Effect of Corrosion Inhibitors Influence on Bond Behavior of reinforced concrete Structures Exposed to Corrosive Environment of Sodium Chloride (NaCl)

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Abstract: Corrosion of reinforced concrete members generates tremendous tensile stress within the concrete surroundings, thereby cutting short expected design life span of structures. This experimental work investigated the influence of corrosion inhibitors of mangifera indica steel coated bar with resins / exudates on the bond behavior of reinforced concrete cube members. Cubes of 150 mm x150 mmx150 mm of uncoated and coated with mangifera indica resins/exudates extracts of thicknesses 150µm,(ABC), 250µm (DEF) and 350µm (GHI) were embedded into concrete and exposed to harsh marine saline / corrosive environment of Sodium Chloride (NaCl) for 60days to accelerate corrosion potential process. Results indicated corrosion potential possibility with evidences of cracks, pitting and spalling. Experimental results indicated increased in failure bond load, bond strength and maximum slip by 36.49%, 66.30% and 85.57% in coated specimens, increased by 27.08%, 55.90, 47.14% of non-corroded as against decreased by 21.30%, 36.80% and 32.00% in corroded specimens respectively. Entire results showed higher failure bond load in corroded as compared to non-corroded and coated members.

Key Words: Corrosion, Corrosion inhibitors, Pull-out Bond Strength, Concrete and Steel Reinforcement

1.0 INTRODUCTION

Corrosion generates tensile stresses in steel reinforcement surroundings in the concrete, resulting to early cracks. In addition, steel reinforcement cross sectional – area reduction is noticed thereby causing decreased in ductility of the structure, especially during the occurrence of corrosion pitting An increase in the size of reinforcing steel bars such as expansion and volume is the result of rust products, it results to weakness of the reinforcing steel bar cross- sectional area as well reduces the rate of bonding between reinforcing steel bar and concrete thereby creating stress within the concrete surroundings, furthermore, cracking and spalling of concrete is noticed due to severe stress which reduces the reinforced concrete structures designed life and durability,(Almusallam *et al*. 1995, Cabrera 1996, Rashid *et al*. 2010).

Otunyo and Kennedy (2018) investigated the effectiveness of resin/exudates in corrosion prevention of reinforcement in reinforced concrete cubes. The reinforced concrete cubes of dimension (150mm x 150mm x 150mm) were coated with dacryodes edulis resin paste of various thicknesses: 150um, 250um, and 300um. The reinforced concrete cubes were exposed to a corrosive environment for 60days after 28 days of curing. Results obtained indicated that the failure bond strength, pull out bond strength and maximum slip of the resin coated reinforced cubes were higher by (19%), (84%) and (112%). respectively than those obtained from the controlled tests.

Similar results were obtained for the maximum slip (the resin coated and non-corroded steel members) had higher values of maximum slip compared to the cubes that had corroded steel reinforcements. For the corroded beam members, the failure bond strength, pull out bond strength and maximum slip of the resin coated reinforcements were lower by (22%), (32%) and (32%). respectively than those obtained from the controlled tests.

Cusens and Yu (1992) studied the an epoxy coated reinforcing steel bars pull-out tests t in concrete which involved the conduction of single pull-out and double control uncoated bars. The size of the test specimen was 250 × 250 × 410 mm with 25mm bars and 150 × 150 × 200 mm with 12mm bars incompliance with BS 4449. Single pull-out test results suggested loaded end of coaded epoxy bars showed mor e end as compared to non-coated reinforcing steel bars. The reinforcing bars were centrally embedded passing completely longitudinal axis.

Kayyali and Yeomans (1995) compared galvanized, black and epoxy-coated rebars were embedded in reinforced concrete beams of size 1500 × 160 × 320 mm by evaluating the bond and slip of coated reinforcement in concrete. The test results revealed minimal bond strength loss from galvanized steel bars and as well as minimal reduction in the bond strength of coated epoxy reinforcing steel bars. Chung *et al*., (2004) studied the effect of corrosion on pullout bond strength and development length. Different level of corrosion were used to corrode the reinforcement, concrete slab specimens with one steel reinforcing bar were used to investigate the bond stress and length development on tension member in flexure. It was concluded that at 2% level of corrosion, increases and fails it reaches an average bond stress. Han-Seung Lee *et al*., (2002) evaluated the corrosion of reinforcing steel as function of degree of bond properties between concrete and reinforcement. They evaluated pull out bond test to ascertain the the bond characteristics between concrete and corroded reinforcing steel bar. Pull-out tests were conducted on specimens with and without confinement reinforcement. Experimentally, results were obtained from load versus free end slip behavior was studied and the rigidity of bond for the analysis of Finite Element with corroded reinforcement in reinforced concrete members. Cairns and Plizzari (2003) affirmed that the split from concrete surrounding resulted from bearing action of ribs that generates bursting forces. Tensile capacity of the ring is exceeded during the development of the bond action, a splitting failure occurs by fracturing the concrete cover surrounding the reinforcement. If the concrete confinement was enough to counter balance the force generated by bond.

2.0 Experimental program

The present study involves direct application of resins / exudates of trees extract known as inorganic inhibitor, coated on the reinforcing steel surface were studied in this test program. The main objective of this study was to determine the effectiveness of locally available surface-applied corrosion inhibitors under severe corrosive environments and with chloride contamination. The test setup simulates a harsh marine environment of saline concentration in the concrete in the submerged portion of the test specimens, corrosion activity of the steel cannot be sustained in fully immersed samples. The samples were designed with sets of reinforced concrete cubes of 150 mm × 150 mm × 150 mm with a single ribbed bar of 12 mm diameter embedded in the centre of the concrete cube specimens for pull out test and was investigated. To simulate the ideal corrosive environment, concrete samples were immersed in solutions (NaCl) and the depth of the solution was maintained.

2.1 MATERIALS FOR EXPERINMENT

2.1.1 Aggregates

The fine aggregate was gotten from the river, washed sand deposit, coarse aggregate was granite a crushed rock of 12 mm size and of high quality. Both aggregates met the requirements of BS 882.

2.1.2 Cement

The cement used was Eagle Portland Cement, it was used for all concrete mixes in this investigation. The cement met the requirements of BS EN 196-6

2.1.3 Water

The water samples were clean and free from impurities. The fresh water used was gotten from the tap at the Civil Engineering Department Laboratory, University of Uyo, Uyo. Akwa - Ibom State. The water met the requirements of BS 3148

2.1.4 Structural Steel Reinforcement

The reinforcements are gotten directly from the market in Port Harcourt.

2.1.5 Corrosion Inhibitors (Resins / Exudates) Mangifera indica

The study inhibitor (Mangifera indica**)** is of natural tree resin /exudate substance extracts. They are abundantly found in Rivers State bushes and they are sourced from plantations and bushes of Odioku communities, Ahoada West Local Government areas, Rivers State, from existed and previously formed and by tapping processes for newer ones.

2.2 EXPERIMENTAL PROCEDURES

2.2.1 Experimental method

2.2.2 Sample preparation for reinforcement with coated resin/exudate

Corrosion tests were performed on high yield steel (reinforcement) of 12 mm diameter with 550 mm lengths for cubes, Specimen surfaces roughness was treated with sandpaper / wire brush and specimens were cleaned with distilled water, washed by acetone and dried properly, then polished and coated with Mangifera indica resin pastes with coating thicknesses of 150µm, 250µm and 300µm before corrosion test. The test cubes and beams were cast in steel mould of size 150 mm × 150 mm × 150 mm. Fresh concrete mix for each batch was fully compacted by tamping rods, to remove trapped air, which can reduce the strength of the concrete and 12 mm reinforcements of coated and non-coated were spaced at 150 mm with concrete cover of 25 mm had been embedded inside the slab and projection of 100 mm for half cell potential measurement. Specimens were demoulded after 24hrs and cured for 28 days. The specimens were cured at room temperature in the curing tanks which then gave way for accelerated corrosion test process and testing procedure allowed for 39 days first crack noticed and a further 21 days making a total of 60 days for further observations on corrosion acceleration process.

2.3 Accelerated corrosion set-up and testing procedure

In real and natural conditions the development of reinforcement corrosion is very slow and can take years to be achieved; as a result of this phenomenon, laboratory studies necessitate an acceleration of corrosion process to achieve a short test period. After curing of beams and cubes specimens for 28 days, specimens were lifted and shifted to the corrosion tank to induce desired corrosion levels. Electrochemical corrosion technique was used to accelerate the corrosion of steel bars embedded in beams specimens. Specimens were partially immersed in a 5% NaCl solution for duration of 60 days, to examine the surface and mechanical properties of rebars.

2.3 Pull-out Bond Strength Test

The pull-out bond strength tests on the concrete cubes were performed out after 54 specimens on Universal Testing Machine of capacity 50KN in accordance with BS EN 12390-2. After curing for 28days, 6 controlled cubes (non-corroded) was kept in a control condition as against corrosion as to ascertain bond difference effects, 48 cubes samples of non-coated and resin / exudates coated were partially place in ponding tank for 39 days placed to examine accelerated corrosion process. After 39 days, the accelerated corrosion subjected samples were examined to determine bond strength effects due to corrosion and corrosion inhibited samples.

The dimensions of the pull-out specimens were 54 cubes 150 mm × 150 mm × 150 mm with a single ribbed bar of 12mm diameter embedded in the centre of the concrete cube. The bond length of the bar was placed at the centre of the concrete cube with 40mm of length protruding from the top of the specimen and with the outer 75 mm of the reinforcing bar enclosed in a PVC tube to ensure that these sections remained un-bonded. Additionally, the reinforcement bar was covered with tape for a distance of 75 mm from both ends of the cube so that the corrosion could take place only within the 50 mm bonded length. The pull-out bond tests were conducted using an Instron Universal Testing Machine of 50KN capacity at a slow loading rate of 1 mm/min. Specimens of 150 mm x150 mm x150 mm concrete cube specimens were also prepared from the same concrete mix used for the cubes cured in water for 28 days, and accelerated with 5% NaCl solution for same 39 days and a further 21 days making a total of 60 days was consequently tested to determine bond strength.

2.4 Tensile Strength of Reinforcing Bars

To ascertain the yield and tensile strength of tension bars, bar specimens of 12 mm diameter of non-corroded, corroded and coated were tested in tension in a Universal Testing Machine and were subjected to direct tension until failure; the yield, maximum and failure loads being recorded. To ensure consistency, the remaining cut pieces from the standard length of corroded and non-corroded steel bars were subsequently used in the bond and flexural test.

3.0 Results and Discussions

Table 3.1 shows the results of pullout bond strength test of failure bond load, bond strength and maximum slip of non-corroded, corroded and mangifera indica (steel bar coated specimen) of 27 samples A – I (9 samples each for non-corroded, corroded and resins / exudates coated with varying thicknesses of 150µm,(ABC), 250µm (DEF) and 350µm (GHI) . Tables 3.2 is the derive average values of ABC to A, DEF to B and GHI to C. Percentage varying values were obtained from summarized average and used for comparison.

Figures 3.1 and 3.3 shows the results of failure bond load versus bond strength and average values of table 3.1, figures 3.2 and 3.4 shows bond strength versus maximum slip of non-corroded, corroded and coated specimens.

3.1 Non-Corroded Concrete Cube Members

Results obtained are 27.08%, 55.90% and 47.14% for failure bond load, bond strength and maximum slip.

3.2 Corroded Concrete Cube Members

Results of corroded when compared to non-corroded members, the pullout bond failure load, bond strength and maximum slip all decreased to 21.30%, 36.80%, 32.00% against 27.08%, 55.90% and 47.14% respectively.

3.2 Mangifera indica Steel Bar Coated Concrete Cube Members

In comparison to corroded concrete cube members on failure bond load, bond strength and maximum slip, coated members recorded tremendous increased by 36.49%, 66.30% and 85.50% as against 21.30%, 36.80% and 32.00% corroded respectively.

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

Control, Corroded and Resin Steel bar Coated

S/N0		A	B	C	D	E	F	G	H	I
Concrete Cube		**Non-corroded Control Cube**								
CCk1-1	Failure Bond Loads (kN)	22.83	21.97	21.47	23.68	22.18	23.04	23.18	21.98	22.84
CCk1-2	Bond strength (MPa)	7.35	7.22	7.09	7.75	7.21	7.96	7.75	7.81	7.36
CCk1-3	Max. slip (mm)	0.114	0.099	0.089	0.119	0.102	0.108	0.109	0.094	0.118
CCk1-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12
2		**Corroded**								
CCk 2-1	Failure Bond load (KN)	17.34	18.09	17.86	18.32	17.57	17.50	18.09	17.57	17.55
CCk 2-2	Bond strength (MPa)	4.25	4.90	4.75	5.27	4.71	4.46	4.87	4.56	4.48
CCk 2-3	Max. slip (mm)	0.054	0.080	0.073	0.085	0.072	0.072	0.078	0.070	0.070
		Coated spemens								
		(150µm) coated (A, B, C)			**(250µm) coated(D,E, F)**			**(350µm) coated (G,H,I)**		
		Mangifera indica (steel bar coated specimen)								
CCk 4-1	Failure load (KN)	21.75	22.30	20.94	25.53	24.35	27.05	25.56	24.43	25.55
CCk 4-2	Bond strength (MPa)	7.65	7.85	6.34	6.85	7.65	7.76	8.75	8.05	8.03
CCk 4-3	Max. slip (mm)	0.115	0.105	0.095	0.112	0.105	0.123	0.171	0.165	0.183
CCk 4-4	Bar diameter (mm)	12	12	12	12	12	12	12	12	12

Table 3.2: Results of Average Pull-out Bond Strength Test (τu) (MPa)

Control, Corroded and Resin Steel bar Coated

S/N0	A	B	C
1	**Non-corroded Control Cube**		
Concrete Cube			

CCk1-1	Failure Bond Loads (kN)	22.09	22.46	22.66
CCk1-2	Bond strength (MPa)	7.22	7.40	7.64
CCk1-3	Max. slip (mm)	0.100	0.104	0.107
CCk1-4	Bar diameter (mm)	12	12	12
2		**Corroded**		
CCk 2-1	Failure Bond load (KN)	17.76	17.77	17.74
CCk 2-2	Bond strength (MPa)	4.63	4.71	4.64
CCk 2-3	Max. slip (mm)	0.069	0.0.72	0.073
CCk 2-5	Bar diameter (mm)	12	12	12

Coated Specimens

150µm) coated (A,) (250µm) coated(B) (350µm) coated (C

Mangifera indica (Steel bar Coated specimen)

CCk 4-1	Failure load (KN)	21.66	25.64	25.18
CCk 4-2	Bond strength (MPa)	7.28	7.42	8.27
CCk 4-3	Max. slip (mm)	0.105	0.113	0.174
CCk 4-4	Bar diameter (mm)	12	12	12

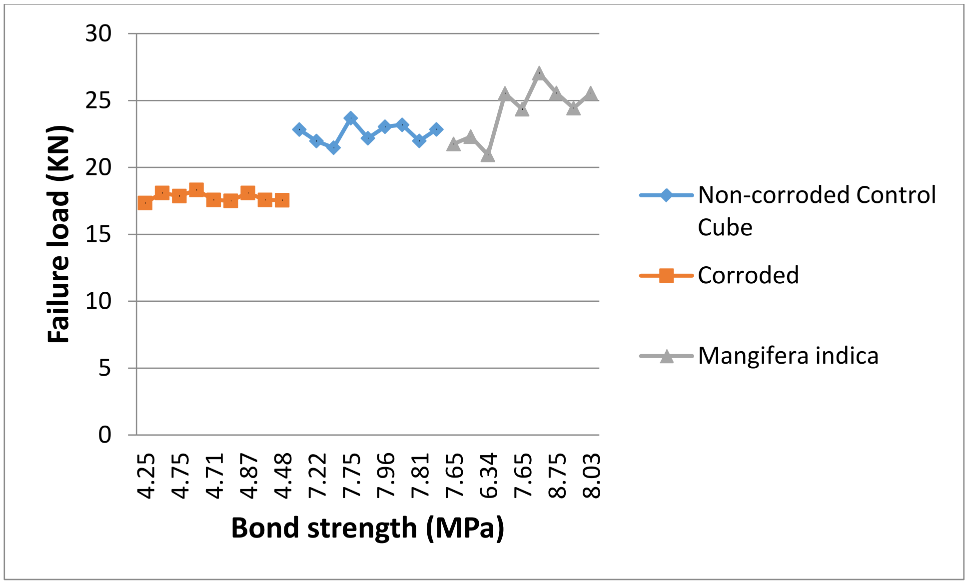

Figure 3.1: Summary Results of Pull-out Bond Strength Test (τu) (MPa) (Failure loads versus Bond Strengths)

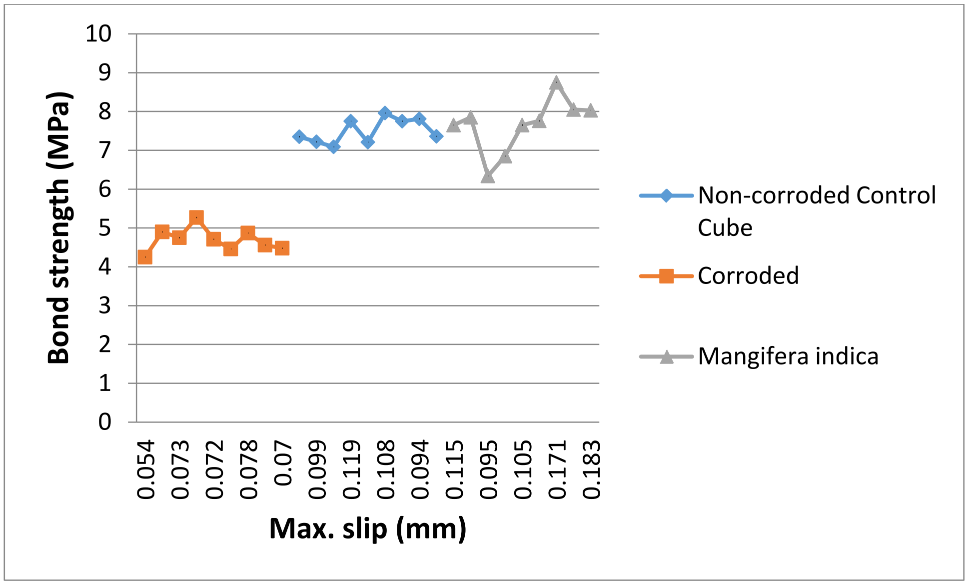

Figure 3.2: Summary Results of Pull-out Bond Strength Test (τu) (MPa) (Bond Strength versus Maximum Slip)

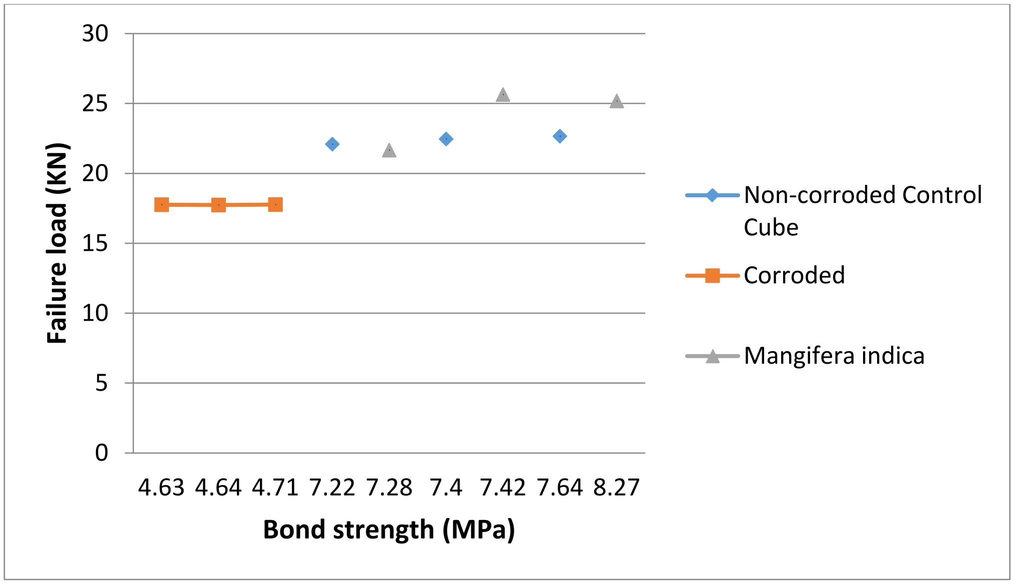

Figure 3.3: Average Results of Pull-out Bond Strength Test (τu) (MPa)
(Failure loads versus Bond Strengths)

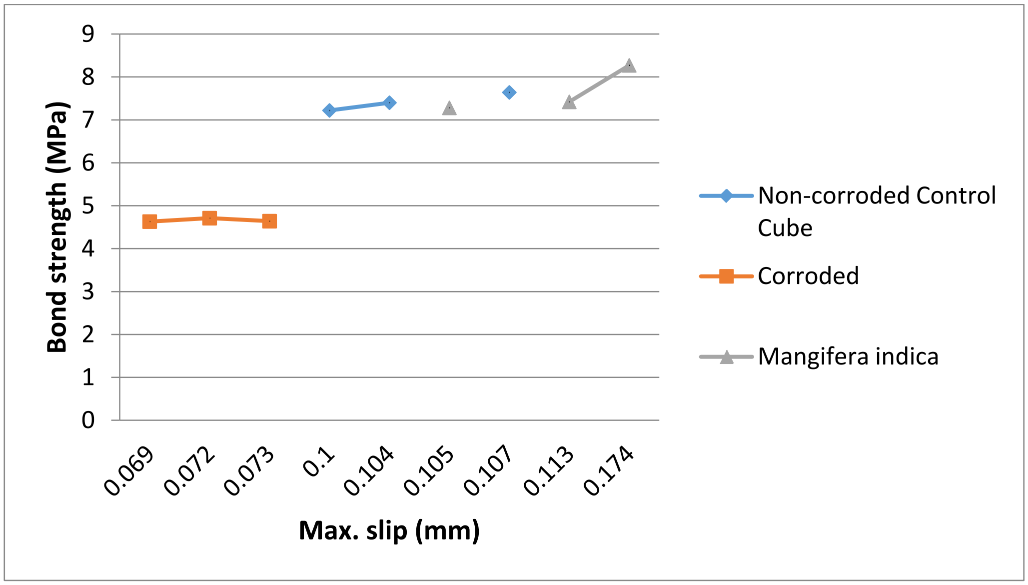

Figure 3.4: Average Results of Pull-out Bond Strength Test (τu) (MPa)
(Bond Strength versus Maximum Slip)

4.0 Conclusion

From the experimental investigations, the following conclusions were drawn:

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i. Bond stresses experienced in inhibitor coated reinforcements are higher compared to the controlled specimens.
ii. Bond strength reduces linearly with increasing corrosion levels.
iii. Effect of coated thickness has much influence in the pull out as compared to the flexural characteristics, bond strength increased was noticed

REFERENCES

Almusallam, A., Ahmed, S., Gahtani, A. & Rauf, A. (1995). Effect of Reinforcement Corrosion on Bond Strength, *Construction and Building Materials*, 10, 123-129.

BS. 882; Specification for aggregates from natural sources for concrete. *British Standards Institute. London, United Kingdom, 1992.*

BS EN 196-6; - Methods of Testing Cement. Determination of fineness, *British Standards Institute. London, United Kingdom, 2010.*

BS 3148 – Methods of test for water for making concrete. *British Standards Institute. London, United Kingdom, 1980.*

BS 4449:2005+A3 – Steel for Reinforcement of Concrete. *British Standards Institute. London, United Kingdom, 2010*

Cabrera, J. G. (1996). Deterioration of Concrete Due to Reinforcement Steel Corrosion, *Cement and Concrete Composites*, 18, 47-59

Cairns, J. & Plizzari G. A. (2003). Towards a Harmonized European Bond Test. *Materials and Structures*, 36, 498-506.

Chung, L., Cho, S.-H., Kim, J.-H. J. & Yi, S.T. (2004). Correction Factor Suggestion for ACI Development Length Provisions Based on Flexural Testing of RC Slabs with Various Levels of Corroded Reinforcing Bars. *Engineering Structures*, 26(8), 1013- 1026

Cusens, A.R. & Yu, Z. (1992). Pullout Tests of Epoxy-Coated Reinforcement in Concrete, *Cement and Concrete Composites*, 14, 269-276.

Han-Seung, L., Takafumi, N. & Fuminori, T. (2002). Evaluation of the Bond Properties Between Concrete and Reinforcement as a Function of the Degree of Reinforcement Corrosion, *Cement and Concrete Research*, 32, 1313-1318.

Kayyali, O.A. & Yeomans, S. R. (1995). Bond and Slip of Coated Reinforcement in Concrete, *Construction and Building Materials*, 9(4), 219-226.

Otunyo, A.W & Kennedy, C. (2018). Effectiveness of Resins/exudates of Trees in Corrosion Prevention of Reinforcement in Reinforced Concrete structures, *Nigerian Journal of Technology, 37,78-86*

Rashid, M.H., Khatun, S., Uddin, S.M.K. & Nayeem, M.A. (2010). Effect of Strength and Covering on Concrete Corrosion, *European Journal of Scientific Research*, 40, 492-499.