

Effect of Corrosion Inhibitors in Reinforced Concrete

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ABSTRACT: Reinforced concrete is widely used as a construction material and plays an important role worldwide due to its excellent properties. Corrosion of reinforcement is one of the drawbacks in reinforced concrete structures, to overcome corrosion problem an attempt has been made in the present investigation by use of corrosion inhibitors. These inhibitors form protective hydrophobic film on the surface of reinforcement with high alkalinity present in concrete. Corrosion behaviour of reinforcement in concrete has been investigated for organic and inorganic inhibitors. The organic inhibitors were extracted from *Azadirachta indica* (neem) and *Ruta graveolens* plants and the inorganic inhibitors used were Sodium Nitrate and Ethylenediaminetetraacetic disodium dihydrate. The inhibitors were added during mixing of concrete and then the reinforced concrete specimens were immersed in the hydrochloric acid (HCl), sodium chloride (NaCl) and magnesium sulphate (MgSO₄) solution to induce corrosion. The corrosion resistance of the reinforcement was evaluated with the help of weight loss measurement and half cell potentiometer study. The results of inhibitors studied showed that *Azadirachta indica* has superior corrosion inhibition efficiency compared to the other inhibitors in acid and chloride solution. Ethylenediaminetetraacetic disodium dihydrate exhibited good corrosion inhibition efficiency in sulphate solution. It was also observed that the efficiency of inhibitors depends on the exposure environment.

KEYWORDS: Corrosion inhibition, organic inhibitors, inorganic inhibitor, exposure environment, inhibition efficiency.

I. INTRODUCTION

Since twentieth century, the use of reinforced cement concrete (RCC) has become common practice due to its excellent properties compared to other construction materials like steel structures, bamboo, clay, bark, mammoth ribs etc. RCC is relatively cheap and easy to maintain. This has led to the widespread use of reinforced and pre-stressed concrete in the construction of structures and infrastructure due to its strength, fire resistance, durability etc. In spite of its advantages, there are some drawbacks with reinforced concrete; one among them is degradation of the reinforced concrete structures due to corrosion of reinforcement. Corrosion degradation of steel reinforcement in concrete is due to aggressive agents present in the surrounding environment, which affects the durability of the structure and leads to the premature failure. Some of the reasons for the degradation of reinforced concrete are chloride attack, acid and sulphate attack, reaction of alkaline pore solution with the carbon dioxide present in the atmosphere [1]. These break down the thin oxide protective layer which surrounds the reinforcement and makes the steel reinforcement susceptible to corrosion [2]. As the process of corrosion sets in, the products of corrosion in the form of rust expand within the structure and leads to cracks, spalling and low structural bearing strength of the structure.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

Preventive measures being used in the construction industries to increase service life of reinforcement in concrete structures are coating reinforcement with epoxy or zinc, waterproofing, reducing water/cement ratio, increasing the cover over reinforcement, commercial chemicals, cathodic protection, penetrating sealers, etc. [2]. One of the most economical and recently used techniques to control or delay the corrosion of reinforcement in concrete is the corrosion inhibitors. The application of inhibitors to the reinforced concrete structure can be done during mixing of concrete or can be applied on the surface of already existing reinforced structure for repair works [3]. Inhibitors can be both organic and inorganic depending on their use. Organic inhibitors include extracts from plants. The advantage of green inhibitor over chemical inhibitors as they are readily available, less toxic, biodegradable, do not contain heavy metals, environmentally friendly and easily renewable [4].

The inhibitors not only participate in reducing the rate of corrosion but it also takes part in the properties like compressive strength of the structure. Inhibitors are a chemical substance or extracts from plant, when added in small concentration delays the rate of corrosion [5]. They form a hydrophobic film on the surface of reinforcement by adsorbing either ions or molecules of inhibitors on the surface. It reduces the corrosion of reinforcement by blocking cathodic or anodic reaction. The use of inhibitors is simple and economical with good inhibiting effect. The effectiveness of inhibitors depends mainly on the concentration of inhibitor, more the concentration more is the inhibitor effect on corrosion [6]. The application requires transport of inhibitor to the reinforcement where it has to reach sufficiently on the surface of reinforcement to protect the steel against corrosion or to reduce the rate of ongoing corrosion. The application of inhibitor does not require any skill it only depends on adding of inhibitor in proper proportion [7].

Many researchers have carried out the behaviour and efficiency of both organic and inorganic inhibitors in terms of its ability to reduce or delay corrosion process. Some of the published work has been briefly highlighted in the following paragraphs.

a) Efficiency of inhibitors: A. Krolikowski et.al. [8] have shown that the efficiency of an inhibitor decreases with increase in time, and depends on the concentration of inhibitor. H. Zarrok, et.al. [9] report that the inhibitors prevent the onset of corrosion if the specimens were flushed before the ingress of chloride. The web site, theconstructor.org [10] report that the rate of penetration of migrating inhibitors will be more at initial stage and reduces as it reaches greater depth. Corrosion of reinforcement can be prevented or delayed by taking care in the selection of type of cement, admixtures, type of concrete, water/cement ratio, adding inhibitor. Abdulrahman A.S et.al. [11] have observed that the inhibition efficiency increases with decrease in temperature. It was observed from literatures that, organic inhibitors show higher inhibition efficiency as compared to inorganic inhibitors.

b) Migrating inhibitor: Dulger B et.al. [12] have found that calcium nitrate is able to inhibit the pitting corrosion of steel and the optimum corrosion inhibitor efficiency was observed below unity. It was also found that calcium nitrate will be effective as a penetrating corrosion inhibitor for steel in concrete if it is present in the sufficient concentration. In present investigation the efficiency of organic and inorganic inhibitors in different exposure conditions are carried out with the help of half cell potentiometer and weight loss measurement.

II. MATERIALS AND METHODS

The materials used for the investigation, were subjected to preliminary tests to assess their characterisation. The binding material used was cement of OPC 43 grade with specific gravity 3.279. Natural river sand was used as a fine aggregate with specific gravity of 2.53, conforming to zone II and natural coarse aggregate of size 12.5mm down size with specific gravity of 2.657 was used in the preparation of concrete. The grade of concrete used was M25 which was designed as per Indian Standard Code [13]. Prisms of size 450 X 75 X 75 mm. were used in the preparation of specimens. Extracts of Organic inhibitors namely Azadirachta indica (neem) and Ruta graveolens. Inorganic inhibitors Sodium Nitrate and EthylenediaminetetraAcetic disodium dihydrate were introduced to the concrete prisms at time of mixing to determine their corrosion resistance capacity.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

2.1. Preparation of plant extract

The leaves of *Ruta graveolens* and *Azadirachta indica* were dried and made into fine powder. 15 grams of the powder was subjected for extraction using 100 ml Methanol at room temperature for 24 hours filtered through Whatman No. 4 filter paper. The extracts were recovered by filtration and kept at 40°C in a rotary vacuum evaporator. The residue was collected and stored at 4°C for further use. 15g of these organic extract were used for the experiment [14].

2.2. Preparation of concrete specimens

Reinforced concrete prisms of size 450 X 75X 75 mm were casted. Two Reinforcement bars of diameter 8mm and length 450mm were embedded while casing at a distance of 37.5mm of the prism and 20mm from the bottom to determine the corrosion rate of the same. Five groups of specimen were prepared and each one group consisted of 6 specimens. Inhibitor admixtures, namely 15g of *Ruta graveolens*, *Azadirachta indica*, Sodium Nitrate and 70.2g of Ethylenediaminetetraacetic disodium dihydrate were used for the experimental programme. The inhibitors were applied to the concrete during mixing. The prisms were demoulded after 24 hours of casting and they were subjected to curing. After 28 days of curing the two specimens from each group were immersed in acid, sulphate and chloride solution to induce corrosion. The reinforced prisms were subjected for testing for rate of corrosion using Half-cell potentiometer and weight loss at an interval of 7 days up to 56 days. The schematic representation of reinforced concrete prism is shown in fig. 1



Fig. 1: Schematic representation of reinforced concrete prism

III. EXPERIMENTAL PROCEEDURE

The corrosion behaviors of the embedded reinforcement bar were monitored by weight loss measurement and half cell potentiometer. Reduction in weight of the specimen caused due to corrosion was found at regular intervals of 7 days up to 56 days. The extent of corrosion of the reinforced bar embedded in concrete was measured at regular intervals of 7 days using half-cell potentiometer. Electrical potential of a point on surface of reinforced bar was measured comparing its potential with copper-copper sulphate reference electrode using a high impedance digital multimeter. The experiment was conducted over a period of 56 days.

The measured values of Half-cell potentiometer can be interpreted on the values given in below table [1]

Table 1- Percentage chance of corrosion activity measured in half cell potentiometer

| SI NO | Half- cell potential (mV) relative to Cu-Cu sulphate reference electrode | % chance of corrosion activity |
|-------|--|--------------------------------|
| 1 | Less than -200 | 10% |
| 2 | Between -200 to-300 | 50% |
| 3 | Above -350 | 90% |

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

IV. RESULTS AND DISCUSSION

The following are the results obtained from investigations carried out to test the efficiency of corrosion inhibitors.

4.1. Half cell potential measurement: Half cell potential measurement of reinforced bars is one of the most used methods to determine the corrosion potential of reinforcement bars embedded in concrete. The Instrument gives the results in terms of mili-Volts, Higher the voltage more will be corrosion potential [Table 1]. The graph [1,2,3,4,5,6] below present the corrosion potential as a function of exposure period for concrete specimens with and without inhibitor immersed in 5% HCl, 5% NaCl and 5% MgSO₄ solutions to initiate corrosion.

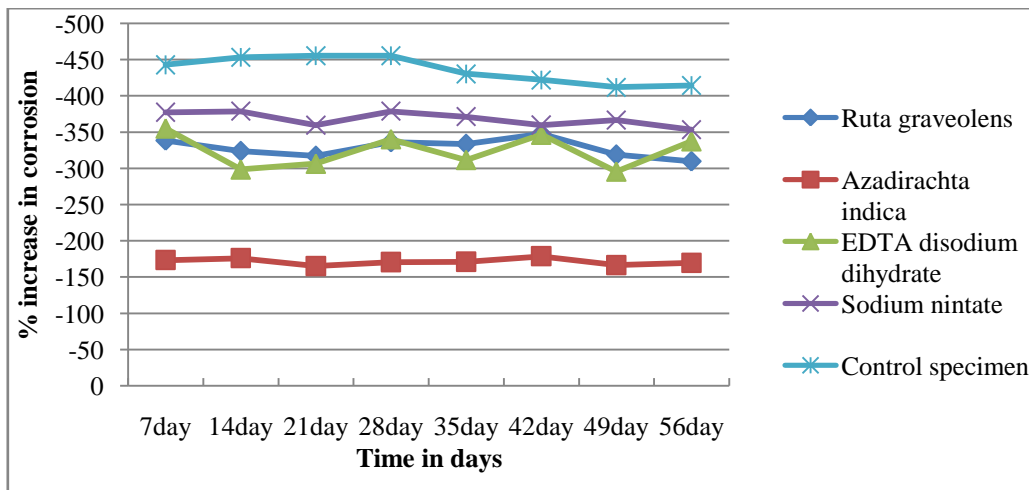


Fig. 2: Average percentage increase in corrosion of top reinforcement immersed in 5% HCl solution

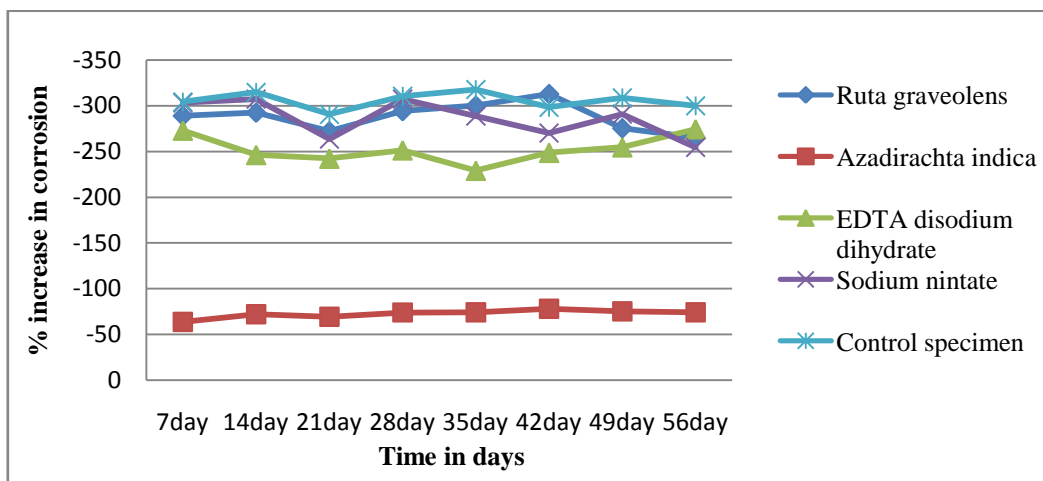


Fig. 3: Average percentage increase in corrosion of bottom reinforcement immersed in 5% HCl solution

Figure 2 and 3 shows the comparison of averages of percentage increase in corrosion of organic inhibitors i.e. Ruta graveolens and Azadirachta indica, inorganic inhibitors Sodium Nitrate and Ethylenediaminetetraacetic disodium dihydrate immersed in 5% HCl solution. The inhibition performance of Azadirachta indica found to be better when compared with other inhibitors. The efficiency of the other inhibitors, namely Ethylenediaminetetraacetic disodium dihydrate, Ruta graveolens and Sodium nitrate is in decreasing order respectively. It was observed that half cell potential reading was more in bottom reinforcement as compared to the top reinforcement.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

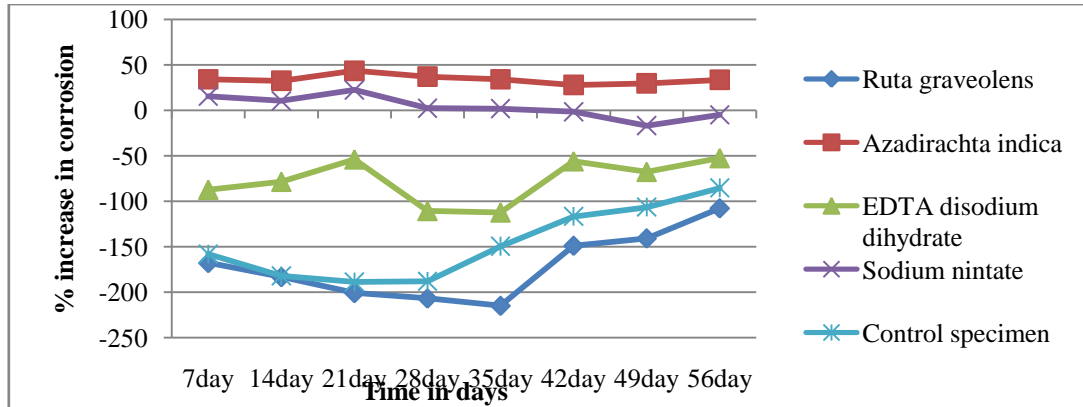


Fig. 4: Average percentage increase in corrosion of top reinforcement immersed in 5% NaCl solution

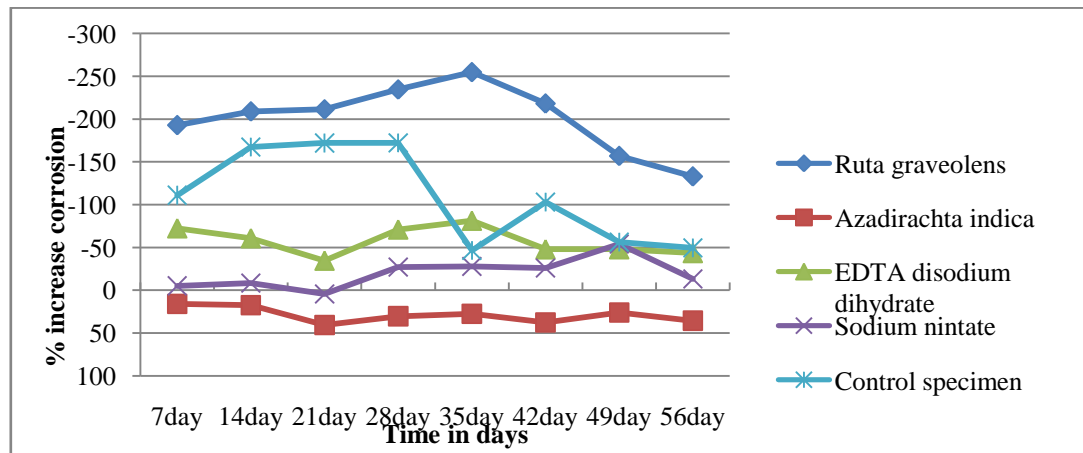


Fig. 5: Average percentage increase in corrosion of bottom reinforcement immersed in 5% NaCl solution

Figure 4 and 5 shows the comparison of averages percentage increase in corrosion of inhibitors immersed in 5% NaCl solution, the efficiency of Azadirachta indica is more compared to Ruta graveolens and inorganic inhibitors. Ruta graveolens showed very low corrosion inhibition in sodium chloride solution. There was gradual decrease in the half cell potential reading and this may be due to good adsorbent capacity of inhibitors on the surface of reinforcement, which blocks the entry of chloride solution.

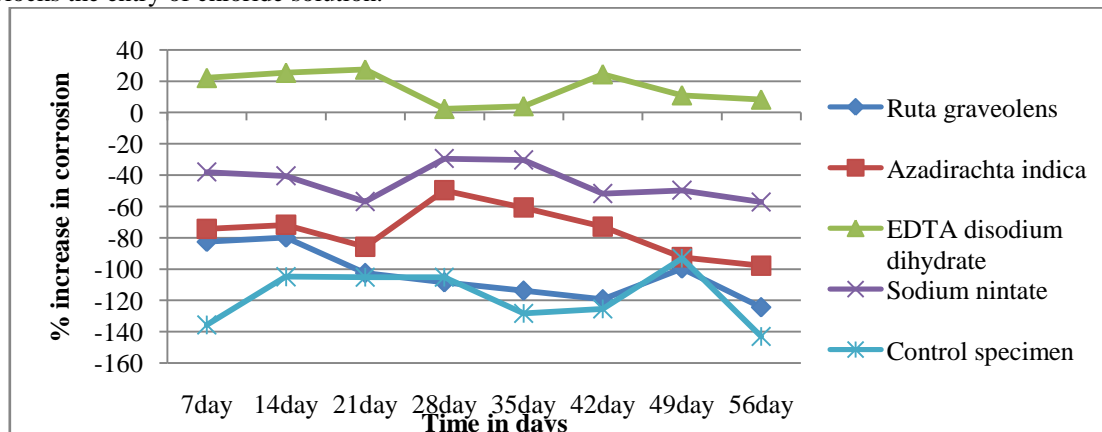


Fig. 6: Average percentage increase in corrosion of top reinforcement immersed in 5% MgSO₄ solution

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

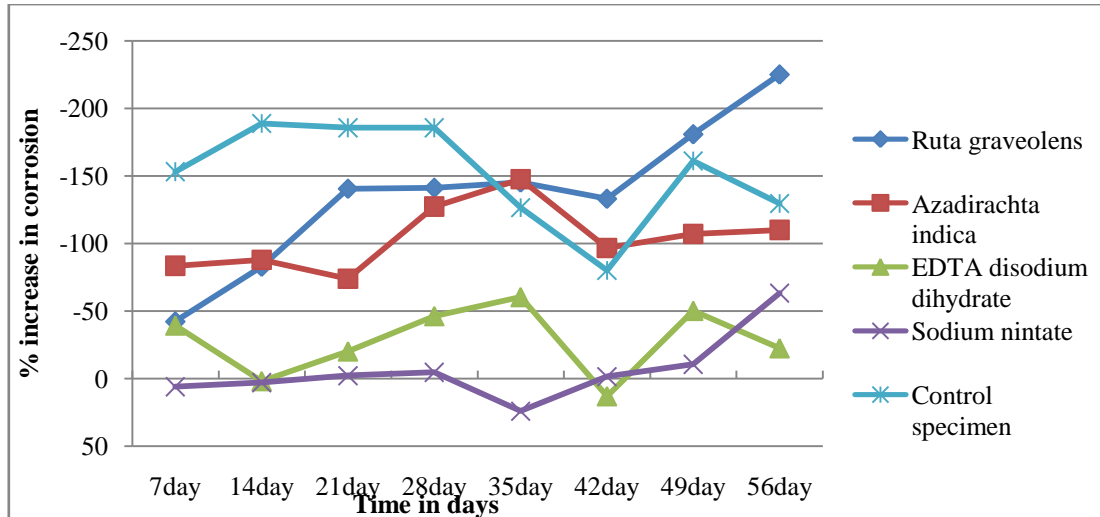


Fig. 7: Average percentage increase in corrosion of bottom reinforcement immersed in 5% MgSO₄ solution

Figure 6 and 7, shows the comparison of averages percentage increase in corrosion of the inhibitors in MgSO₄ solution. The efficiency of inorganic inhibitors i.e. Ethylenediaminetetraacetic disodium dihydrate and Sodium Nitrate was more compared to organic inhibitors. The control specimen without inhibitors in its matrix exhibited maximum corrosion in reinforcement.

4.2. Weight loss measurement: The simplest and longest established method of estimating corrosion loss in reinforced concrete is weight loss analysis. The weighed specimen under consideration is introduced into the acid solution to induce corrosion, and later removed and checked for percentage weight loss of the specimens. The results are insignificant; weight loss of the specimens was mainly due to concrete and partially due to reinforcement.

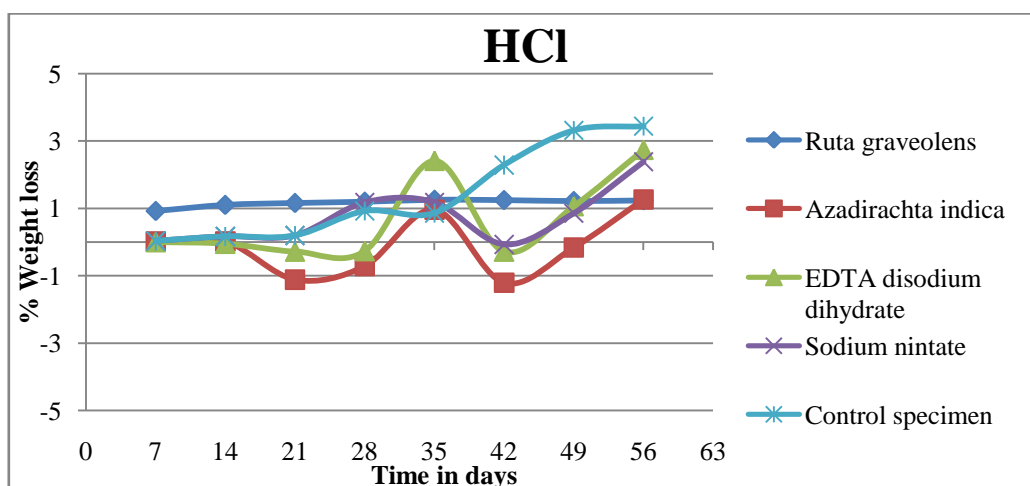


Fig. 8: % Weight loss of concrete reinforced prisms immersed in 5% HCl solution

It was observed that weight loss measurement conducted for the reinforced concrete prism immersed in HCl solution showed gradual decrease in its weight which might be due to vigorous reaction of acid with alkaline concrete as shown in fig. 8. The maximum weight loss in specimens was mainly due to concrete and partially due to reinforcement.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

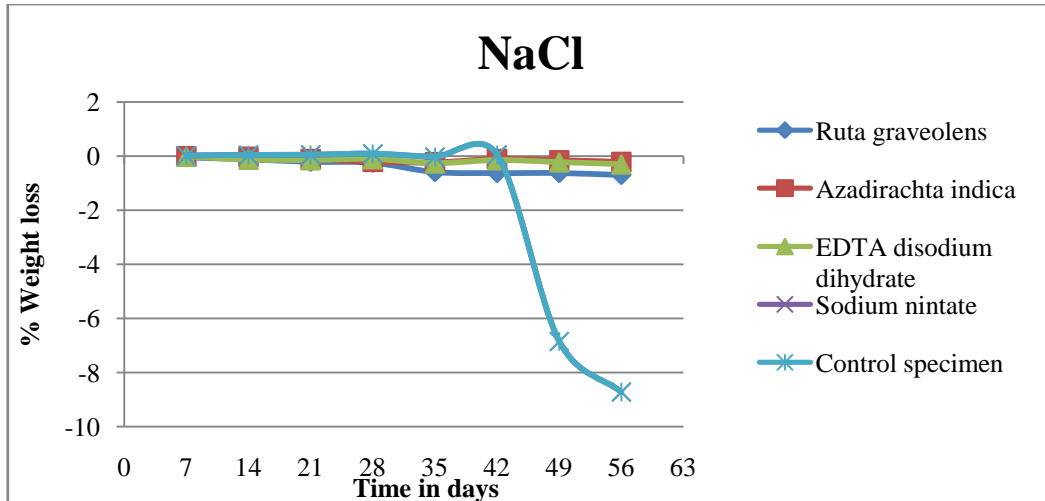


Fig. 9: % Weight loss of concrete reinforced prisms immersed in 5% NaCl solution

It was observed that there was gradual weight gain in specimens immersed in 5% NaCl solution, which might be due to the ingress and deposition of chloride ions inside the pores of concrete as shown in fig. 9. The weight gain in the specimens is mainly due to concrete, by water absorption in concrete pores.

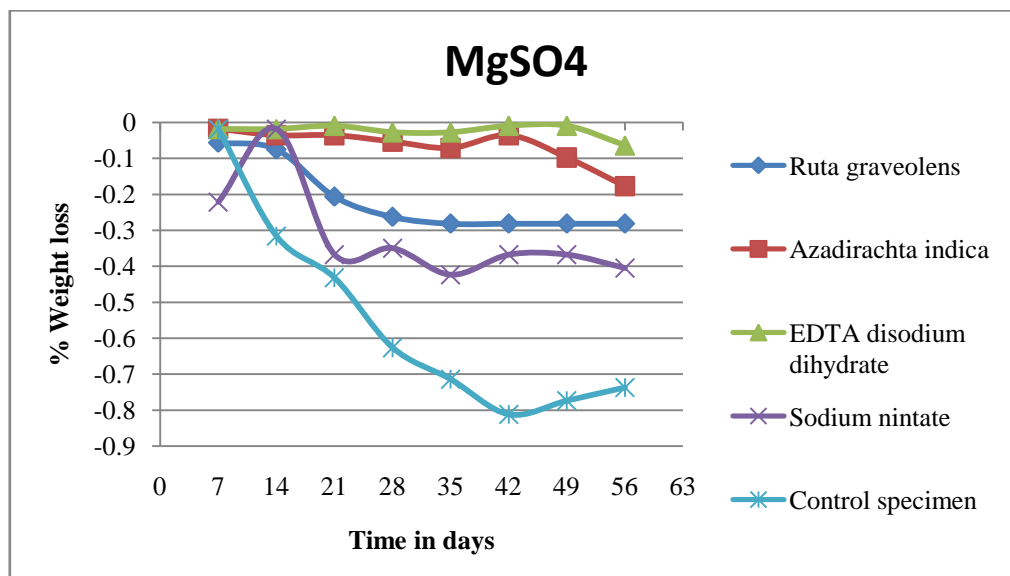


Fig. 10: % Weight loss of concrete prisms immersed in 5% MgSO4 solution

It was observed that there is gradual gain in weight of prisms immersed in 5% magnesium sulphate solution as shown in fig. 10. This gain in weight may be due to absorption of water in concrete pores. The contribution to the weight gain is mainly due to concrete and partially due to reinforcement embedded in concrete.

V. CONCLUSION

Based on the results of this experimental investigation on effect of corrosion inhibitors in reinforced concrete under corrosive environment, the following conclusion was drawn:

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

1. Measurement of corrosion potential with Half-Cell potentiometer is very rapid and can be used effectively to determine the rate of corrosion easily.
2. Higher corrosion was observed in the bottom reinforcement when compared to the center reinforcement due to lesser cover.
3. The organic inhibitor, Azadirachta indica showed better inhibition efficiency in acid and chloride environment.
4. The efficiency of EDTA disodium dihydrate was better in magnesium sulphate environment.
5. Compared to all the inhibitors Ruta graveolens showed least corrosion inhibition efficiency.
6. Weight loss measurement of the reinforced concrete prism was insignificant. Weight loss was mainly due to concrete and partially due to reinforcement.
7. Ruta graveolens showed very less corrosion in HCl and NaCl solution.
8. The inhibitor that is to be used for a specific environment has to be different. A specific type of inhibitor is to be suggested for a particular environment. This can be found out from experimental investigations.

ACKNOWLEDGEMENT

We sincerely thank management, CEO, Principal, Head of Department and Professor and Head, Department of Microbiology of M.S.Ramaiah Institute of Technology, Bangalore-560054, affiliated to VTU, Belgaum for the facility provided to conduct the experimentation and all the technical guidance.

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