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Original Research Article

Corrosion Resistance Potential Bond-slip Mechanisms of Reinforcing Steel in Corrosive Media

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Abstract

This study investigated the potential use of eco-friendly material of organic classes to curb the menace of corrosion effect on reinforcing embedded in concrete structures and exposed to corrosive media. The obtained results of 36 concrete cubes; 12 controlled, 12 uncoated (corroded) and 12 exudates / resins coated cured for 360 days under freshwater and induced corrosion accelerated process as detailed in experimental procedures. From the computed results, the maximum obtained value of the corroded sample is -39.551% as against 78.562% and 82.183% of controlled and coated samples respectively. The results showed decreased failure bond load in corroded sample and an increase in coated judging from controlled sample as a standard for comparison. The results of bond strength maximum obtained values are corroded -29.789% against controlled 35.831% and 67.905%, enumerative results showed low and decreased bond strength of corroded samples resulted from the effect of corrosion damaged to the reinforcing surface and fibre. Higher bond strength obtained from coated samples resulting from the gummy and sticky exudates/resin that formed higher bonding with the rib. Results of slippage in controlled and coated samples showed higher values to failure as against lower slippage in coated. Results indicated that the diameter of uncoated decreased by maximum value of -1.293% and coated increased by 1.31%, results showed that reduction is attributed to the effect of corrosion on the surface modification through the formation of pits and unusual expansion, also similar factor is applicable on the cross - sectional area, corroded has maximum reduction value of (-7.414% and coated increased by 14.934%, weight loss and gain are corroded -28.567% decreased (loss) and coated 48.006% increase (gain). Summarized results showed the effect of affected the overall mechanical properties of reinforcing steel thereby reducing bond characteristics of steel and concrete by creating stresses in the surroundings and further weakened pullout bond resulting in diameter and cross – sectional area reduction and weight decreased. The effect of coating increased diameter and cross – sectional area and weight gain resulting from the varying thickness coated to reinforcing steel.

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

1.0 INTRODUCTION

Corrosion inhibitors are extensively used to delay the effect of corrosion on reinforcing steel embedded concrete and exposed to the harsh marine environment. Cement-added chemical substances, which, whilst used nicely, can lessen the effect of corrosion of steel reinforcement embedded in reinforced concrete [1]. Corrosion inhibitors create an impervious membrane on the steel surface that resists the reactions of anodic or cathodic on the metal. Corrosion assumes in many forms and its results occur when there is a chemical reaction between the reinforcement and its environment. Rust can be seen as the product of corrosion which results in the expansion in the size of reinforcing steel, creates pressure on the surrounding concrete, cracks in concrete, and reduction in the effective cross-sectional area of the bars, which in turns reduces and weakens the bond between reinforcement and concrete, which seriously affects the quality and service-life [2-4].

Investigated the bond strength of corrosive and exudates/resin coated specimens of reinforced concrete structures of 150mm x 150mm x150mm concrete cubes, immersed in accelerated media for 150 days with non-coated and coated reinforcements. Results revealed that non-corrosive and exudates/resin-coated specimens have high bond strength and low failure load, whereas corroded specimens recorded higher failure load on lower load application [5].

Experimentally investigated the effect of corrosion on adhesive strength and development length. Different degrees of corrosion are used to corrode reinforcement; samples of concrete slabs with reinforcing bars were used to assess the effect of corrosion rates on joint stresses and length of development of flexural stress elements. It was concluded that the average bond stress increased before the corrosion rate reached 2% and then decreased after the 2% corrosion rate [6].

Investigated the effect of corrosion on the bond between reinforcing steel and concrete in a series of tests on 14 samples for cylinder elongation. Studies were carried out for seven different corrosion rates, ranging from no corrosion to extensive corrosion, with 9 mm longitudinal cracks caused by destructive stresses due to the volumetric expansion of corrosion products. It was stated that bond strength lost by 9% resulting from weight loss of 4% due to corrosion effects that affected the surrounding concrete and reinforcing steel. The width of these transverse cracks increases with the degree of corrosion and means less bond between the reinforcing steel and the concrete [7].

Studied the premature and reduced service life and durability of reinforced concrete and attributed it to the corrosion effect on the reduction of bond strength between steel and concrete. Obtained experimental results showed decreased percentile values against control and exudates/resins coated members. In comparison, obtained values of corroded specimens decrease while non-corroded and exudates/resins coated members increases, these indications clearly showed the potential of acacia senegal exudates/resins in coated activities of reinforcing steel. Entire results showed higher values of pullout bond strength and low failure load in control and coated to corroded specimens [8].

Assessed the corrosion rate of reinforcement as a function of the adhesive properties between concrete and reinforcement. Tensile tests were carried out and evaluated to determine the effect of reinforcing corrosion on the bond behavior between corroded reinforcement and concrete. The reinforcing strip is corroded within the specimen by an accelerated corrosion process to draw it to the desired size. Tensile tests were carried out on samples with and without reinforcement. Load behavior in relation to end free shear is examined. Finite element analysis was also performed based on the download test results. It has been shown that the maximum bond strength and bond stiffness decrease proportionally with increasing corrosion rate. The equations for calculating the maximum bond strength and bond stiffness for finite element verification of reinforced concrete elements with corroded reinforcement are obtained from the test [9].

Evaluated the effect of non-coated and exudate/resin coating on the bond strength parameters of reinforced concrete structures under a harsh corrosive environment. The results of the average failure bond load are 16. 019% percent difference of control and coating. Relatively, corroded members showed lower failure load and bond strength properties for the coated and controlled samples. High values of the failure load, bond strength, and pull-out bond tests of the maximum slips of the exudates/resin coating samples are recorded on the depleted samples [10].

Confirmed that separation from the concrete environment is the result of the effect of the rib loading, which creates a destructive force, the resulting compressive force exerted by the ribs on the concrete inclined to the axis of the beam. The ring tension in the concrete cover around the beam is created by the radial component of the applied force. As soon as the tensile strength of the rings is exceeded during the development of the bonding effect, damage to the gap occurs due to the destruction of the concrete shell around the reinforcement. When the specific containment is sufficient to compensate for the force created by the connection [11].

Found that the displacement of the rod relative to the concrete (slip) consisted of the bending of the cornea and the movement caused by the breaking of the concrete in front of the ribs. Cracking occurs after the hoop stress exceeds the tensile strength of the restraining effect. Depending on the crack formation, the area around the reinforcement with cracked concrete tends to be plastic, while the rest of the cracked concrete remains elastic. The plastic area continues to expand radially as the crack spreads [12].

Investigated the effect of corrosion inhibitors on reinforced steel coated and embedded in concrete members and underwent rapid corrosion accelerated process to determine experimentally steel failure bond strength for 150 days. Overall results showed high values of control drag-binding strength and the exudates/adhesive coated members as against corrugated samples [13].

Investigated the strength of the bond between the concrete and the reinforcement elasticity due to the effect of the reduction of the steel reinforcement on the saltwater presence. Artocarpus altilis exudates/resins extract enhanced reinforcing steel by 150μm, 300μm, and 450μm thickness and non-coated were placed in concrete and saturated in sodium chloride for 150 days. Comparable results showed that the values of the applied load are reduced in non-coated (corroded) and coated samples increased. The overall results showed high values of the strength of the controlled binding bonds and the coating exudates/resins over corroded samples due to fibre and diameter reduction from the effect of corrosion [14].

Explored the impact of olibanum exudates/resins in reinforcing steel corrosion in coastal zones under the influence of saltwater on concrete structures. Non-coated and exudates / resin-coated steel were embedded in concrete cubes and pooled in a corrosive medium to evaluate the effects of corrosion. Tests have shown that the values of non-coated samples have deteriorated due to reduced corrosion attacks. The average percentage bond strength load is 33.13% and the coating members are 45.66% and 71.84% compared to the control differential. The mean maximum slip values were 0.083 mm and mean 33.87% and 75.30%, respectively, compared to the control and coated 25.30%. Experimental results show that reduced samples have lower bond strength and higher failure bond load and lower maximum slip, while exudates/resin coated samples have lower test specimens and higher percentage values compared to corrosive samples [15].

2.0 Test program

This research involves the direct application of exudates/resins tapped from plants known as inhibitors, which are coated in steel reinforcement, embedded in concrete structures and experimentally tested in the laboratory. The work is aimed at utilizing locally available eco-friendly inorganic extracts of tree extrudes as anti-corrosive materials to curb the ravaging effect of corrosion to reinforcing steel. The test specimen reflects severe acid conditions that represented sea salt concentration conditions in reinforced concrete, cubes with embedded reinforcing steel were wholly submerged and specimens maintained in pooling tank for corrosion accelerated process. Samples were designed with 36 numbers of reinforced concrete cubes of 150 mm × 150 mm × 150 mm, with a single strip of 12 mm diameter embedded centrally for pullout bond testing for controlled, non-coated, and coated samples and all immersed in sodium chloride (NaCl) for 360 days after initial 28 days curing process. Samples of acidic media were monthly renewed and samples monitored for effective performance.

2.1 Materials and methods for testing

2.1.1 Aggregates

Fine and coarse aggregates were purchased. Both met the requirements of [16]

2.1.2 Cement

Portland lime cement grade 42.5 is the most common type of cement in the Nigerian market. It was used for all concrete mixtures in this trial. Meets the requirements of Cement [17]

2.1.3 Water

The water samples were clean and free from contaminants. Freshwater was obtained from the tap at the Department of Civil Engineering Laboratory, Kenule Beason Polytechnic, Bori, Rivers State. Water [18] met the requirements

2.1.4 Structural steel reinforcement

Reinforcements are obtained directly from the market at Port Harcourt, [19]

2.1.5 Corrosion Inhibitors (Resins / Exudates) Anogeissus latifolia (Combretaceae)

The ghatty gummy sticky exudates were obtained from tree trunk of Anogeissus leiocarpus from Benue State, in Achaba, Ebukodo and Ologba villages of Apa Local Government Area.

2.2 Experimental procedures

Corrosion acceleration test was performed on high yielding steel (reinforcement) with a diameter of 12 mm and a length of 650 mm, the sample surface was treated with a wire brush and the samples were thoroughly cleaned with water, washed with acetone, and then polished (Anogeissus latifolia (Combretaceae) exudates/resins), corrosion Pastes with 150µm, 300µm, 450µm, and 600µm coatings before testing. The test cubes were cast with a 150 mm x 150 mm x 150 mm metal mold and demolished after 72 hours. Samples were treated at room temperature in tanks for an initial curing period of 28 days, followed by a rapid acceleration corrosion test and a trial procedure that allowed 360 days of regular monthly monitoring. For corrosion-accelerated specimens the cubes were taken approximately every 3 months at 90 days, 180 days, 270 days, and 360 days, and the gain of failure bond loads, binding strength, maximum slip, re-cross-sectional area reduction/increase, and weight loss/steel reinforcement.

2.3 Accelerated corrosion setting and testing method

In real and natural phenomena, the manifestation 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 to unravel by the introduction of accelerated media representing the saltwater of the sea area. The samples were immersed in a 5% NaCl solution for 360 days to test the surface and mechanical properties of the transitions and effects and to test both the unbound and the exudate/resin coated samples.

2.4 Pull-out Bond Strength Test

The tensile-bond strength test of concrete cubes was carried out on 12 samples each with a total of 36 samples of filtered water, non-coating and coated members, and subjected to a 50kN Universal Testing Machine according to 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 Reinforcing Bars

Yield strength and Ultimate tensile strengths of 12 mm diameter, non-coated and coated reinforcing concrete cube members subjected to the universal testing machine for maximum failure to direct tension.

3.1 TEST RESULTS AND DISCUSSION

The results of the laboratory analytical studies using anogeissus latifolia (combretaceae) exudates/resin obtained from plant trunk as an inhibitive material against corrosion of reinforcing steel embedded in concrete was studied with its application as coating material. This study is aimed at investigating the potential use of eco-friendly material of organic classes to curb the menace of corrosion effect on reinforcing embedded in concrete structures and exposed to corrosive media.

Tables 3.1, 3.3 and 3.3 are the data obtained from the results of 36 concrete cubes; 12 controlled, 12 uncoated (corroded) and 12 exudates / resins coated cured for 360 days under freshwater and induced corrosion accelerated process as detailed in 2.2 Experimental procedures. Tables 3.4 and 3.5 are the summarized results from tables 3.1, 3.2 and 3.3 of average and percentile values as plotted in figures 1 -6b and discussed in subtitles 3.3 and 3.4of failure bond load, bond strength, maximum slip Mechanical properties of reinforcing bars.

Table 3.1: Results of Pull-out Bond Strength Test (τu) (MPa) of Non-corroded Control Cube Specimens

Sample Numbers	**ALC**	**ALC 1**	**ALC 2**	**ALC 3**	**ALC 4**	**ALC 5**	**ALC 6**	**ALC 7**	**ALC 8**	**ALC 9**	**ALC10**	**ALC11**
	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)	28.125	27.647	27.671	28.750	27.475	28.483	28.180	27.297	28.499	27.614	28.658	28.118
Bond strength (MPa)	8.407	8.640	7.940	7.726	8.440	8.757	9.095	9.471	8.647	8.667	9.587	9.738
Max. slip (mm)	0.101	0.107	0.101	0.101	0.116	1.000	0.104	0.105	0.109	0.116	0.119	0.105
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)	11.956	11.947	11.957	11.956	11.947	11.966	11.952	11.941	11.953	11.955	11.943	11.953
Rebar Diamete r- at 28 Days Nominal(mm)	11.956	11.947	11.957	11.956	11.947	11.966	11.952	11.941	11.953	11.955	11.943	11.953
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)	0.587	0.584	0.590	0.584	0.586	0.586	0.585	0.593	0.583	0.584	0.589	0.585
Rebar Weights- at 28 Days Nominal(Kg)	0.587	0.584	0.590	0.584	0.586	0.586	0.585	0.593	0.583	0.584	0.589	0.585
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) of Corroded Concrete Cube Specimens

Samplin g and Durations	**Samples 1 (90 days)**			**Samples 2 (180 Days)**			**Samples 3 (270 Days)**			**Samples 4 (360 Days)**		
Failure Bond Loads (kN)	16.980	16.293	16.583	16.025	15.273	16.141	15.720	16.028	15.726	16.961	15.840	16.574
Bond strength (MPa)	7.181	7.191	6.955	7.178	6.944	6.917	6.715	7.404	6.379	6.867	6.714	7.027
Max. slip (mm)	0.080	0.083	0.084	0.093	0.084	0.087	0.086	0.076	0.082	0.083	0.084	0.075
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)	11.857	11.848	11.850	11.848	11.840	11.868	11.855	11.844	11.856	11.848	11.846	11.856
Cross- section Area Reduction/Increase (Diameter, mm)	0.042	0.042	0.050	0.050	0.049	0.040	0.044	0.044	0.042	0.048	0.043	0.043
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)	0.513	0.510	0.515	0.509	0.512	0.512	0.511	0.518	0.509	0.510	0.515	0.511
Weight Loss /Gain of Steel (Kg)	0.046	0.050	0.045	0.048	0.049	0.049	0.050	0.042	0.051	0.053	0.044	0.048

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

Sampling 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)	28.697	26.608	27.172	27.768	28.583	28.284	28.808	28.625	28.690	30.501	29.625	29.827
Bond strength (MPa)	10.031	10.923	9.421	10.351	10.724	11.647	11.741	11.071	11.105	11.811	11.122	11.669
Max. slip (mm)	0.125	0.126	0.127	0.130	0.121	0.140	0.123	0.127	0.135	0.132	0.137	0.135
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)	11.957	11.948	11.958	11.957	11.948	11.967	11.958	11.947	11.957	11.954	11.948	11.958
Rebar Diameter- After Corrosion(mm)	12.007	11.999	12.008	12.007	11.998	12.017	12.008	11.997	12.007	12.004	11.998	12.008
Cross- section Area Reduction/Increase (Diameter, mm)	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Rebar Weights- Before Test(Kg)	0.591	0.592	0.592	0.590	0.593	0.593	0.593	0.593	0.592	0.595	0.591	0.591
Rebar Weights- After Corrosion(Kg)	0.661	0.662	0.662	0.660	0.662	0.662	0.663	0.663	0.662	0.664	0.661	0.661
Weight Loss /Gain of Steel (Kg)	0.070	0.070	0.070	0.067	0.068	0.070	0.070	0.070	0.069	0.073	0.070	0.070

Table 3.4: Results of Average Pull-out Bond Strength Test (τu) (MPa) of Control, Corroded and Exudates/ 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)	27.814	28.236	27.992	28.130	16.619	15.813	15.825	16.458	27.492	28.212	28.707	29.984
Bond strength (MPa)	8.329	8.308	9.071	9.331	7.109	7.013	6.832	6.869	10.125	10.908	11.306	11.534
Max. slip (mm)	0.103	0.106	0.106	0.113	0.082	0.088	0.082	0.081	0.126	0.130	0.128	0.135
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)	11.953	11.956	11.949	11.950	11.896	11.899	11.895	11.895	11.954	11.957	11.954	11.953
Rebar Diameter- After Corrosion(mm)	11.953	11.956	11.949	11.950	11.851	11.852	11.852	11.850	12.004	12.007	12.004	12.003
Cross- section Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	0.044	0.046	0.044	0.045	0.050	0.050	0.050	0.050
Rebar Weights- Before Test(Kg)	0.587	0.585	0.587	0.586	0.559	0.559	0.560	0.560	0.592	0.592	0.593	0.592
Rebar Weights- After Corrosion(Kg)	0.587	0.585	0.587	0.586	0.512	0.511	0.513	0.512	0.661	0.661	0.662	0.662
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	0.047	0.049	0.048	0.048	0.070	0.068	0.070	0.071

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

	Non-corroded Control Cube				**Corroded Cube Specimens**				**Exudate / Resin steel bar coated specimens**			
Failure load (KN)	67.367	78.562	76.890	70.918	-39.551	-43.949	-44.877	-45.110	65.430	78.410	81.411	82.183
Bond strength (MPa)	17.166	18.467	32.770	35.831	-29.789	-35.708	-39.567	-40.442	42.428	55.540	65.472	67.905
Max. slip (mm)	24.859	361.652	29.509	40.163	-34.593	-32.452	-36.285	-40.028	52.889	48.043	56.948	66.743
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)	0.483	0.483	0.450	0.469	0.491	0.491	0.490	0.490	0.493	0.494	0.493	0.493
Rebar Diameter- After Corrosion(mm)	0.859	0.876	0.820	0.848	-1.275	-1.293	-1.268	-1.278	1.292	1.310	1.285	1.295
Cross- section Area Reduction/Increase (Diameter, mm)	0.000	0.000	0.000	0.000	-11.442	-7.414	-12.993	-10.637	12.920	8.008	14.934	11.903
Rebar Weights- Before Test(Kg)	4.909	4.612	4.726	4.684	5.471	5.471	-.462	5.467	5.787	5.787	5.777	5.783
Rebar Weights- After Corrosion(Kg)	14.531	14.578	14.530	14.554	-22.519	-22.769	-22.632	-22.691	29.063	29.482	29.252	29.352
Weight Loss /Gain of Steel (Kg)	0.000	0.000	0.000	0.000	-32.435	-28.567	-31.038	-31.917	48.006	39.991	45.006	46.880

3.2 Failure load, Bond Strength, and Maximum slip

Surface and internal cracks usually develop in the concrete and support corrosion reinforcement. This in turn leads to an excessive reduction in bond strength, which is characterized by the adhesion and slip resistance between the steel and the encasing concrete. In the end, the serviceability and durability of reinforced concrete are significantly reduced and potentially lead to the collapse of the structure. Therefore, the study of the development of adhesive strength and corrosion resistance of reinforcement remains a popular research interest [20]. The data presented in tables 3.1 – 3.3 enumerated the laboratory test results obtained from the study of pullout bond strength test of 36 concrete cubes subdivided into three of controlled, corroded and exudates/resin coated samples. The obtained results from 3.1 3.2 and 3.3 are summarized into average and percentile average values as to determine minimum and maximum values as well as the differences among the three concrete cubes samples. Obtained minimum and maximum calculated average and percentile originated results of failure bond load are controlled 27.814kN and 28.236kN (67.367% and 78.562%), corroded 15.813kN and 16.619kN (-39.551% and -45.11%), coated 27.492kN and 29.984kN (65.43% and 82.183%). Bond strength values for controlled are 8.308MPa and 9.331MPa (17.166% and 35.831%), corroded 6.832MPa and 7.109MPa (-29.789% and -40.442%), Coated are 10.125MPa and 11.534MPa (42.428% and 67.905%). Results of maximum slip are controlled are 0.103mm and 0.106mm (24.859% and 61.652%), corroded 0.081mm and 0.088mm (-40.028% and -32.452%), coated 0.126mm and 0.135mm (48.043% and 66.743%). The obtained values from tables 3.1 -3.5 are graphically plotted in figures 1-6b against corresponding parameters to explained the behavioral and the characterized properties of the tested concrete cubes subjected to failure in 50KN Instron Universal Testing machine. From the computed results, the maximum obtained value of corroded sample is -39.551% as against 78.562% and 82.183% of controlled and coated samples respectively. The results showed decreased failure bond load in corroded sample and an increased in coated judging from controlled sample as a standard for comparison. The results of bond strength maximum obtained values are corroded -29.789% against controlled 35.831% and 67.905%, enumerative results showed low and decreased bond strength of corroded samples resulted from the effect of corrosion damaged to the reinforcing surface and fibre. Higher bond strength obtained from coated samples resulting from the gummy and sticky exudates/resin that formed higher bonding with the rib. Obtained maximum slip values are corroded 32.452% against controlled 61.652% and coated 66.743%. Results of slippage in controlled and coated samples showed higher values to failure as against lower slippage in coated. Summarized results showed the effective and potency in the used of Anogeissus latifolia exudates/resin in curbing corrosion attack on reinforcing embedded in concrete and exposed to corrosive media as confirmed in the studies of [8, 10, 13, 15]. The effect of corrosion from the results weakened the perfect relationship (bond) characteristics between concrete and reinforcing steel and these factors shortened the designed life span [2-4].

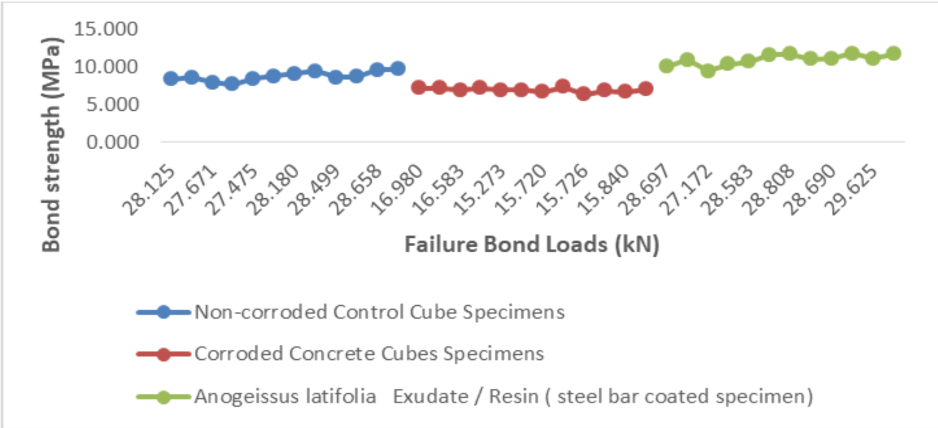

Figure 1: Failure Bond loads versus Bond Strengths

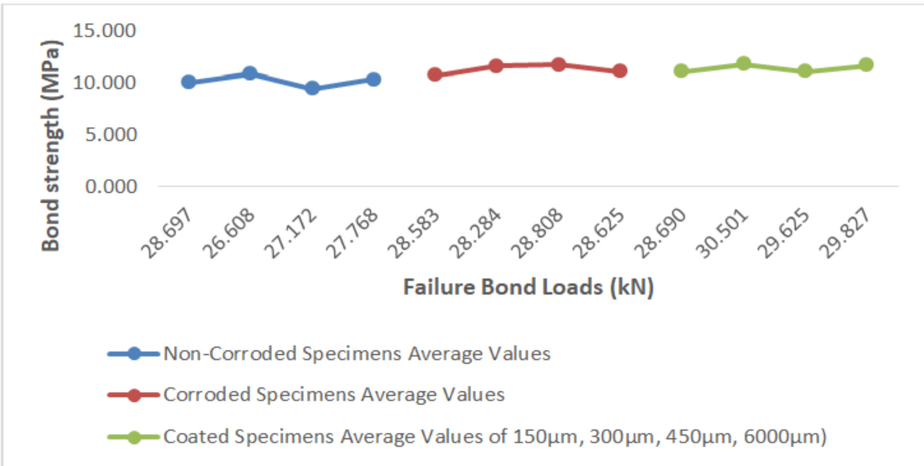

Figure 1a: Average Failure Bond loads versus Bond Strengths

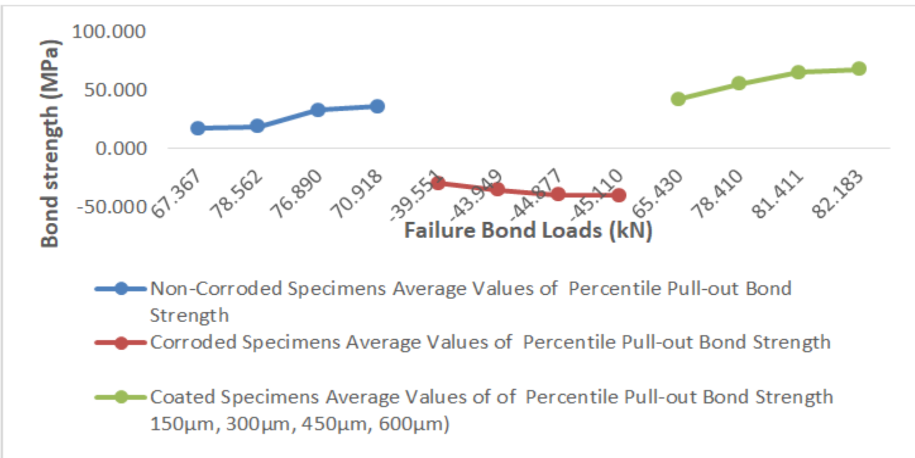

Figure 1b: Average Percentile Failure Bond loads versus Bond Strengths

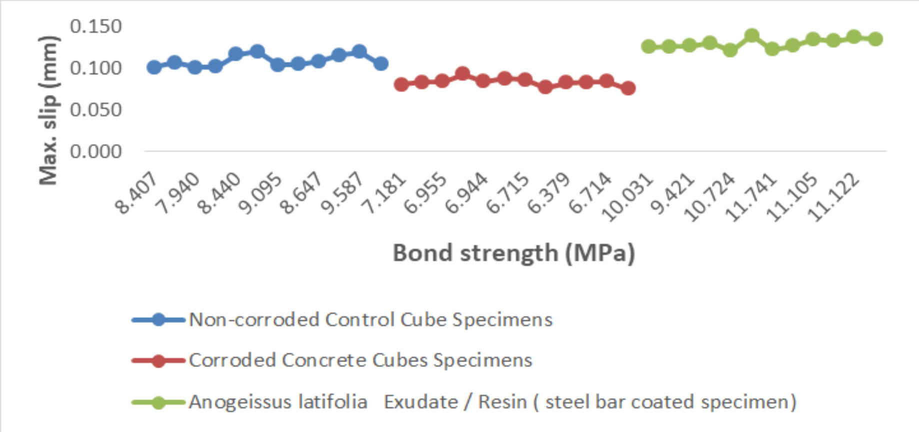

Figure 2: Bond Strengths versus Maximum Slip

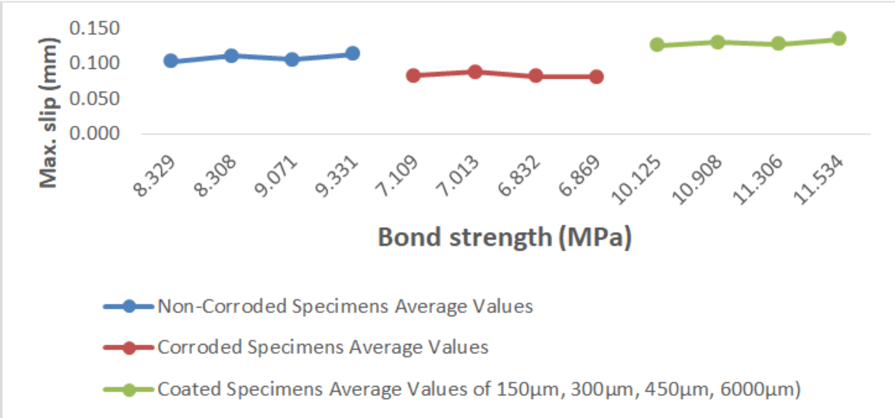

Figure 2a: Average Bond Strengths versus Maximum Slip

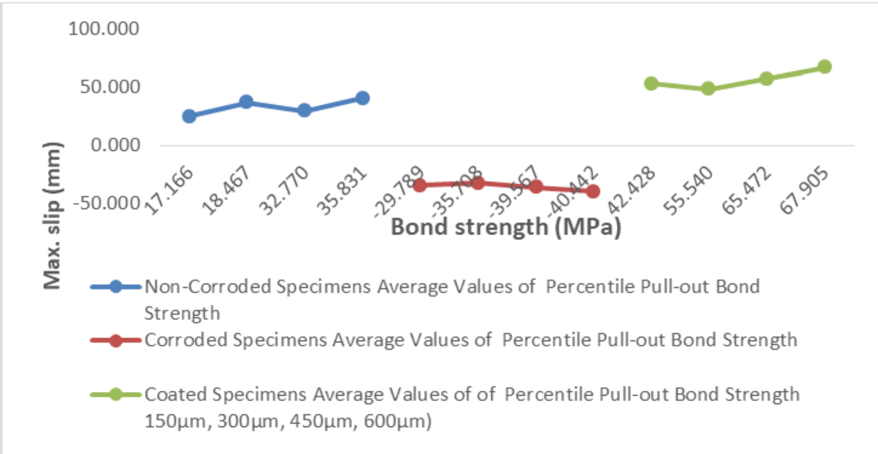

Figure 2b: Average Percentile Bond Strengths versus Maximum Slip

3.3 Mechanical Properties of Reinforcing Bars

Results presented in tables 3.1 – 3.3 are the laboratory results generated from pullout bond test from 36 randomly selected concrete cubes of controlled, corroded and coated subjected to failure state in as detailed in subtitled 3.2 for failure bond load, bond strength and maximum slip. Summarized results from into tables 3.4 -3.5 and represented in figures 3-6b enumerated the characterized results of summarized minimum and maximum obtained values of mechanical properties of reinforcing steel (controlled, corroded and coated) as detailed in the experimental procedures in subtitled 2.2.

The summarized minimum and maximum values obtained from tables 3.4 and 3.5, showed the nominal diameter steel bars of all samples at 100%, and the minimum and maximum diameters of the steel bars measured before the test are within the range of 11.949 mm and 11.956mm (0.45% and 0.483%).

The diameter after corrosion test of uncoated (corroded) are 11.85mm and 11.852mm (-1.293% and -1.268%), for coated are 12.003mm and 12.007mm (1.285% and 1.31%).

The results of cross - sectional area for uncoated (corroded) are 0.044mm and 0.046mm (-7.414% and -12.993%), for coated are 0.050mm and 0.050mm (8.008% and 14.934%). The result for rebar weight before test for all samples are 0.585Kg and 0.587Kg (4.303% and 5.797%), weight after corrosion test for corroded are for 0.511Kg and 0.513Kg (-22.769% and -22.51%), coated are 0.661Kg and 0.662Kg (29.063% and 29.482%), and weight loss /gain of steel are corroded 0.047Kg and 0.049Kg (-32.435% and -28.567%) and coated values are 0.068Kg and 0.071Kg (39.991% and 48.006%).

Results indicated that the diameter of uncoated decreased by maximum value of -1.293% and coated increased by 1.31 %, results showed that reduction is attributed to the effect of corrosion on the surface modification through the formation of pits and unusual expansion, also similar factor is applicable on the cross - sectional area, corroded has maximum reduction value of (-7.414% and coated increased by 14.934%, weight loss and gain are corroded -28.567% decreased (loss) and coated 48.006% increase (gain). Summarized results showed the effect of affected the overall mechanical properties of reinforcing steel thereby reducing bond characteristics of steel and concrete by creating stresses in the surroundings and further weakened pullout bond resulting into diameter and cross – sectional area reduction and weight decreased as confirmed in the studies of [8, 10, 13, 15]. The effect of coating increased diameter and cross – sectional area and weight gain resulting from the varying thickness coated to reinforcing steel.

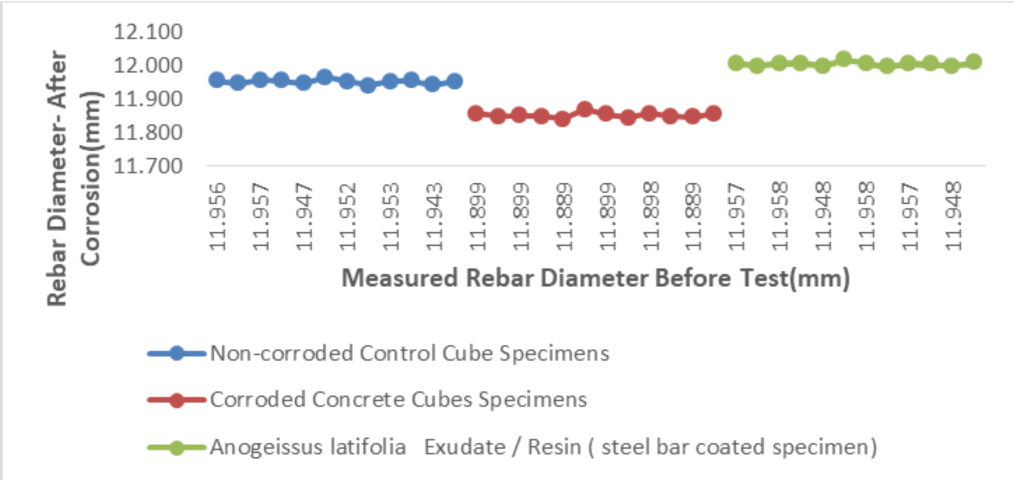

Figure 3: Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion)

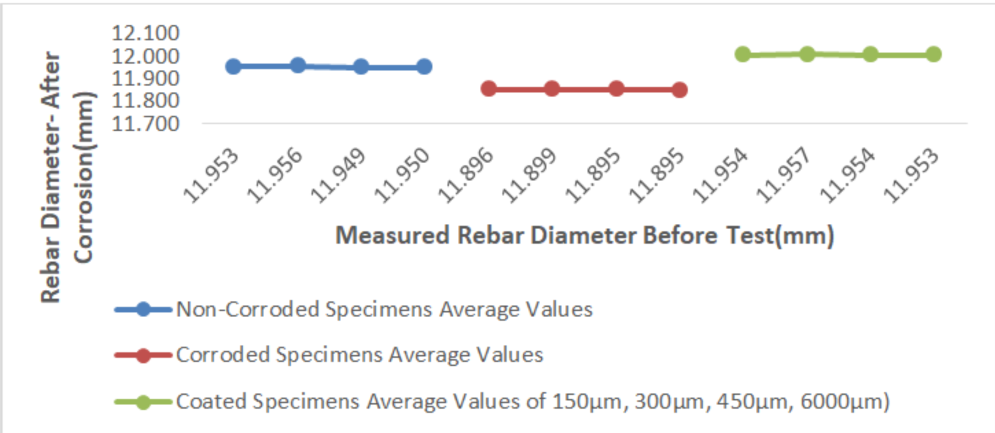

Figure 3a: Average Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion

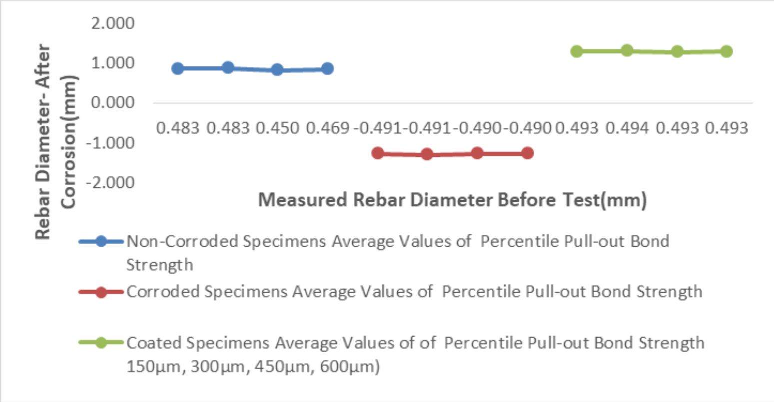

Figure 3b: Average Percentile Measured (Rebar Diameter Before Test vs Rebar Diameter- After Corrosion)

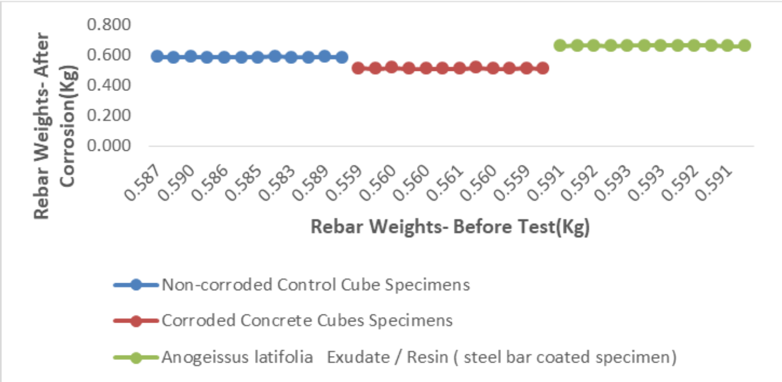

Figure 4: Average Rebar Diameter- After Corrosion versus Cross – Sectional Area Reduction/Increase

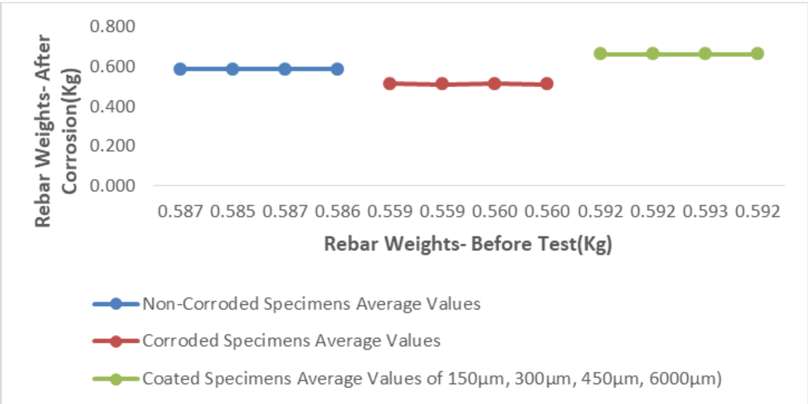

Figure 4a: Average percentile Rebar Diameter- After Corrosion versus Cross - sectional Area Reduction/Increase

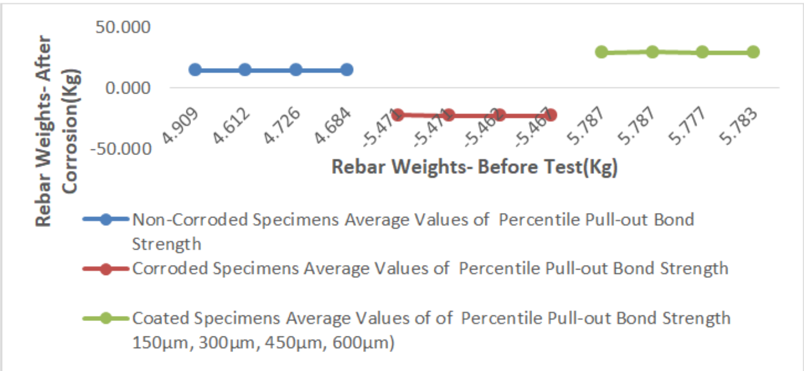

Figure 4b: Rebar Weights- Before Test versus Rebar Weights- After Corrosion

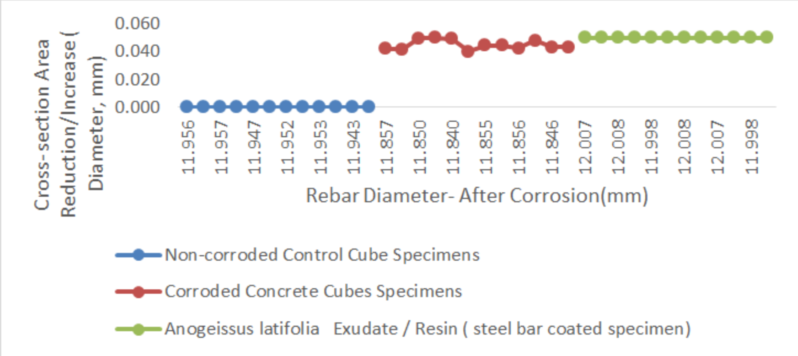

Figure 5: Rebar Weights- Before Test versus Rebar Weights- After Corrosion

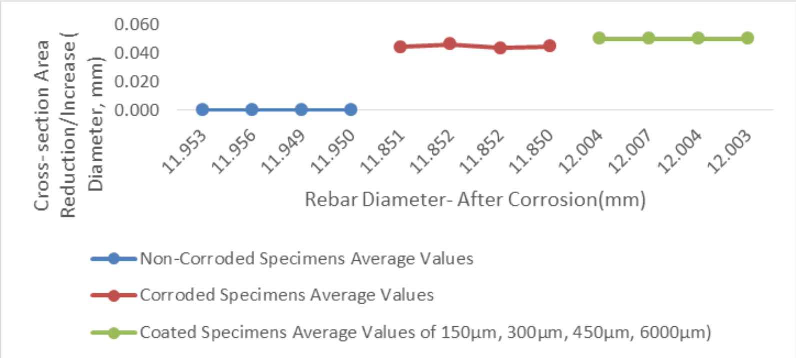

Figure 5a: Average Rebar Weights- Before Test versus Rebar Weights- After Corrosion

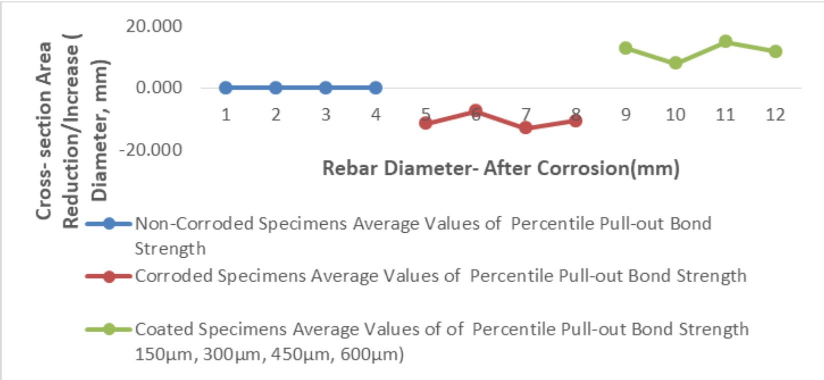

Figure 5b: Average Percentile Rebar Weights- Before Test versus Rebar Weights- After Corrosion

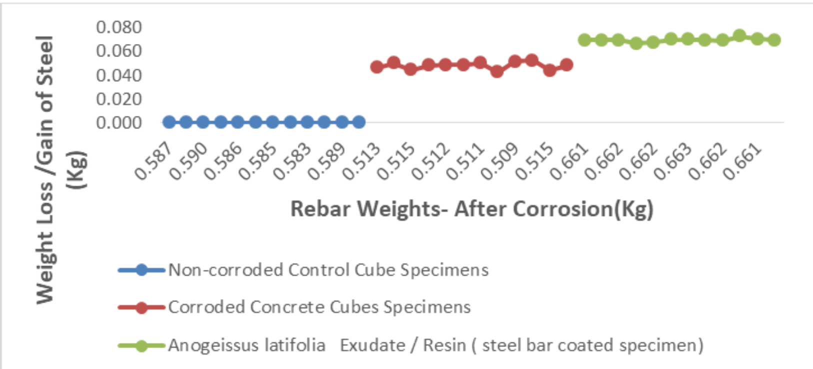

Figure 6: Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

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

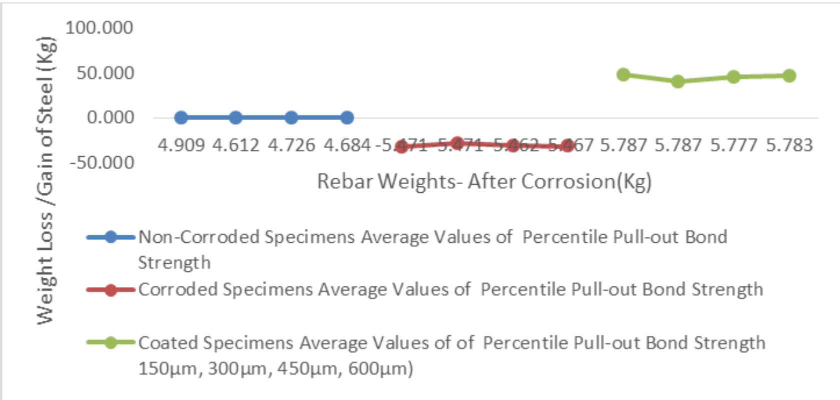

Figure 6b: Average percentile Rebar Weights- After Corrosion versus Weight Loss /Gain of Steel

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

Comparatively, from the data in tables 3.1, 3.2 and 3.3 and in figures 3, 4,5 and 6 for 12 controlled samples pooled in a freshwater tank for 360 days, 12 uncoated and 12 coated pooled in 5% sodium chloride (NaCl) aqueous solutions for 360 days ad described in 3.1 – 3.3 and summarized into tables 3.4 – 3.5 and figures 3a,3b,4a,4b,5a,5b, 6a and 6b for average and percentile values for failure bond loads, bond strength and maximum slip , cross – sectional reduction / increase, diameter of rebar before /after corrosion, weight loss/gain. The results obtained in comparison showed that the failure bond load for controlled and coated maintained close range of values while corroded members yielded on lower load application, similar factors are on bond strength and maximum slip. On the mechanical properties of the reinforcing steel, the effect of corrosion on the reinforcing steel exhibited cross – section reduction on the diameter of the bar as compared to nominal diameter before test, weight loss also notice while and coated members possess cross -sectional area increased, diameter increase and weight increase as compared to nominal rebar, these increased resulted from the coating materials varying thicknesses. It can be concluded that the studied exudate/resin showed potency of inhibitory characteristics against corrosion attack and can be used as an inhibitor to corrosion.

4.0 CONCLUSION

In the experiment, the results obtained are drawn as:

i. The exudates/resin of Anogeissus latifolia (Combretaceae) an inhibitive characteristic to reinforcing steel
ii. Perfect bonding notice coated samples while uncoated has weakened interaction between concrete and steel
iii. Lower failure bond load, bond strength, and maximum slip are the traces witnessed in corroded samples
iv. The coated and control sample have higher values of bond load and bond strength.
v. Loss of weight and cross – section not notice in corroded

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