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Bond Strength Characteristics of Reinforcements Embedded in Reinforced Concrete Structures in Corrosive Marine Environment

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ABSTRACT: *Failure effects from deteriorative structural members attacked by harsh marine salt water was studied to curb the strength reduction in the mechanical properties of rebar embedded in concrete and exposed to chloride media. The researched work examined the effect of natural exudates/resins of trees as corrosion inhibitors against corroded specimens. Steel coated exudate/resin members embedded in concrete and immersed in accelerated chloride media for 150 days were studied and obtained average failure bond load of corroded values are 17.7333kN, 17.7666kN and 17.7066kN, summed to 17.7355kN represented -38.0402% against 61.3958% and 63.3064% percentile difference of control and coated exudates/resin member. Bond strength load corroded values are 5.66333kN, 5.84333kN, 5.66666kN summed to 5.7244kN, represented percentile value of -41.4676% against 70.846% 109.4335% percentile difference control and coated and maximum slip average values of corroded are 0.0702mm, 0.07753mm, 0.07386mm, summed to 0.07387mm, represented -37.7066% against 60.5292 and 186.3261% percentile difference of control and coated. Comparatively, results of corroded specimens decreased while control and exudates/resins coated specimens increased, these resulted from adhesive properties of controlled specimens ribbed reinforcement and exudates coated specimens. Entire results showed higher values of pullout bond strength in control and exudates/resin coated to corroded specimens.*

KEY WORDS: *Corrosion, Corrosion inhibitors, Pull-out Bond Strength, Concrete and Steel Reinforcement*

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I. INTRODUCTION

The deteriorations and failures of reinforced concrete structures in the coastal marine of severe environment are caused by corrosion of reinforcing steel. The corrosion of reinforcement embedded in concrete reduces the service, life span and the intended purpose, its integrity and capacity of the structures. Chloride induced corrosion of reinforced concrete structures built within the marine environment are at risk due to the presence of high chloride concentrations and humid or saturated conditions. Corrosion is one of the main causes for the limited durability of reinforced concrete [1]. The essence of bonding in reinforced concrete member is the mechanical interlocks between concrete and reinforcing as well as the deformity characteristic in the ribs of the reinforcement.

[2] Developed the bond zone element contact surface between the steel bar and concrete, along with the surrounding concrete in immediate proximity, was modelled by a material law that represents the special properties of the bond-zone [3]. Bond strength are influenced by bar geometries, concrete properties, the presence of confinement around the bar, as well as surface conditions of the bar [4] .

[5] Studied on the bond behavior of corroded reinforcement bars and have found that when the mass loss of the reinforcement due to corrosion reaches approximately 2%, concrete cracks along the bar. A small

amount of corrosion increases both the bond strength and bond stiffness, but the slip at failure decreases considerably. However, they stated that when the mass loss exceeds 2%, bond stiffness decreases considerably.

[6] Investigated the effect of the diameter of the steel bar, corrosion degrees resulting from cover thicknesses of mild steel bars embedded in mortar. They found that there is a significant effect of rebar diameter, cover thickness, and specimen size on the corrosion intensity.

[7] Studied and evaluated the effect of corrosion on bond existing between steel and concrete interface of corroded and resins / exudates coated reinforcement with ficus glumosa extracts from trees. Experimental samples were subjected to tensile and pullout bond strength and obtained results indicated failure load, bond strength and maximum slip values of coated were higher by 33.50%, 62.40%, 84.20%, non- corroded by 27.08%, 55.90% and 47.14% respectively. For corroded cube concrete members, the values were lower by 21.30%, 38.80% and 32.00% on failure load, bond strength and maximum slip to those ones obtained by Control and coated members. The entire results showed good bonding characteristic and effectiveness in the use of ficus glumosa resins / exudates as protective materials against corrosion.

[8] investigated the primary causes resulting from short service life, integrity and capacity of reinforced concrete structures in the marine environment of saline origin is corrosion. Results gotten showed reduction of failure bond load bond strength and maximum slip of corroded specimens to 21.30%, 38.80% and 32.00% respectively, while coated specimens 51.69%, 66.90%, 74.65%, for Control specimen, 27.08%, 55.90% and 47.14%. Entire results showed lower percentages in corroded and higher in coated members. This justifies the effect of corrosion on the strength capacity of corroded and coated members.

[9] Investigated the corrosion of steel reinforcement in concrete is one of the principal factor that caused the splitting failures that occurred between steel and concrete, the used of epoxy, resin/exudates has been introduced to curb this trend encountered by reinforced structures built within the saline environment. Results obtained showed presence of corrosion in uncoated members. Failure load of pullout bond and maximum slip were 21.30%, 36.80% and 32.00% for corroded members, 36.47%, 64.00% and 49.30% for coated members respectively. The values of corroded members were lower compared to coated members. Results showed that resins / exudates enhances strength to reinforcement and serves as protective coat against corrosion.

[10] indicated that the cover over reinforcement has the most significant effect on the extent of rebar corrosion.

[11] Investigated the effect of corroded and inhibited reinforcement on the stress generated on pullout bond splitting of control, corroded and resins / exudates paste coated steel bar. In comparison, failure loads of Symphonia globulifera linn, Ficus glumosa, Acardium occidentale l are 36.47%, 32.50% and 29.59% against 21.30% corroded, bond strength are 64.00%, 62.40%, 66.90 against 38.88% and maximum slip are 89.30%, 84.20%, 74.65% against 32.00% corroded. Entire results showed values increased in coated compared to corroded specimens resulted to adhesion properties from the resins / exudates also enhances strength to reinforcement and serves as protective coat against corrosion.

[12] This study investigate the effect of reinforcement corrosion and inhibitor on bond and pull out capacity of degraded and inhibited steel reinforcement and monitor significant changes on the surface conditions of steel reinforcing bars embedded in concrete.

[13] Studied the bond strength exhibited by reinforcement embedded in concrete is controlled by corrosion effects. Results showed that uncoated specimens corrosion potential with signs associated with cracks, spalling and pitting. Pullout bond strength results of failure load, bond strength and maximum slip for dacryodes edulis are 75.25%, 85.30%, 97.80%, moringa oleifera lam; 64.90%, 66.39%, 85.57%, magnifera indica; 36.49%, 66.30% and 85.57%, for Control, 27.08%, 5590% and 47.14% while corroded are 21.30%, 36.80% and 32.00%. The entire results showed lower values in corroded specimens as compared to coated specimens, coated members showed higher bonding characteristics variance from dacryodes edulis (highest), moringa oleifera lam (higher) and magnifera indica (high) and coated serves as resistance and protective membrane towards corrosion effects.

II. MATERIALS AND METHODS FOR EXPERIMENT

The investigative work involves the layering / coating of exudates / resins paste extracts known as corrosion inhibitors to the surface of reinforcing steel with the aim and objective of effectively using locally available eco-friendly inorganic inhibitors as anti-corrosive materials in embedded reinforcement in concrete cubes, exposed to harshly and severed marine environment. Designed concrete cube samples of 150 mm × 150 mm × 150 mm with an insertion single ribbed 12mm diameter bar for pullout bond experimental test. Simulated set-up was done with the immersion cubes into Sodium Chloride (NaCl) solution at 5% to water ratio of a liter as to achieve the rapid corrosive media.

Aggregates
Rivers Sand (fine aggregate) and coarse aggregates were all gotten from the market and all met the requirements of [14]

Cement
Cement for the experimental work is grade 42.5 Portland limestone and it met requirements [15]

Water
Clean tap water was obtained from the Civil Engineering Department Laboratory, Kenule Beeson Polytechnic, Bori, and Rivers State. The water met the requirements of [16].

Structural Steel Reinforcement
12mm diameter bar was purchased from the market and was tested the requirements of [17]

Corrosion Inhibitors (Resins / Exudates) Celtis zenkeri
Celtis zenkeri exudates / resins was purchased from local tappers and its of natural inorganic products

Sample preparation for reinforcement with coated resin/exudate
Test was carried with 12mm diameter high tensile steel with cut lengths of 550mm. Specimens were properly washed with acetone, brushed with hard metal sandpaper / wire brush and dried. Coating thicknesses of 150µm, 300µm and 450µm of exudates / resin pastes were directly applied on the rough surfaces of reinforcing steel bar, embedded centrally into concrete cubes of 150 mm × 150 mm × 150 mm, demolded after 72 hours and placed at room temperature for initial 28days with clean tap water. The real ideal corrosion test were conducted for 120 days with the first noticed cracks and pitting and was further examined for 30 days extension making 150 days corrosion test processes.

Accelerated Corrosion Set-Up and Testing Procedure
In real life and natural processes, corrosion procedure is slower and may take many years to show full manifestation. Electrochemical corrosion application and techniques was adopted to accelerate the corrosion of reinforcing steel bar embedded in concrete cubes specimen. Simulated laboratory acceleration was initiated to achieve corrosion processes within possible period with the tanking and partially immersion of concrete cubes through the introduction of 5% NaCl solution for duration of 150 days after initial 28 day cured as to examine the changes exhibited by reinforcing steel bar surface and mechanical properties

Pull-out Bond Strength Test
Testing was performed on 27 specimens of concrete cubes of 150 mm × 150 mm × 150 mm with a single embedded 550mm length of 12mm diameter rebar of controlled, corroded and inhibited specimens using Universal Testing Machine of capacity 50KN in accordance with BS EN 12390-2. Pullout bond test was conducted for 120days and 30 days extended period after first crack and pitting examination, this was done as to ascertain to effect of exudates / resins on the surface and mechanical properties and the signifance of locally available inorganic material to steel bars.

Tensile Strength of Reinforcing Bars
Tensile strength test was conducted using Universal Testing Machine and specimens of controlled, corroded and inhibited (coated) specimens were subjected to direct tension until failure; the yield, maximum and failure loads being recorded.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Tables 1, 2 and 3 are the detailed results of pullout bond strength test of failure bond load, bond strength and maximum slip obtained from 27 samples of control, corroded and celtis zenkeri exudates/ resins steel bar coated specimens paste on reinforcement embedded in concrete cubes member. Table 4 and 5 showed the results of average and summary pull-out bond strength values of failure load, bond strength and maximum slip of control, corroded and resins/exudates coated specimens. Figures 1 and 2 are the plots of entire failure bond load versus bond strength and bond strength versus maximum slip, while figures 3 and 4 are the plots of average failure bond load versus maximum slip obtained from tables 1, 2 and 3.

Control Concrete Cube Members
Results from tables 3.1, fused into 3.4 and 3.5 as presented in figures 3.1 – 3.4, are the average pullout out bond strength of failure load values of 28.1415kN, 29.0165kN, 28.7166kN, summed to 28.6245kN,

indicated 61.3958% percentile value, bond strength average values are 9.5352MPa, 9.925MPa and 9.926MPa, summed to 9.7896MPa and percentile value of 70.846%. Maximum slip average values are 0.1134666mm, 0.1224mm, and 0.1198mm summed to 0.1180mm, represented 60.5292% percentile values.

Corroded Concrete Cube Members

From table 2, fused into 4 and 5, presented in figures 1 – 4, average obtained failure bond load are 17.7333kN, 17.7666kN and 17.7066kN, summed to 17.7355kN represented -38.0402% against 61.3958% and 63.3064% percentile difference of control and coated exudates/resin member. Bond strength load are 5.66333kN, 5.84333kN, 5.66666kN summed to 5.7244kN, represented percentile value of -41.4676% against 70.846% 109.4335% percentile difference control and coated and maximum slip average values are 0.0702mm, 0.07753mm, 0.07386mm, summed to 0.07387mm, represented -37.7066% against 60.5292 and 186.3261% percentile difference of control and coated. Comparactively, results of corroded specimens decreased while control and exudates/resins coated specimens increased resulted from adhesive properties of controlled specimens ribbed reinforcement and exudates coated specimens

Celtis zenkeri exudates Steel Bar Coated Concrete Cube Members

Results from table 3 into 4 and 5, as shown in figures 1 – 4, obtained failure bond load average values are 28.0533kN, 29.3666kN, 29.473kN summed to 28.9633kN, represented 63.3064% against -38.0402% corroded percentile differences, bond strength average values are 11.611MPa, 11.750MPa, 12.60667MPa summed to 11.9888MPa, represented 109.4335% against -41.4676% and maximum slip values are 0.1905mm, 0.19883mm, 0.245167mm summed to 0.2115mm represented 186.3261% against -37.7066% corroded percentile differences. Entire results showed higher values of pullout bond strength in control and exudates/resin coated to corroded specimens

Table 1. Results of Pull-out Bond Strength Test (τu) (MPa)

S/no		Control Cube Specimens								
Concrete Cube	**Sample**	2AC	2BC	2CC	2DC	2EC	2FC	2GC	2HC	2IC
CKC1-1	Failure Bond Loads (kN)	28.88	28.02	27.52	29.73	28.23	29.09	29.23	28.03	28.89
CKC1-2	Bond strength (MPa)	9.63	9.5	9.37	10.03	9.49	10.24	10.03	10.09	9.64
CKC1-3	Max. slip (mm)	0.1268	0.1118	0.1018	0.1318	0.1148	0.1208	0.1218	0.1068	0.1308
CKC1-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 2. Results of Pull-out Bond Strength Test (τu) (MPa)

S/no		Corroded Cube Specimens								
Concrete Cube	**Sample**	2AC2	2BC2	2BC2	2DC2	2EC2	2FC2	2GC2	2HC2	2IC2
CKC 2-1	Failure Bond load (KN)	17.31	18.06	17.83	18.29	17.54	17.47	18.06	17.54	17.52
CKC 2-2	Bond strength (MPa)	5.28	5.93	5.78	6.3	5.74	5.49	5.9	5.59	5.51
CKC 2-3	Max. slip (mm)	0.0552	0.0812	0.0742	0.0862	0.0732	0.0732	0.0792	0.0712	0.0712
CKC2-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 3. Results of Pull-out Bond Strength Test (τu) (MPa)

		Celtis zenkeri exudates (steel bar coated specimen)								
S/no		(150µm) coated			(300µm) coated			(450µm) coated		
Concrete Cube	Sample	3AC3	3BC3	3BC3	3DC3	3EC3	3FC3	3GC3	3HC3	3IC3
CKC3-1	Failure load (KN)	28.14	27.69	28.33	28.92	29.74	29.44	29.65	29.82	28.94
CKC3-2	Bond strength (MPa)	11.98	12.18	10.67	11.18	11.98	12.09	13.08	12.38	12.36
CKC3-3	Max. slip (mm)	0.2005	0.1905	0.1805	0.1975	0.1905	0.2085	0.2365	0.2505	0.2485
CKC3-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 4. Results of Average Pull-out Bond Strength Test (τu) (MPa)

S/no		Control Cube			Corroded Cube Specimens			Exudate steel bar coated specimens		
Concrete Cube	Sample	Control Specimens Average Values			Corroded Specimens Average Values			Coated Specimens Average Values of 150µm, 300µm, 450µm)		
CKC 4-1	Failure load (KN)	28.1415	29.0165	28.7166	17.7333	17.7666	17.7066	28.0533	29.3666	29.473
CKC 4-2	Bond strength (MPa)	9.5352	9.925	9.926	5.66333	5.84333	5.66666	11.611	11.750	12.60667
CKC 4-3	Max. slip (mm)	0.11346	0.1224	0.1198	0.0702	0.07753	0.07386	0.1905	0.19883	0.245167
CKC 4-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

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

		Control Cube			**Corroded Cube Specimens**			**Exudate steel bar coated specimens**		
		Summary Specimens Average Values of Control, Corroded and Exudate Steel bar Coated			**Summary of Percentile Values of Control, Corroded and Exudate Steel bar Coated**			**Percentile Difference of Control, Corroded and Exudate Steel bar Coated**		
CKC5-1	Failure load (KN)	28.6245	17.7355	28.9633	161.3958	61.9595	163.3064	61.3958	-38.040	63.3064
CKC5-2	Bond strength (MPa)	9.7896	5.7244	11.9888	170.8462	58.53219	209.4333	70.846	-41.467	109.4335
CKC5-3	Max. slip (mm)	0.1180	0.0738	0.2115	160.5294	62.2934	286.3262	60.5292	-37.706	186.3261
CKC5-4	Bar diameter (mm)	12	12	12	100	100	100	0	0	0

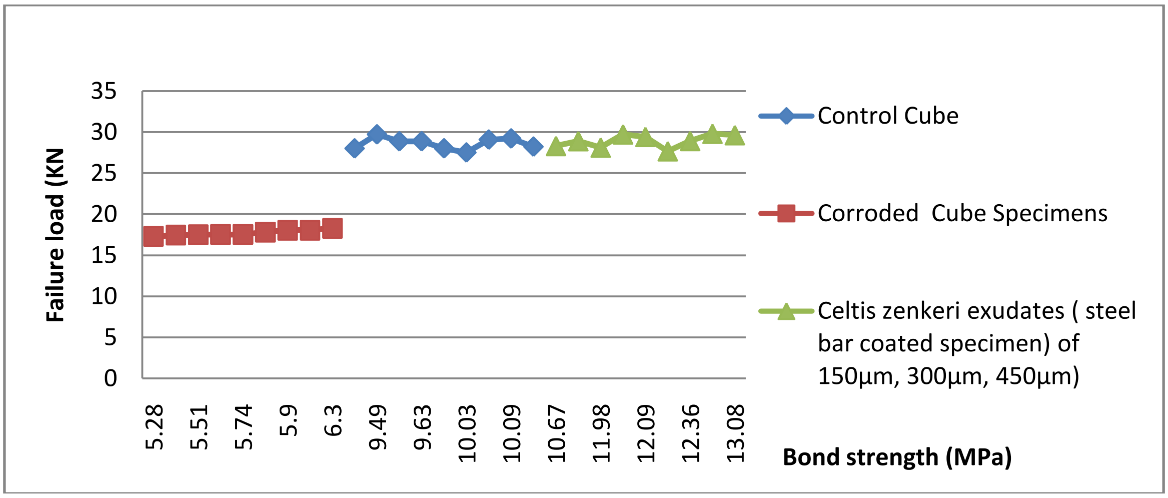

Fig. 1. Failure loads versus Bond Strengths Summary Results

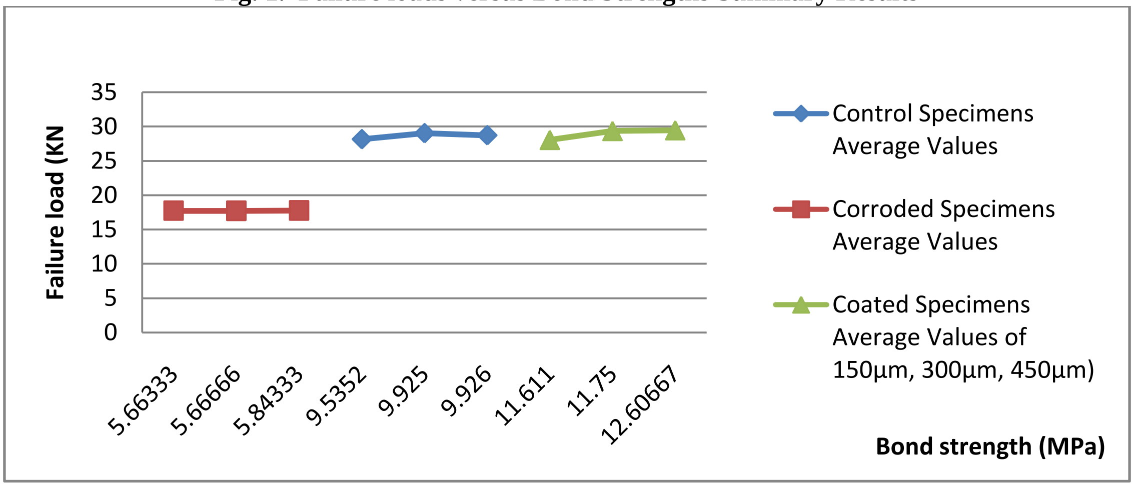

Fig. 2. Failure loads versus Bond Strengths Average Results

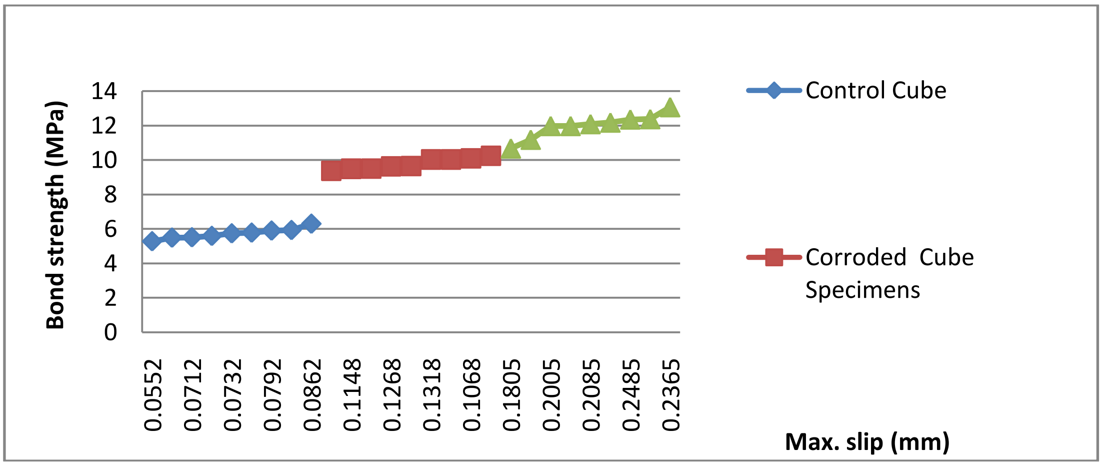

Fig. 3. Bond Strength versus Maximum Slip Summary Results

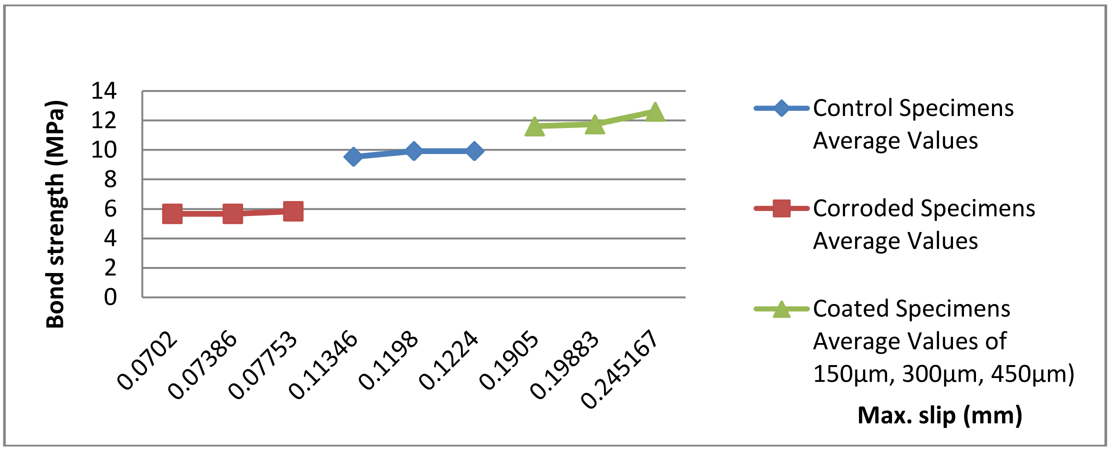

Fig. 4. Bond Strength versus Maximum Slip Average Results

VI. CONCLUSION

Experimental work showed the results below;

i. Celtis zenkeri exudates/ resins coated specimens recorded higher pullout bond values
ii. Low pullout bond percentile values were recorded in corroded specimens
iii. Effects of corrosion on the strength capacity of corroded were recorded as higher failure bond load was experienced
iv. Summarized results showed higher values of pullout bond strength in control and exudates/ resins coated to corroded specimens
v. Comparatives results indicated high bonding strength in inhibited specimens to corroded members.

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