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Research Paper

STUDY ON PERFORMANCE OF CORROSION INHIBITORS IN CONCRETE

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The delay in corrosion initiation of rebar embedded in concrete by corrosion inhibitors are investigated in this study. The objective is to study the eco-friendly, hydrophobic green plant inhibitors (Bambusa arundinacea, Coconut coir) and compares its effectiveness with inorganic inhibitors (calcium nitrite and ethanolamine). The organic inhibitors used were Bambusa Arundinacea (BA) and Coconut coir powder (CC) and the inorganic inhibitors used were Calcium Nitrite (CN) and Ethanol Amine (EA). The inhibitors were added during mixing of concrete (2% by weight of cement) and then chloride was added into the concrete as a magnesium chloride (1.5% by weight of cement) of corrosion reagent. Five combinations of mix were preferred such as C, CN, EA, CC and BA mixes and the corrosion resistance is evaluated by gravimetric weight loss and accelerated corrosion test. On Comparison of the green corrosion inhibitors and inorganic corrosion inhibitors, influences over mechanical properties of both are almost equal. The results of accelerated corrosion tests and gravimetric weight loss indicate that Bambusa arundinacea and calcium nitrate, Coconut coir and Ethanol amine differ in corrosion initiation period by 9.8% and 12.5%, 8.1% and 15.2% respectively.

Keywords: Concrete, Corrosion, Rebar, Corrosion inhibitor

INTRODUCTION

Corrosion is "the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties". For steel embedded in concrete, corrosion results in the formation of rust which has two to four times the volume of the original steel and none of the good mechanical properties. Corrosion also produces pits or holes in the surface of reinforcing steel, reducing strength capacity as a result of the reduced cross-sectional area. steel in concrete is usually in a non-corroding, passive condition. However, steel reinforced concrete is often used in severe environments where sea water or deicing salts are present. When chloride moves into the concrete, it disrupts the passive layer protecting the steel, causing it to rust and pit.

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carbonation of concrete is another cause of steel corrosion. When concrete carbonates to the level of the steel rebar the normally alkaline environment, which protects steel from corrosion, is replaced by a more neutral environment. Under these conditions the steel is not passive and rapid corrosion begins. The rate of corrosion are hindered by coatings of rebar, mix proportioning and corrosion inhibitor. Abdul Rahman and Mohammad Ismail (2011 and 2014) studied the effect of green corrosion inhibitor in concrete. Monalisa Kunda *et al.* (2016) commented on the usage of green corrosion inhibitor. Vishnudevan and Thangavel (2006) evaluated the performance of organic based corrosion inhibitor.

MATERIALS AND METHODS

Materials

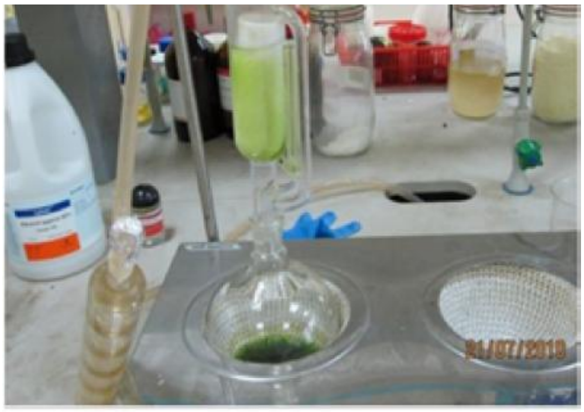
Chettinadu PPC fly ash cement (PPC) was used in this research with specific gravity 2.9. The chloride was added into the concrete as magnesium chloride ($MgCl_2$) of analytical grade reagent. The $MgCl_2$concentration used was 1.5% by mass of cement.The materials used for the Natural river sand was used as a fine aggregate with specific gravity of 2.67, confirming to zone II and natural coarse aggregate of size 20 mm with specific gravity of 2.93 was used in the preparation of concrete. The grade of concrete used was M30and water/cement (w/c) ratio of 0.45 which was designed as per Indian Standard Code. Inhibitor admixtures, namely 2% of calcium nitrite, ethanolamine, Bambusa arundinacea and Coconut coir powder were added on the basis of weight of cement.

Methods

Preparation of Plant Extracts

Fresh leaves of Bambusa Arundinacea (Indian Bamboo) was washed under running water, shade dried and ground into powder (Mohammad *et al.*, 2011). The extraction was done using soxhlet extraction process. 3 g of pulverized samples were placed in a porous container and allowing condensed solvent (ethanol) to extract continuously. The condenser function was to cool the solvent vapour and cause it to condense (turn back to liquid). Figure 1 shows a ring type of condenser which functions by increasing the surface area that can be used to transfer heat. The extracts from soxhlet apparatus were rotary evaporated to expel the ethanol.

Figure 1: Soxhlet Extraction Apparatus with Extract



Concrete

In this study concrete mix of M30 is designed as per IS: 10262-2009. Five mixes have been carried out and quantity of materials required are shown in the Table 1. Five combinations of mix were preferred such as C refers to control mix of M30 grade concrete, CN refers to M30 grade concrete admixed with Calcium nitrate inhibitor, EA refers to M30 grade concrete admixed with Ethyl amine inhibitor, CC refers to M30 grade concrete admixed with Cocunut coir inhibitor and BA refers to M30 grade concrete admixed with *Bambusa arundinacea* inhibitor mixes. Inhibitor admixtures, namely 2% of calcium nitrite, ethanolamine,

Table 1: Material Requirements

Materials	Quantity (kg/m^3)
PPC Cement	388.89
Fine Aggregate	684.79
Coarse Aggregate (20 mm)	1272.31
Water	191.79
Calcium nitrite	7.78
Ethanol amine	7.78
Coconut coir	7.78
Bambusa arundinacea	7.78
Magnesium chloride	5.83

Bambusa arundinacea and Coconut coir powder were added on the basis of weight of cement and Magnesium chloride (1.5% by weight of cement) are added to all of the five mixes to induce chloride induced corrosion.

EXPERIMENTAL INVESTIGATION

Preparation of Concrete Specimens

Totally, thirty concrete cube of size 150 mm were casted, which comprises of three specimens for each mix type for 7th day and 28th day compressive strength. Similarly fifteen prisms of size 400 mm x 100 mm x 100 mm were casted for flexural strength. Similarly fifteen cylindrical specimens of size 100 mm diameter and 200 mm length are casted for split tensile strength and young's modulus. To evaluate the corrosion resistance, the specimens with the following nomenclature are casted as shown in Figure 2. A bar diameter 16 mm and length 35 cm. The bar kept with a clear cover 40 mm on bottom for the cylinder specimen. The cylinder specimen size is 150 mm dia and 300 mm height.

Figure 2: Specimens for Corrosion Test

Tests on Concrete

The specimens were subjected to various tests, namely; compressive strength test, split tensile strength, flexural strength and modulus of rupture. The corrosion resistance of the reinforcement was evaluated with the help of gravimetric weight loss test and accelerated corrosion test.

Accelerated Corrosion Test

The experimental test setup are as shown in Figure 3. To assess the corrosion protection efficiency under accelerated test conditions, concrete cylinders of size 75 mm diameter and 150 mm length were cast with High Yield Strength Deformed (HYSD) steel bar of 16 mm diameter embedded centrally into it. The steel

Figure 3: Accelerated Corrosion Test Setup

rods were cleaned with pickling acid and degreased and then embedded in such a way that a constant cover is maintained all round and also the protruding rod was insulated by PVC sleeve. After 28 days curing, all the specimens were taken out and dried for 24 hours then subjected to acceleration corrosion process in order to accelerate reinforcement corrosion. The rebar projecting at the top is connected to the positive terminals of the power pack (anode) and the stainless steel plate is connected to the negative terminal (cathode). The test specimens were subjected to a constant voltage of 6 volts from D.C power pack. The applied voltage is kept constant continuously and the current response is monitored and recorded with respect to time.

Gravimetric Weight Loss Test

To get the marine/saline environment, the concrete is kept in the 3.5% NaCl solution. On average, seawater in the world's oceans has a salinity of about 3.5% (35 g/L), which is a specific gravity of about 1.025. After the curing period under alternate wetting (3 days) and drying (3 days) conditions over a period of 60 days. At the end of 90 days the cylinders were broke open and the final weight of the specimens was taken. The difference between the initial and final weight gives the weight loss of the specimen. From the weight loss obtained corrosion rate can be calculated using the following formula:

Corrosion rate in millimeter/year

$= 87600 \times W/(\rho * A * T)$

where, W = weight loss in grams ($W_1 - W_2$), ρ = Density of steel gm/cm^3, A = Area of the embedded rebar in cm^2

T = Time in hours

RESULTS AND DISCUSSION

Mechanical Properties of Hardened Concrete

The mechanical properties of hardened concrete are summarised in Table 2. The compressive strength of concrete with calcium nitrite inhibitor is increased by 13.62% than conventional concrete. At the same time, compressive strength of concrete with Bambusa Arundinacea inhibitors is nearly same as calcium nitrite concrete. From the Figure 4, split tensile strength of concrete with calcium nitrite inhibitor is increased by 10.73% than conventional concrete. At the same time, Split tensile strength of concrete with Bambusa Arundinacea inhibitors is increased by 4.29% than conventional concrete. The addition of given green inhibitors do not significantly affect the Split tensile of concrete. From the Figure 5, Flexural strength of concrete with calcium nitrite inhibitor is increased by 13.46% than conventional concrete. At the same time, so, the addition of given green inhibitors do not significantly affect the Flexural strength of concrete. In summary the addition of Bambussa Arundinacea inhibitor does not impact negatively on the hardened properties of concrete.

Corrosion Resistance of Hardened Concrete

From the Figure 6, the sudden increase in current (mA) can be identified as initiation time of the corrosion. It is observed that the chemical inhibitors have high corrosion initiation time. Similarly, the green corrosion inhibitors showed better results compared to convention concrete. So, the green corrosion inhibitors are best substitution materials for chemical corrosion inhibitors. From the Figure 7, it is inferred that the corrosion rate is high for the conventional

Table 2: Mechanical Properties of Hardened Concrete with Various Inhibitor Types

S. No.	Mix Designation	Average Compressive Strength (N/mm^2) at 7th Eay	Average Compressive Strength (N/mm^2) at 28th Day	Split Tensile Strength at 28th Day	Flexural Strength at 28th Day	Young's Modulus at 28th Day
1	C	24.15	35.6	2.33	6.09	36179
2	CN	27.01	40.45	2.58	6.31	39157
3	EA	24.67	36.52	2.43	6.15	37932
4	CC	23.21	34.24	2.25	5.91	35120
5	BA	26.05	38.76	2.51	6.24	38754

Figure 4: Split Tensile Strength of Hardened Concrete with Various Inhibitor Types

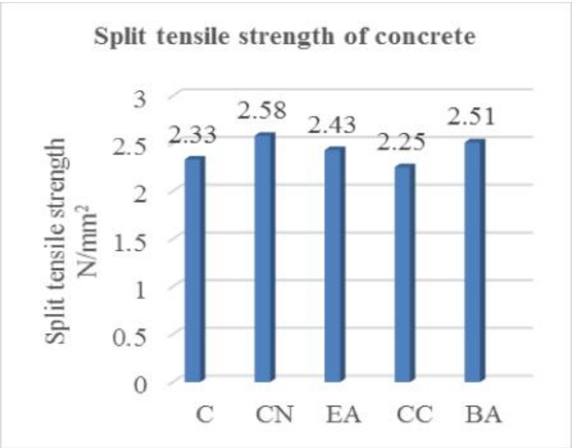


Figure 6: Corrosion Initiation Period of Hardened Concrete with Various Inhibitor Types

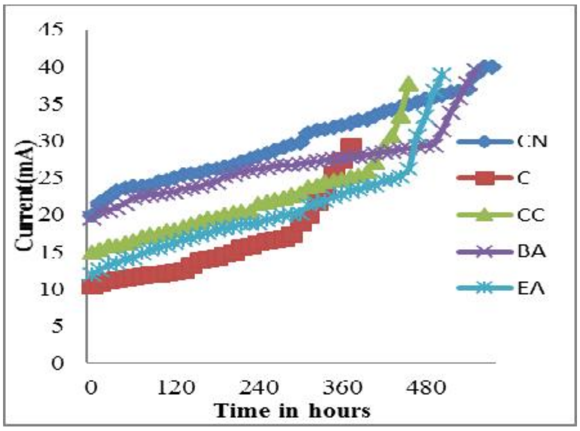


Figure 5: Flexural Strength of Hardened Concrete with Various Inhibitor Types

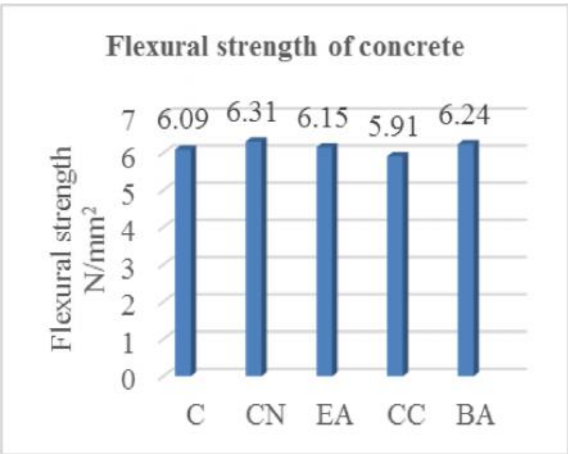
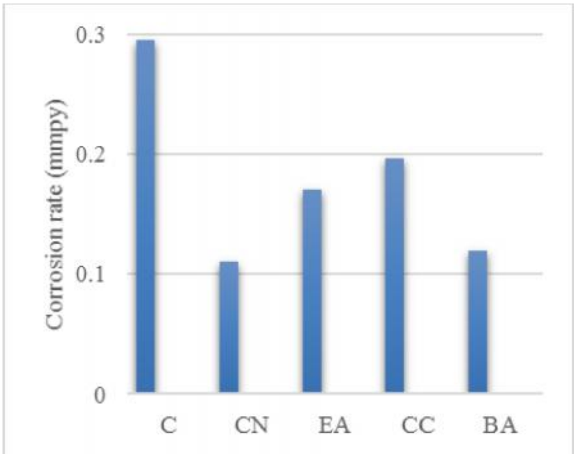


Figure 7: Corrosion Rate of Hardened Concrete with Various Inhibitor Types



concrete. The high electron's movement results in the increase in current rate. The green corrosion inhibitors are showed better results compared to conventional concrete.

CONCLUSION

The following conclusions can be drawn from this work, in the abilities of calcium nitrite, ethanol amine, Bambusaarundinacea and coconut coir to inhibit the initiated corrosion of steel embedded inconcrete:

1. Compressive strength, Split tension strength and Flexural strength of corrosion inhibitors admixed concrete are high compared to control concrete.
2. On Comparison, of the green corrosion inhibitors and inorganic corrosion inhibitors, the influences of them over mechanical properties of both are almost equal.
3. The results of accelerated corrosion tests indicate that Bambusa arundinacea and calcium nitrate, Coconut coir and Ethanol amine differ in corrosion initiation period by 9.8% and 12.5% respectively. In case of gravimetric weight loss test, Bambusa arundinacea and calcium nitrate, Coconut coir and Ethanol amine differ in corrosion rate by 8.1% and 15.2% respectively.
4. Hence Bambusa arundinacea can be considered as a substitute for calcium nitrite and coconut coir can be an alternative for ethanol amine.

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