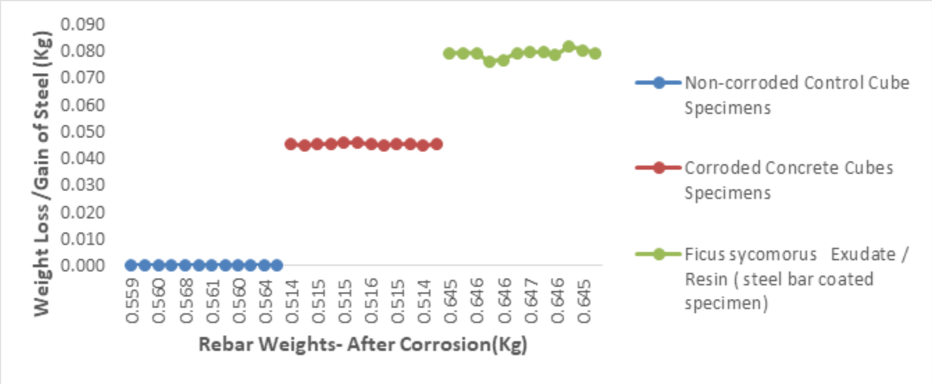

Figure 6: Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

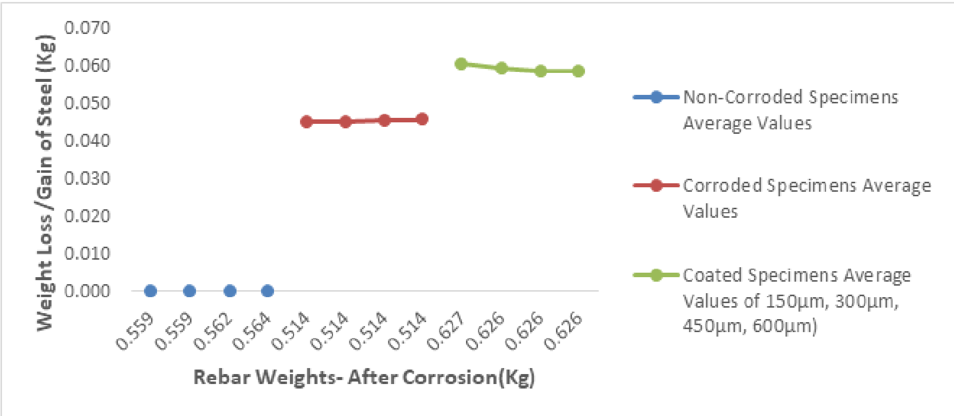

Figure 6a: Average Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

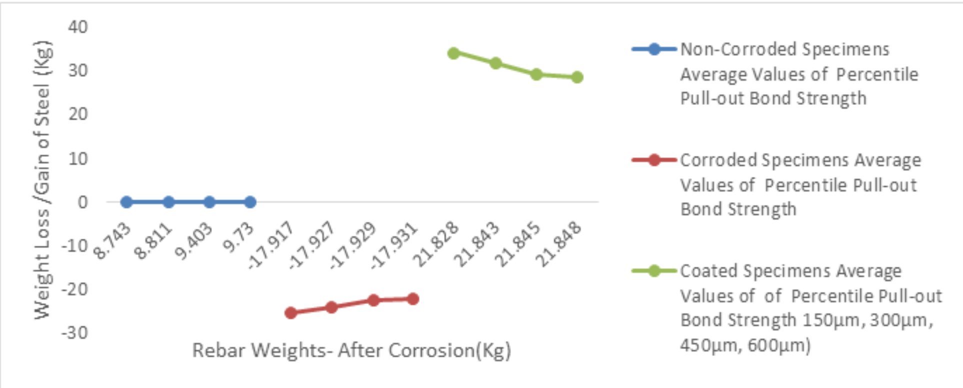

Figure 6b: Average percentile Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

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

Results from tables 3.1-3.3 are the results of randomly samples of controlled, uncoated, and exudate/resin coated cubes pooled in distilled water for controlled and the other induced for 360 days in corrosion accelerated media of 5% sodium chloride aqueous solution and examined the performances of the inhibitive material properties of ficus sycomorus exudate/resin in the preventive scourge exhibited by corrosion and that of uncoated (corroded) on the degree assessment that is caused by corrosion. Tables 3.4 and 3.5 are the derived values obtained from tables 3.1-3.3 of average and percentile values as represented in figures 1–6b. Comparatively, the values obtained from the experimental work on failure bond load showed that the corroded samples have lower values as compared to coated and controlled resulting from low interaction between concrete and steel due to loss of rib and fibre reduction, the same factor was appeared in bond strength with lower or fewer values as compared to coated and controlled samples as shown in studies of [5, 7, 10, 9]. Also, the effect of corrosive medial reduces the diameter of reinforcing steel after corrosion, the effect of corrosion formed pits which resulted to swollen rebar surface whereas coated and controlled maintained perfect diameter with an increasing diameter from coating thicknesses. Reduction in cross–sectional properties were, weight loss was all seen in corroded samples resulting from damaging and destructive effect from corrosion manifestation while coated gained weight and as well as increased in cross-sectional properties. Clear examinations on the study and investigations, coated exudate/resin has demonstrated and shown to be good inhibitive material against corrosion.

4.0 CONCLUSIONS

Experimentally, the results obtained showed the following Summary:

i. Ficus sycomorus exudate/resin has proven to be an inhibitive material against corrosion, offering high resistive properties against corrosion manifestation
ii. Non-coated (coated) samples exhibited low pullout bond average percentile value denoting the negative scourge from corrosion attack
iii. The interaction between concrete and steel is lose due to loss of ribs and fibre from corrosion attack
iv. Higher value of failure bond load and bond strength were recorded in coated and controlled samples
v. Weight loss, and cross -sectional reductions recorded in corroded over coated and controlled

REFERENCES

1. Macdonald, D. (2003). Design options for corrosion protection. 8th International Symposium, Australia, 75-83.
2. Novokshcheov, V. (2000). Salt penetration and corrosion in pre-stressed concrete member. Washington, D. C., Federal Highway.
3. Huang, R., & Yang, C. C. (1997). Condition Assessment of Reinforced Concrete Beams Relative to Reinforcement Corrosion, *Cement and Concrete Composites*, 19, 131-137.
4. Charles, K., Letam, L. P., & Gbinu, S. K. (2018). Effect of Resins / Exudates Inhibited Steel on the Flexural Strength of Reinforced Concrete Beam under Corrosive Environment, *International Journal of Advances in Scientific Research and Engineering*, (4)4, 52-61.
5. 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,
6. 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.
7. Gede, T. E., Charles, K., & Geofrey. (2019). Reinforcement Bond Strength Interface Behavior of Corroded and Coated in Concrete Members, "European Academic Research, 7(7), 3399–3412,
8. 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.
9. 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,.
10. 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.
11. BS882; "Specification for Aggregates from Natural sources for Concrete," British Standards Institute. London, United Kingdom, 1992.
12. BS EN 196-6. (2010). Methods of Testing Cement Determination of Fineness. British Standards Institute," London, United Kingdom, -
13. BS 3148. (1980). Methods of Test for Water for making Concrete. British Standards Institute, London, United Kingdom.,
14. BS 4449:2005+A3. (2010). Steel for Reinforcement of Concrete. British Standards Institute, London, United Kingdom,
15. Park, R., & Paulay, T. (1975) Reinforced Concrete Structures. John Wiley & Sons, New York.
16. 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.
17. 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*, 138-59.