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# Chloride Inducement on Bond Strength Yield Capacity of Uncoated and Resins / Exudates Inhibited Reinforcement Embedded in Reinforced Concrete Structures

**Charles Kennedy[1], Gbinu Samuel Kabari[2], Ogunjiofor Emmanuel Ifeanyi[3] , Okabi Ifeanyi Sunday[4]**

**[1]Faculty of Engineering, Department of Civil Engineering, Rivers State University, Nkpolu, Port Harcourt, Nigeria.**

**[2]School of Engineering, Department of Civil Engineering, Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria.**

**[3]Department of Civil Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State, Nigeria**

**[4]School of Environmental Technology, Department of Architecture, Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria**

**Authors E-mail: [1]ken_charl@yahoo.co.uk, [2]kabarisamuel@gmail.com, [3]ogunjioforemmanuel@gmail.com, [4]ifyokabi@gmail.com**



**Abstract**

***The primary causes of the reduction of service life, integrity and capacity of reinforced concrete structures in the marine environment of saline origin is corrosion. This research work experimented on the preventive trend of corrosion using inhibitors of inorganic origin from tree extracts of acardiun occidentale l. resins / exudates. Resins / exudates paste were directly applied on the reinforcement as coating materials with thicknesses of 150µm, 250µm and 350µm, embedded in concrete cube and immersed in sodium chloride (NaCl) and accelerated for 60 days. Results obtained on comparison showed failure bond load, bond strength and maximum slip decreased in corroded specimens to 21.30%, 38.80% and 32.00% respectively, while coated specimens 51.69%, 66.90%, 74.65%, for non-corroded 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.***

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

## 1.0 Introduction

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Corrosion of reinforcing steel is widely accepted as the primary cause of premature deterioration in reinforced concrete structures Shetty *et al* [1]. Deteriorations, failures do occurred and accelerated in reinforced concrete structures exposed to costal marine and harsh environments. When steel reinforcement corrodes, the life span, service and the intended purpose and its integrity and capacity of the structure is affected as well as reduced. Reinforced concrete structures built within the marine environment are at risk due to chloride-induced corrosion of reinforcement resulted from 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 (Fu and Chung, [2]. Bond strength influenced by bar geometries, concrete properties, the presence of confinement around the bar, as well as surface conditions of the bar (ACI, 2003) . Auyeung *et al*.,. [3] 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.

Ravindrarajah and Ong [4] investigated the effect of the diameter of the steel bar, and the thickness of the cover on the degree of corrosion 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.

Otunyo and Kennedy [4] 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.

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Rasheeduzzafar *et al.* [5] indicated that the cover over reinforcement has the most significant effect on the extent of rebar corrosion.

Rasheeduzzafar *et al*., [6] based on their field and laboratory results, recommended the following cover for structures serving in various environments of the Arabian Gulf:

i. Building components which are permanently exposed to the salt - laden corrosive atmosphere

ii. Building components which are protected against weather and the aggressive conditions of exposure: 1.0 to 1.5 inch 28.

iii. Concrete components exposed to seawater and footings as well as other main structural members cast against the ground: 3.0 inch.

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.

## 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 [7]

### 2.1.2 Cement

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The cement used was Eagle Portland Cement, it was used for all concrete mixes in this investigation. The cement met the requirements of [8]

### 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 [9]

### 2.1.4 Structural Steel Reinforcement

The reinforcements are gotten directly from the market in Port Harcourt. [10]

### 2.1.5 Corrosion Inhibitors (Resins / Exudates) Acardium occidentale l.

The study inhibitor (Acardium occidentale l.) 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 (Acardium occidentale l.), 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 resins / 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 27 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 Experimental results and discussion

Table 3.1 shows detail of the entire results obtained from 27 samples of non-corroded, corroded and acardium occidentale l. (steel bar coated specimens) of resins / exudates paste on reinforcement embedded in concrete cubes members. Results of pullout bond strength test of failure bond load, bond strength and maximum slip. Table 3.2 outlined the results of average values of failure load, bond strength and maximum slip of non-corroded, corroded and resins/exudates coated specimens.

Figures 3.1 and 3.2 are the plots of entire failure bond load versus bond strength and bond strength versus maximum slip, while figures 3.3 and 3.4 are the plots of average failure bond load versus maximum slip obtained from tables 3.1 and 3.2.

### 3.1 Non-corroded Concrete Cube Members

Results obtained from table 3.1 and summarized in table 3.2 indicated pullout out bond strength of failure bond load, bond strength and maximum slip as 27.08%, 55.90% and 47.14% respectively

### 3.2 Corroded Concrete Cube Members

From tables 3.2, the obtained percentile values from table 3.1, the failure bond load, bond strength load and maximum slip are 21.30%, 36.80%, 32.00%. In comparison to non-corroded, results of obtained values of corroded specimens decreases while non-corroded increases.

### 3.3 Acardium occidentale l. Steel Bar Coated Concrete Cube Members

Results obtained values from tables 3.1, 3.2 and figures 3.1 – 3.4 showed increased values of

51.69%, 66.90%, 74.65% of failure bond load, bond strength and maximum slip as against decreased values of 21.30%, 36.80%, 32.00% respectively. Entire results showed higher values of pullout bond strength in non-corroded and coated to corroded.

**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 |
| CCk 2-5 | Bar diameter (mm) | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| | | **Coated spemens** | | | | | | | | |
| | | **(150µm) coated (A, B, C)** | | | **(250µm) coated(D,E, F)** | | | **(350µm) coated (G,H,I)** | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | **Acardium occidentale l. ( steel bar coated specimen)** | | | | | | | | | |
| CCk 3-1 | Failure load (KN) | 22.15 | 23.15 | 22.68 | 22.45 | 25.35 | 25.75 | 25.45 | 27.35 | 27.75 |
| CCk 3-2 | Bond strength (MPa) | 7.05 | 7.38 | 7.19 | 7.15 | 8.05 | 8.09 | 8.15 | 7.85 | 8.23 |
| CCk 3-3 | Max. slip (mm) | 0.091 | 0.108 | 0.093 | 0.092 | 0.122 | 0.126 | 0.122 | 0.166 | 0.185 |
| CCk 3-4 | Bar diameter (mm) | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |

**Table 4.2 : Results of Average Pull-out Bond Strength Test (τu) (MPa)**

**Control, Corroded and Resin Steel bar Coated**

| S/N0 | | A | B | C |
|---|---|---|---|---|
| Concrete Cube | **Non-corroded Control Cube** | | | |
| CCk1A-1 | Failure Bond Loads (kN) | 22.09 | 22.46 | 22.66 |
| CCk1A-2 | Bond strength (MPa) | 7.22 | 7.40 | 7.64 |
| CCk1A-3 | Max. slip (mm) | 0.100 | 0.104 | 0.107 |
| CCk1A-4 | Bar diameter (mm) | 12 | 12 | 12 |
| 2A | **Corroded** | | | |
| CCk 2A-1 | Failure Bond load (KN) | 17.76 | 17.77 | 17.74 |
| CCk 2A-2 | Bond strength (MPa) | 4.63 | 4.71 | 4.64 |
| CCk 2A-3 | Max. slip (mm) | 0.069 | 0.0.72 | 0.073 |
| CCk 2A-5 | Bar diameter (mm) | 12 | 12 | 12 |
| | **Coated specimens** | | | |

| | | 150µm) coated (A, B, C) | (250µm) coated(D,E, F) | (350µm) coated(G,H, I) |
|---|---|---|---|---|
| 3A | **Acardium occidentale l. ( steel bar coated specimen)** | | | |
| CCk 3A-1 | Failure load (KN) | 22.66 | 24.51 | 26.85 |
| CCk 3A-2 | Bond strength (MPa) | 7.21 | 7.76 | 8.07 |
| CCk 3A-3 | Max. slip (mm) | 0.097 | 0.113 | 0.157 |
| CCk 3A-4 | Bar diameter (mm) | 12 | 12 | 12 |



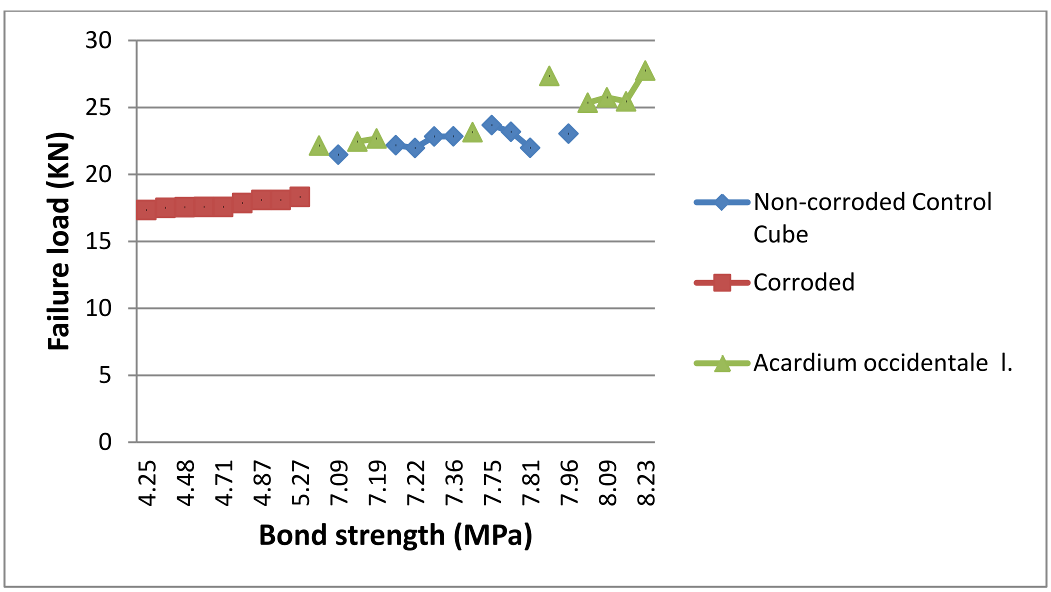

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**Figure 3.1: Summary Results of Pull-out Bond Strength Test (τu) (MPa)**

**(Failure loads versus Bond Strengths)**

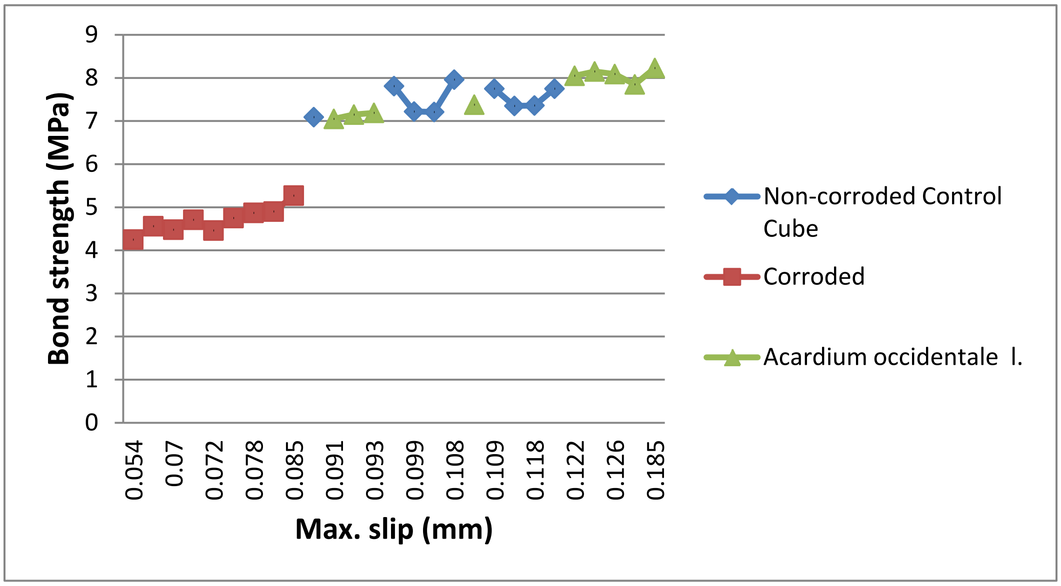




**Figure 3.2: Summary Results of Pull-out Bond Strength Test (τu) (MPa)**

**(Bond Strength versus Maximum Slip)**

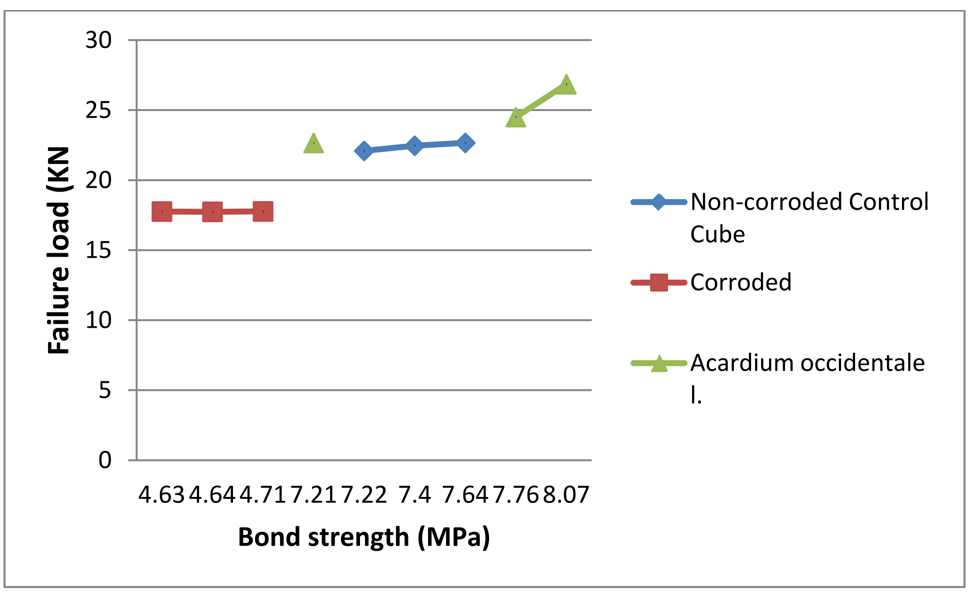

**Figure 3.3: Average Results of Pull-out Bond Strength Test (τu) (MPa)**

**(Failure loads versus Bond Strengths)**

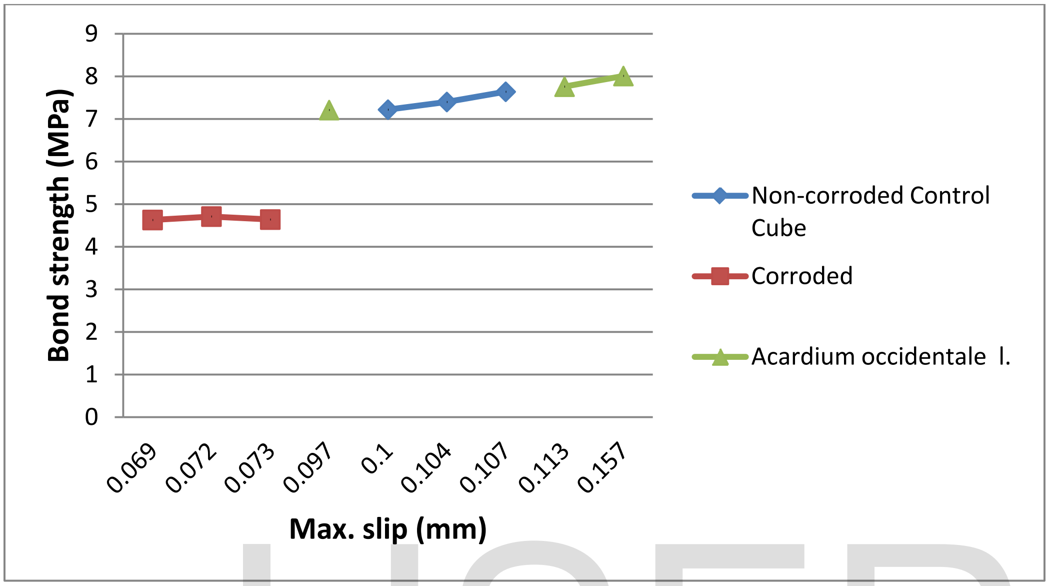


**Figure 3.4: Average Results of Pull-out Bond Strength Test (τu) (MPa)**

**(Bond Strength versus Maximum Slip)**



## 4.0 Conclusion

Experimental results showed the following conclusions:

i. Entire results showed lower percentages in corroded and higher in coated members.

ii. Results justified the effect of corrosion on the strength capacity of corroded and coated members.

iii. Entire results showed higher values of pullout bond strength in non-corroded and coated to corroded specimens

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iv. Bond test indicated that the bond stresses experienced in inhibitor coated reinforcements are higher compared to the controlled specimens.

v. Bond strength reduces linearly with increasing corrosion levels.

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