Experimental Study on Corrosion Prevention In R.C. Slabs

K. P. Senthilnathan[1],
[1] Asst. Professor, Dept. of Civil Engg.
Chettinad college of Engg & Technology,
Puliyur, Karur Taminadu,
India,

Dr. R. Murugesan[2]
[2] Professor,Dept. of Civil Engg.
Institute of Road and Transport Technology,
Erode.Taminadu, India Erode

G. Vijayakumar[3],
[3] Asst. Professor, Dept. of Civil Engg.
University College of Engineering ,
Ariyalur,Taminadu, India,

Abstract - **Most of the structures while in service are subjected to aggressive influences of environment, these corrosion attacks on structures cause damage and lead to failure of the structural element or the whole structure. Corrosion causes deterioration of material and leads to destruction of structures, especially in coastal and industrial area. Corrosion of steel is an electro-chemical phenomenon. Electro-chemical corrosion result because of the existence of different metals of non-uniformities in steel or non-uniformities in chemical or physical environmental, afforded by the surrounding concrete. This project is aimed at preventing corrosion in RC slab using anti-corrosive agents such as providing zinc coating to the steel roads. In this work an attempt is planned to apply the coating to the rebars with anti-corrosive agents. In order to study the corrosion of rebars up to the cracking of concrete, in a short-term time, the corrosion process is accelerated by impressing a direct current, the corrosion process is monitored continuously. After the corrosion process is over, load test is to be conducted and the results of the study are presented**

Keywords -. **OPC - Ordinary Portland Cement, GGBS-Ground Granulated Blast Furnace Slag, NZ - Nito-Zinc primer coating, UC - Uncoated**

I. INTRODUCTION

Concrete is the mostly and widely used man-made construction material in the world, and second only water as the most utilized substance on the planet. It is obtained by mixing cementitious material, water, and aggregate in required proportions. The mixture when placed forms and allowed to cure hardness into a rock like mass knows as concrete. Concrete has high compressive strength, but its tensile strength is very low. In situations where tensile stresses are developed the concrete is strengthened by steel bars called reinforced cement concrete.

Reinforced cement concrete is used throughout the world to build infrastructure and building. Today, the large numbers of civil infrastructures around the world are in a state of serious deterioration due to carbonation, chloride attack, etc.

A. Corrosion

Corrosion is defined as the destruction of material due to chemical reaction with the environment, and also the loss of steel due to the formation of rust.

The corrosion of steel reinforcement is the depassivation of steel with reduction in concrete alkalinity through carbonation. Most material undergo corrosion on exposure to natural environments (such as air, water, and soil) or other artificial environments (such as gases, liquids, and moisture).

B. Corrosion process

Corrosion of steel is an electrochemical phenomenon. Electrochemical corrosion results because of the existence of different metals or non-uniformities in steel or non-uniformities in chemical or physical environment, afforded by the surrounding concrete. This electrochemical corrosion is believed to be the predominant case for essentially all of the corrosion that occurs. The initiation of corrosion process is shown in Fig 1.
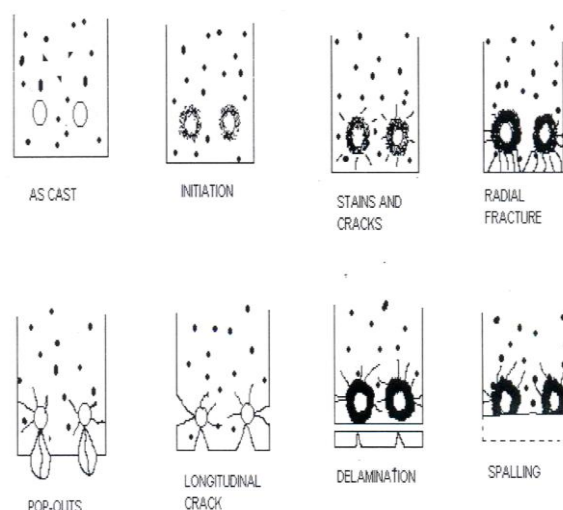

Figure 1. Typical Symptoms of Corrosion in a RC beam

C. Corrosion Mechanism

Corrosion of steel in concrete is initiated and maintained generally by two mechanisms.

i) Presence of depassivating ions (particularly chlorides) in large enough amounts to destroy passivating films locally. **(Fig No. 2)**

ii) Reduction in alkalinity of concrete (pH around 9.5) due, to the effect of atmospheric carbon-di-oxide.
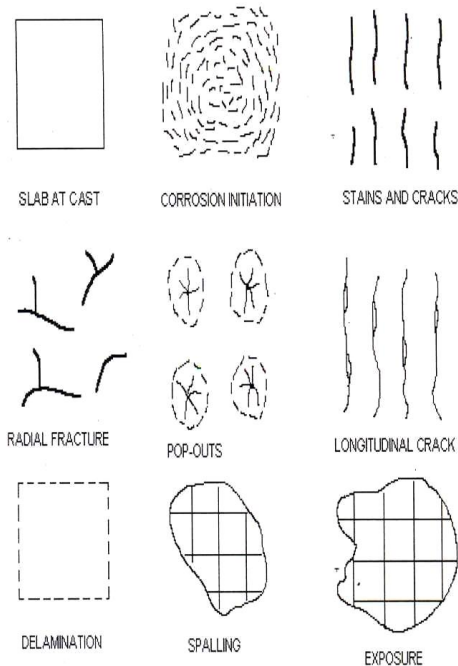

Figure 2. Typical Symptoms of Corrosion in a Reinforced Concrete Slab

The reaction at the anode and cathode are expressed as given below.

$Fe \rightarrow Fe^{2+} + 2e^{-}$ (at Anode)

$O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-}$ (at Cathode)

$Fe^{2+} + 2OH^{-} \rightarrow Fe(OH)_2$ (at Anode)

$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3$ (at Anode)
(Hydrated red rust)

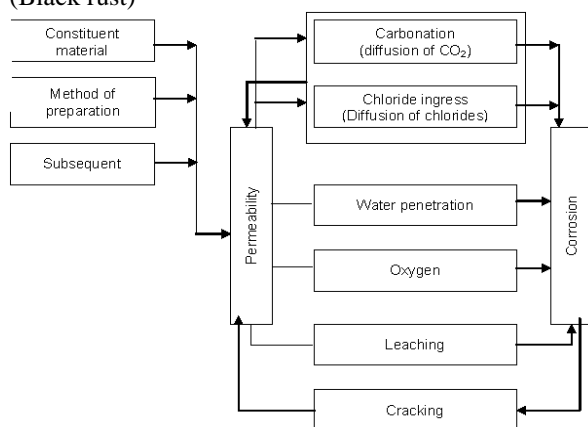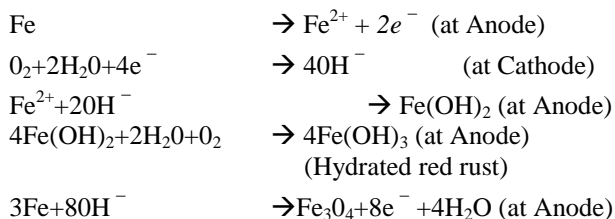$3Fe + 8OH^{-} \rightarrow Fe_3O_4 + 8e^{-} + 4H_2O$ (at Anode)
(Black rust)

Figure 3. Corrosion Permeability Interaction Model

Current flows in the steel from anode to cathode in the presence of oxygen and water and results in the production of hydroxyl ions at the cathode.

As these migrate to the anode they react with ferrous ion and form hydrous ions oxide (Black rust). The red rust is responsible for the cracking of concrete because its volume is four times larger than that of steel, while the black rust volume is only twice as large as steel. The major factors influencing corrosion of rebars are shown in Fig 3.

D. Factors Influencing Corrosion

a) Concrete quality
b) Chloride content
c) Alkalinity of concrete
d) Resistivity of concrete
e) Cover thickness
f) Sea Water Attack (Environment)

E. Methods of Corrosion Control

a. Corrosion control by mix proportions:
b. Corrosion control by coatings:

Coatings may be of the following types
1) Organic coating on rebars
2) Inorganic coatings on rebars
3) Metallic coatings on rebars
4) Coating on concrete
Concrete surface *coatings may be of the following types:*
i) Inorganic coatings
ii) Organic coatings
c. Cathodic Protection
d. Corrosion inhibitors:
e. Stainless Steel Reinforcement:
f. Chloride content

F. Causes for corrosion

1) Surface heterogeneity
2) Impurities, grains and grain boundaries, cut edges
3) Environmental variations
4) Industrial: H_2S, NH_3, SO_2
5) Marine: salt
6) Urban
7) Rural

All steel in contact with soil is subjected to corrosion. Also local condition can causes unequal corrosion; the rate is normally around 5 μm/year, but can vary between 0 μm/year and 50 μm/year.

The copper earth mats can causes galvanic corrosion. Copper in direct electrical contact with the tower steel increases the rate of the corrosion: 500μm/year and even higher have been measured. Steel stays on wood poles have broken due to galvanic corrosion after only 10 years in service. The corrosion rate on steel towers caused by galvanic action is much smaller than that of the stays. The tower has a much larger area exposed to the soil, and corrosion proceeds more evenly on this large area.

G. Corrosion Behaviour Of Steel In Concrete

The parameters normally influencing the corrosion of reinforcement in concrete can be broadly classified into two namely, environmental and material parameters, with the material parameters including both that are relevant the usefulness of the formation generated.

The concrete characteristics such as alkalinity, resistivity, permeability and diffusion, influence the time to initiation of corrosion initially and later up to the cracking of concrete. These parameters vary with time. The final result depends both on future hydration of cement in concrete & the deterioration of the concrete itself. Once the cracking for, the environment may be considered to be directly in contact with the steel reinforcement.

The reinforcement is generally in a passive state up to the initiation of corrosion and after initiation it is influenced by the environment in concrete up to cracking and lateral by the environment itself. The major governing the rate of corrosion are the metallurgical composition of steels, surface characteristics & the mechanical working of steel.

II. SCOPE AND OBJECTIVE OF THE PRESENT STUDY

The slabs are of a variety of design and were constructed to different specifications. The slabs increase in service in more than 100 years and are experiencing deterioration on various accounts.The scope of this work will bring out some of the facts related to slab corrosion and in turn will help in implementation of suitable corrosion preventing strategies.

Basically there are three protection techniques which prevent the corrosion of rebars in concrete.
a) Changing the environment around the reinforcing steel, by decreasing the amount of chloride reaching the rebar to a value low enough to retard or prevent corrosion.

b) Changing the nature of rebar surface so as to resist corrosion, either by surface treatment or bulk alloying.

c) Changing the electrochemical nature of the surface of the rebar by impressed current (cathodic protection).

A.Details of the work

1). Admixtures Used

One of the methods that have been selected for the present work is the application of coating material to the rebars embedded in concrete. It has been decided to study the effectiveness of Nito-zinc primer (manufactured by FOSROC chemicals India Ltd) as an anti-corrosive agent and introducing the GGBS(Ground Granulated Blast Furnace Slag) as a admixtures for partial replacement of cement.

2. Shape and size of the specimen

The size of the slab used was 500mm long and 500mm width and 50mm in section. Clear cover to steel 15mm.

Figure 4 Specimens Reinforcement Details

3) Modification of the steel surface

In this method of prevention of corrosion of rebars, anti-corrosive coating is applied on the rebar surface before concreting is done. This coating protects steel from corrosive agents and thus prevents corrosion. This type of treatment is necessary for rebars when chloride concentration is normally high.

The essential requirements of a good coating to rebars embedded in concrete are:
♦ It should be alkali and chloride resist.
♦ It should provide adequate bond between steel and concrete.
♦ It should have proper adhesion to steel.
♦ It should be capable of withstanding handling stresses,

Advantages of using epoxy coating are:
1)Ease in application
2)Low shrinkage after curing.
3)Viscosity is high that it can be applied all along the rod easily.
4)Good resistance to moisture.
5)Good chemical resistance.

4). Mix Proportion of the Coating

The mix proportion of the coating may be varied from structure to structure depending on the aggressive nature of the environment. Rich mixes may be used for aggressive environments. In this work the mix proportion of the coating used is:

Metallic zinc: Epoxy resin - 3:2 (by weight)

5). Application of the coating material
♦ The reinforcement is cleaned with the rust clear solution in order to remove the loose rust particles present on the reinforcement.

♦ After application of the rust clear solution the reinforcement is washed with water and wiped out.

♦ Holes are drilled in the main rods at the center to have electrical wire connection.

♦ The coating material is applied with a brush and it is allowed to dry for 24 hours. Thereafter, the second coat is provided after the application of first coating in order to fill the small gaps, if any.

♦ After application of the coating material the initial weight of the main rods is taken.

B. Methods used to induce the corrosion

The method used to induce corrosion is Galvanostatic method (accelerated corrosion method)

1). Galvanostatic Method (Accelerated Corrosion Test)

The basic principle of this method is derived from the galvanic cell theory. The slabs were partially immersed in 3% Sodium chloride solution. The slabs were subjected to corrosion by supplying current from an external D.C. source. The schematic diagram of this test set-up is shown in Fig 4.

From previous analysis, it was found that the density of current around 1.8 to 2.0 mA/cm^2 of the surface area of the rod was required to induce corrosion. The slabs placed in fibre reinforced plastic tank were subjected to a current density of 1.8 mA /cm^2 from an external D.C source. The stainless steel plate, which acts as cathode was placed below the slab as, shown in figure.

Fig 5. Experimental test setup

The stainless steel plate was 1.5mm thick. The current density was adjusted using knobs provided in D.C rectifier to maintain a constant current density throughout the test.

2). Half Cell Potentiometer for Measuring Corrosion Intensity

This method is sometimes called the corrosion potential of rest potential method/ corrosion potential measurements. The objective of this method is to measuring the voltages that are present over rebar in concrete. The half-cell is a hollow tube containing a copper electrode and immersed in copper sulfate solution. The bottom of the tube is porous and covered in a sponge material.

The copper sulfate permeates this sponge that can then be placed on a concrete surface allowing an electrical potential (voltage) to be measured. The objective of the method is to measure the voltage difference between the rebar and the concrete over the rebar. Large negative voltage (-350mV) indicate that corrosion may be taking place. Voltage smaller than about -200mV generally mean corrosion is not taking place.
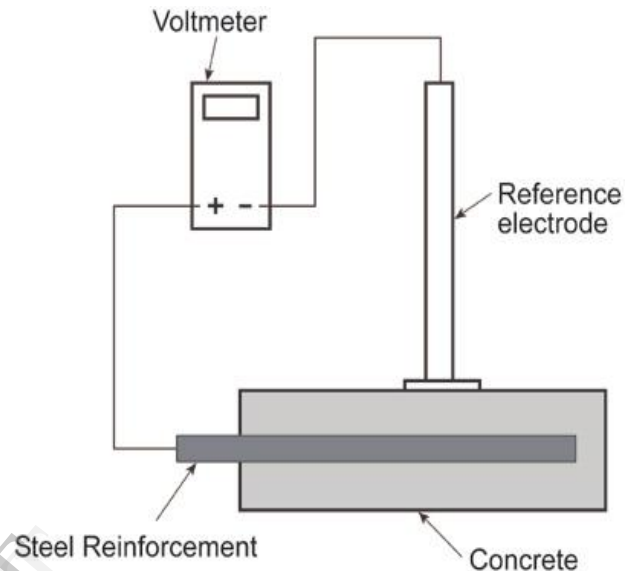

Fig 6. Half cell measurement circuit for detecting rebar corrosion

3). Method of Preparation of Half-Cell

♦ Check electrical continuity of cell between copper rot and terminal of the wire, which is connected to the copper rod.

♦ Clean the copper rod using emery sheet to obtain the red colour surface of the copper rod free from sulphate coating.

♦ Prepare saturated copper sulphate solution using copper sulphate crystals with glass beakers and glass stick.

♦ Remove the half-cell cover and fill with copper sulphate solution in the half-cell tube and close cover tightly.

♦ Keep the cell unit vertically for about 5 to 10 minutes so that the copper sulphate solution should permeate through sponge bottom of the cell.

ASTM limits prescribes the below 350mV corrosion do not occur. From the 350mv to 600mV. There is a potential head exceeds 600mV there is a probability of occurrence of corrosion. When the potential head exceeds 600mV there is a probability of 90% of the corrosion can occur.

Table 1. Potential Valve (ASTM Standard)

Corrosion	Potential (C-CSE)
> 95%	More Negative than -350mV
50%	-200 to -350mV
< 5%	More Positive than -200mV

III. RESULT AND DISCUSSION

A. R.C. Slab loading test

After completion of the galvanostatic process, the slabs were subjected to two points loading to initiate pure bending in middle third span. The left and right supports of the slab were simply supported. Gradual static loads were applied and deflections were observed. Loads at formation of cracks, crack propagation and crack width were noted. The slabs were tested to failure.
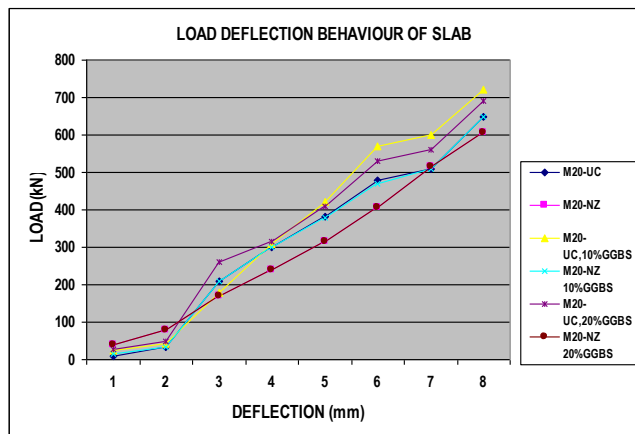

Figure 7. Load Vs Deflection behaviour of Slab

B. Weight loss on rebar

Measurement of weight loss of rebars is one of the methods used to qualify corrosion. The weight loss in main rods was calculated. The details of weight loss of rebar are given in the table

The Nito-zinc coated rebar is showing the less loss of weight than uncoated rods almost in all the beams. That the coating of rebar was 50% more effective than the uncoated rods in terms weight of loss of rebars. The corroded rebar was having the irregular shape (difference in cross-section) indicating that uniform corrosion did not take place. This lead to less load carrying capacity of the slab. The slabs were tested to failure. In the case of slabs subjected to accelerated corrosion the load carrying capacity was less than that of companion specimen. In the case of the slabs (both coated and uncoated) in which corrosion was accelerated for 100 hours the load carrying capacity of epoxy (Nito-zinc) coated beam was greater than that of uncoated slab. Comparison of the results of slabs with the ordinary Portland cement and GGBS cement indicates slabs with OPC exhibit higher load carrying capacity than beams with GGBS cement.
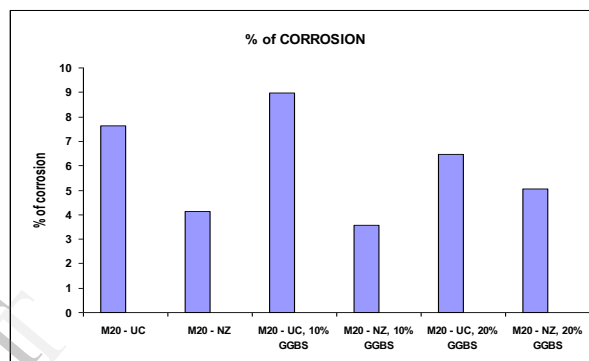

Figure 8. Crack Pattern on Specimen
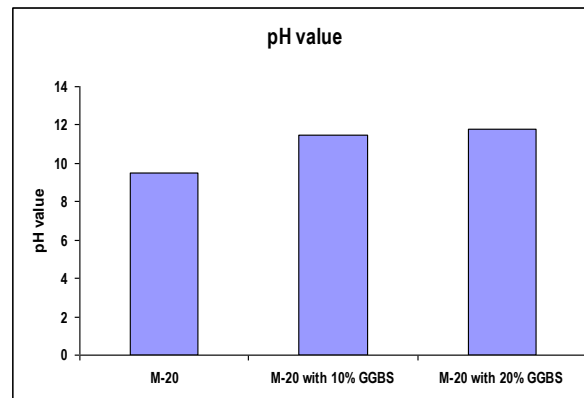

Fig.8 Percentage of Corrosion

Fig. 9 pH value

IV. CONCLUSION

In the present work an attempt was made to study the corrosion protection of rebar using coating materials and M20 grade of concrete. The efficiency of the coating was compared with that of the uncoated rebar. The weight loss method was used to determine the percentage of corrosion. The corrosion of concrete is taken as the end point of the corrosion process. The rate of corrosion was monitored using the saturated calomel as the reference electrodes alternative measurement. The rod diameter, spacing and cover are kept constant.

From this study the following conclusion can be drawn.

✓In the case of slab (with coated and uncoated rebar) which were subjected to 100 hours of accelerated corrosion, the load carrying capacity of epoxy coated rebar slab was greater than that of the uncoated rebar slabs.

✓The load carrying capacities of OPC slabs and GGBS (10%, 20%) cement slabs were compared. From this we observe that the load carrying capacity of the OPC slabs are higher than that of GGBS cement (replacement of cement by 20%) slabs.

✓The bond strength of coated rebar is practically same as that of uncoated rebar.

✓The pH value in the slabs cast with OPC and GGBS are same.

REFERENCES

1. A.R.Santhakumar, (2009) Concrete Technology, Third impression, oxford university press, New Delhi.
2. A.S.S.Sekar, V.Saraswathy and G.T.Parthiban, (2007) Cathodic Protection of Steel in Concrete Using Conductive Polymer Overlays, Int.
   J. Electrochem. Sci., **(2) 872 – 882**.
3. B.Kamashwari, K.Kumar, S.Sivakumar, (July-Sep 2010) Effect of reinforcement corrosion on flexural behavior of concrete beams, Amrapali, *Technical Journal of Civil Engineering*, Vol-I.
4. Gonzalez, J.A *et al*., (1998) "Some considerations on the effect of chloride ions on the corrosion of steel reinforcements embedded in concrete structures", Magazine of Concrete research, Vol **50**, No. pp. **190-197**
5. Gonzalez, J.A *et al*., (March 1990) "On the mechanism of steel corrosion in concrete. The role of oxygen diffusion", Magazine of Concrete research, Vol.**42**, No. pp.**23-27**
6. IS : 10262 -1982 , Recommended Guide Lines for Concrete Mix Design, Bureau of Indian Standards, New Delhi.
7. IS: 456-2000, Indian Standard Plain and Reinforced Concrete Code OF Practice, 4th Revision, Bureau of Indian Standards, New Delhi.
8. Jagadeesan, K., (Jan 1995) "Effect of corrosion on the reinforced concrete beams, "Ph.D., Thesis, Anna University.
9. Jennifer L. Kepler, David Darwin, Carl E. Locke, Jr., (May 2000) Evaluation of Corrosion Protection Methods for Reinforced Concrete Highway Structures, University of Kansas Center for Research, INC., Lawrence, Kansas.
10. Kannan, N., (March 1992) "Influence of cover on corrosion of reinforcement in concrete", M.E., Thesis, Coimbatore Institute of Technology.
11. Lamya Amleh and Saeed Mirza, (May 1995) 'Corrosion influence on bond between steel and concrete', Indian Control Journal, Vol **69** No.**5**.
12. Leema Rose, K. Suguna and P.N. Ragunath, (2009) Strengthening of Corrosion-Damaged Reinforced Concrete Beams with Glass Fiber Reinforced Polymer Laminates, *Journal of Computer Science* **5 (6): 435-439**.
13. M. Dugarte, A.A. Sagüés, R. G. Powers, I. R. Lasa, (2007) ″Evaluation of Point Anodes for Corrosion Prevention in Reinforced Concrete″, Paper No. 07304, **14** pp., Corrosion/2007, NACE International, Houston**.**
14. M. Z. Jumaat, M. M. Rahman and M. A. Alam, (June 2010) Flexural strengthening of RC continuous T beam using CFRP laminate, *International Journal of the Physical Sciences* Vol. 5(6), pp. **619-625**.
15. M.S. Shetty, Concrete Technology Theory and Practice, Chand (S.) & Co Ltd, India.
16. Makita, M., *et al.,* (1980) "Marine Corrosion-behaviour of reinforced exposed to Tokyo Bay", Performance of Concrete in Marine Environment, SP 65-16, ACI Detroit, pp. **271-289**.
17. R.K.Dhir,* M.R.Jones* and M.J.McCathy* (March 1994) 'Chloride-induced reinforcement corrosion', Magazine of Concrete research, 46, No.169, Dec **269-277**.
18. Senthilnathan, K.P. (2002) "Experimental studies on reduction of rebar corrosion on RC beams (using anti corrosive agents)" M.E., Thesis, Coimbatore Institute of Technology.
19. Srinivasan, S., *et al*., (Jan 1994) "Corrosion monitoring of marine concrete structures – on apparaisal", Indian Concrete Journal Vol **68**,No.**1**.
20. Sukumar.P, (Feb 2000) "Experimental investigation on the reduction of corrosion in RCC using Epoxy zinc coated rebar". M.E., Thesis, Coimbatore Institute of Technology.
21. Thangavel, K. *et al*., (May 1995) "Influence of protective coating on steel – concrete bond", *Indian Concrete Journal*, Vol 69 No.5 pp **289-293**.
22. Wibenga, J.G., (1980) "Durability of concrete structures along the north sea coast of Netherlands", Performance of concrete in Marine Environment, SP 65-16, ACI Detroit, pp **437-452**.