A Critical Challenge of Corrosion of Reinforcement & its Protection

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Abstract - The failure of concrete structures due to corrosion of embedded steel has caused damage of very high magnitude. Corrosion loss consumes considerable portion of the budget of the country by way of either restoration measures or reconstruction. Moreover, the repair operation themselves are quite complex and require special treatments of the cracked zone, and in most instances the life expectancy of the repair is limited. Many of the strategic reinforced and prestressed concrete structures have started showing signs of distress within a short period usually the condition of the structures is monitored by visual inspection and remedial measures are resorted to only when the condition becomes very serious by way to heavy rusting of steel reinforcements followed by cracking and spalling on concrete.

Keywords – Steel Corrosion, Assessment, Monitoring, Controlling techniques.

I. INTRODUCTION

Steel has been extensively used as the reinforcement for concrete structures from decades. So corrosion of reinforcing steel is one of the major causes of premature deterioration of reinforcement concrete structures worldwide. The steel commonly used in reinforced concrete generally have low to medium carbon and they are not heat treated. These steels are not susceptible to stress corrosion cracking in concrete. The failure of concrete structures due to corrosion of embedded steel has caused damage of very high magnitude. The corrosion products formed have been observed to exert enormous stresses on surrounding concrete, promoting the deterioration of the structure like concrete cracking, spalling, disbondment and ultimate failure of structure. Corrosion loss consumes considerable portion of the budget of the country by way of either restoration measures or reconstruction. Moreover, the repair operation themselves are quite complex and require special treatments of the cracked zone, and in most instances the life expectancy of the repair is limited. Accordingly, corrosion monitoring can give more complete information of changing condition of a structure in time. Hence, protection of reinforcement from corrosion will ensures that the structure serves for desired service life. Engineers need better techniques for assessing the condition of the structure when the maintenance or repair is required. These methods need to be able to identify any possible durability problems within structures before they become serious. This seminar reviews all the electrochemical and nondestructive techniques from the point of view of corrosion assessment and their applications to bridges, buildings and other civil engineering structures.

II. CORROSION MECHANISM & REASONS

Corrosion is an electrochemical process. In this process oxidation of Iron (Fe^{++}) molecules naturally occurs immediately after the bars are manufactured and exposed to the atmosphere and will continue long as sufficient oxygen and moisture are available to react with the steel. So corrosion is consists of an anode and cathode process. Following are some reasons of corrosion of reinforcement.

1. Water Permeability: Is the single largest factor for ignition and propagation of corrosion. Water not only takes part in chemical reaction but also works as a carrier for transporting harmful chemicals to concrete and rebars such as chloride ions. Higher permeability reduces resistivity of concrete. If the surface of the concrete is subject to long-term wetting, the water will eventually reach the level of the reinforcement, either through diffusion through the porous structure of the concrete, or by traveling along cracks in the concrete. Concrete roof decks, by their nature, are meant to be protected from moisture. However, the presence of moisture on roofing systems may result from failure of the roofing membrane, poor detailing of drainage facilities, or lack of maintenance of drainage facilities.

2. Oxygen Permeability: Oxygen is very much an essential part for corrosion to occur; it also plays an important role in setting up corrosion cells. Oxygen permeability produced due to cracks, difference in cover thickness and heterogeneity of concrete.

3. Carbonation: Is the major cause of corrosion. Carbonation of concrete has dual effect or reducing the alkalinity of concrete as well as releasing more water. Effect of carbonation increases with porosity of concrete, period of exposure and reduces with moisture in surrounding area. t is well known that if bright steel is left unprotected in the atmosphere a brown oxide rust quickly forms and will continue to grow until a scale flakes from the surface. This corrosion process will continue unless some external means is provided to prevent it. One method is to surround the steel with an alkaline environment having a pH value within the range 9.5 to 13. At this pH value a passive film forms on the steel that reduces the rate of corrosion to a very low and harmless value. Thus, concrete cover provides chemical as well as physical protection to the steel. Concrete is permeable and allows the slow ingress of the atmosphere; the acidic gases react with the alkalis (usually calcium, sodium and potassium hydroxides), neutralizing them by forming carbonates and sulphates, and at the same time reducing the pH value. If the carbonated front penetrates sufficiently deeply into the concrete to intersect with the concrete reinforcement interface, protection is lost and, since both oxygen and moisture are available, the steel is likely to corrode. The extent of the advance of the carbonation front depends, to a considerable extent, on the porosity and permeability of the concrete and on the conditions of the exposure.

4. Chloride Ingress: The best known and most damaging factor leading to corrosion is the chloride ingress (i.e. chloride entrance) most of failures are attributed ti this structures in cold climates where salt is used as deicing agent has reportedly shown distress due to this factor. The chloride ingress can be by diffusion, capillary suction as well as by permeation. Diffusion of chloride ions occurs through slow moments through simple absorption can suck in large amounts of chloride permeation of chloride ions is through cracks in concrete.Chloride ions react with iron compound and create a iron – chloride complex (fecl2) which also react with hydroxides (OH-) and form hydrated iron oxide compounds. Simultaneously oxygen (O2) react with water (H2O) and formed hydroxides. Together, this two reactions form a corrosion cell. At low levels of chloride in the aqueous phase, the rate of corrosion is very small, but higher concentration increases the risks of corrosion.

III. TECHNIQUES FOR MONITORING CORROSION OF REINFORCEMENT

Many of the strategic reinforced and prestressed concrete structures have started showing signs of distress within a short period usually the condition of the structures is monitored by visual inspection and remedial measures are resorted to only when the condition becomes very serious by way to heavy rusting of steel reinforcements followed by cracking and spalling on concrete. It is desirable to, monitor the condition of such strategic structures right from the construction stage by carrying out periodic corrosion surveys and maintaining a record of data. For measurement of the corrosion rate of reinforcing steel in concrete, any electrochemical and non-destructive techniques are available for monitoring corrosion of steel in concrete.

3.1. Open Circuit Potential Measurement

In reinforced concrete structures, concrete acts as an electrolyte and the reinforcement will develop a potential depending on the concrete environment, which may vary from place to place. The principle involved in this technique is essentially measurement od corrosion potential of rebar with respect to a standard refrance electrode.The steel rebar in concrete structure should be accessible in a few locations for giving electrical connection. The positive therminal of high impediance voltmeter is connected to exposed rebar and negative terminal to trance points and the corresponding potentials are recorded these are reffered to as either open circuit potential or corrosion potential.

Table No:1 – Open circuit potential corrosion

Potential	Possibility of corrosion (%)
Mare –ve than 275	>90
Between 275 - 125	Uncertain

More + ve than 125	< 10

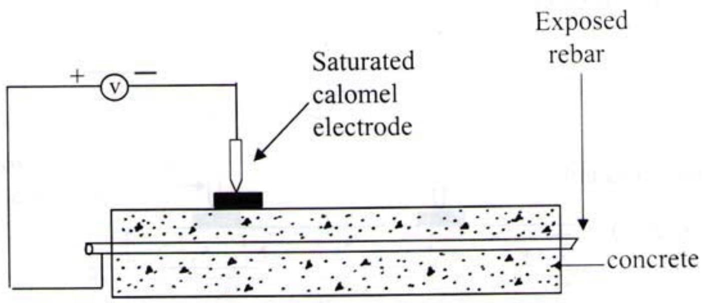

Fig.1. Open Circuit Potential Measurement

3.2. Surface Potential Measurements
During corrosion process, electric current flows between cathodic and anodic sites through the concrete and this flow can be detected by measurement of potential drop in the concrete.

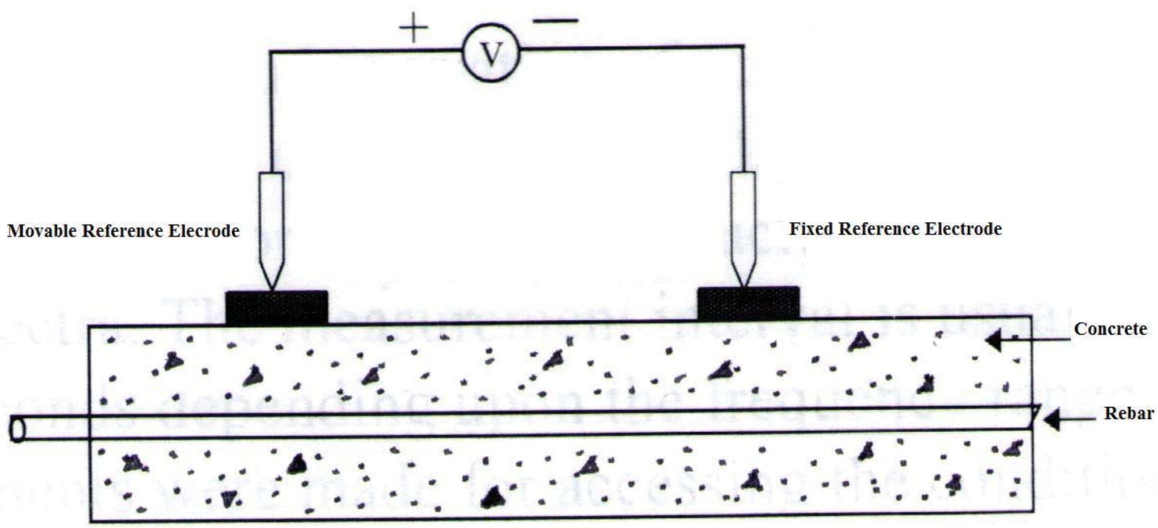

Fig.2. Surface Potential Measurement.

Hence surface potential measurement is used as non-destructive technique for identifying anodic and cathodic regions in concrete structure and indirectly detecting the probability of corrosion of rebar in concrete. Two reference electrodes are used for surface potential measurements. In this measurement, one electrode is kept fixed on the structure on symmetrical point the other electrode called moving electrode is moved along the structure on the nodal points. The potential of movable electrode when placed at nodal points is measured against the fixed electrode using a high impedance anodic area where corrosion is possible.

3.3. Cover Thickness Measurement
A cover meter or photometer is used for measuring concrete cover. By means of this it is able to detect rebar size, direction and position. Measurements are based on the damping of a parallel resonant circuit. An alternating current with a given frequency flows through the probe coil, thus creating an alternating magnetic field. Metal objects within the range of this field alter coil voltage as a function of cover and bar diameter. It comprises of a probe and an indicator unit. The electronic system, controls, indicator instruments are assembled on the indicator joint front panel. Eleven different bar diameter may be set in a rotary selector switch with a range from 8 to 34 mm. By means of this, the maximum cover thickness that can able to be measured is 120 mm. A loud audio signal and bright light on the detection head gives a clear warning of areas of low concrete cover (user programmable for depth of cover). Fig. shows the cover meter used for measuring the cover thickness as well diameter and size of the rebar.


Fig.3. Cover meter

IV. STRATEGIES FOR RESISTING CORROSION OF REINFORCEMENT IN CONCRETE

***Concrete**:* A common method of improving the corrosion resistance of structural element is to increase the concrete cover thickness. The increased cover provides an additional sacrificial layer to delay the permeation and diffusion of external agents and delays the ignition of corrosion. Also the key to avoid corrosion of the embedded steel is to have the proper thickness; well compacted and impermeable concrete. By achieving proper compaction of concrete, there is no space for permission of oxygen or external agents to affect embedded steel. So by taking proper precaution while making, placing and curing of concrete, corrosion resistance of steel will increase.

Corrosion Inhibitors: Corrosion inhibitors are defined as those chemicals which, when added to fresh concrete, will provide some level of protection via active chemical interaction with the potential corrosion reactants. are often used in combination with low permeability concrete and usually they have the effect of increasing the threshold chloride concentration needed to initiate corrosion. Inhibitors play an important role in protecting uncoated high strength steel. They are also used in cementicious grouts for filling the ducts. Inhibitors may also reduce the subsequent corrosion rate after the initiation of corrosion, which ultimately leads to less corrosion – induced concrete deterioration. Generally Inhibitors admixtures classified as anodic, cathodic and mix Inhibitors. They are also distinguished as passivation Inhibitors, organic and precipitation Inhibitors. Organic Inhibitors consist of primarily amines and esters. They form a protective film on a surface on steel reinforcing bars and sometimes delay the arrival of chloride ion at steel reinforcing bars.

Reinforcement Protection by Using Special Steels: i) by changing chemical composition of steel: Resistance of corrosion is depending on its chemical composition most of the reinforcement steels that are used have low to medium carbon content. To some steels, copper has been added in small quantities (0.2 %) to increase weathering resistance. Also some amounts of copper, chromium & Nickel have been observe to increase corrosion resistance. Also silicon is reported to increase the corrosion resistance in small amounts. So special purpose steels, that contain 3.5% Nickel, 0.2% Copper and 0.1% Tungsten have been developed for use in concrete. These steel also exhibit more than twice the corrosion resistance of mild steel.

ii) by using corrosion resistance TMT bars (Thermo mechanically treated) TMT bars offer better strength, ductility and corrosion resistance compared to CTD (Cold twist deform) bars, to further improve the corrosion resistance , special form of TMT bars with addition of copper, chromium and higher level of phosphorous have been developed. These bars do not require special precautions during handling and transportation as is the case with epoxy coated, cement slurry coated or galvanized bars. In TMT bars, hot bars coming out of last rolling mill stand are rapidly force of water jets. Rapid quenching provides intensive cooling of surface resulting in the bars having hardened surface with hot core. The rebars are then allowed to cool in ambient conditions.

Reinforcement Protection by Metallic Coatings: Metallic coatings like epoxy (epoxy coated bars) or Zinc(galvanized steel).The great advantages of zinc coating is that the complex zinc and zinc iron alloy layers produced by immersing steel in molten zinc are metallurgically bonded to the base steel. The coating thus provides an integral barrier as well as sacrificial to any localized corrosion while at the same time it remains passive during transportation and storage. There is also increasing evidence that chromate treated galvanized bars have nearly the same and sometimes even better evidence on performance of chromate – treated galvanized bars to chlorides in concrete. The different types of metallic coatings are cadmium, tin, nickel and aluminum. The Zinc and cadmium coatings were able to protect well. Aluminum coatings were observed to corrode rapidly due to high alkalinity.

New Technique: Sand Blasting – an anticorrosive treatment: Sand blasting is the process of de-rusting of reinforcement. Generally all reinforcement comes at site having little amount of corrosion. Therefore there is need to de-rest and anticorrosive treatment. In sand blasting process a big hopper is filled with Narmada sand and it is fired to the reinforcement with very high pressure. Air pressure of 7 kg/ cm^2 is maintained at the hopper. During sand blasting care should be taken is that proper mask are available for labours. Sand blasting removes the rust and corrosion of reinforcement. It makes the surface adequate and ready for chemical treatment.

Cement Polymer Composite Coating

The film thickness of cement polymer composite coating is 150 ± 25 μm .This is passivating cum barrier type coating.This coating can be brush applied or sprayed.To overcome the disadvantages of cement slurry coating this method is adopted.

Advantages:

a.It possesses adequate bendability characteristic making it enable for shop coating.

b.It is a passivating cum barrier type of coating and hence defects in the coating may not lead to severe under cutting.

c.It can be brush applied or sprayed and hence defects in the coating can be easily patch repaired.

Cement polymer composite coating is a passivating cum barrier type of coating and has very high corrosion resistance against chlorides.

Procedure of Composite cement polymer Coating:

1. Remove loose rust on steel bars by brushing.

2. Dip the reinforcement rods in the pickling solutions (HCL).

3. Take out the bars from pickling solution.

4. Wash the steel bars thoroughly in water.

5. Dip the bars in alkaline solution and rubbed with Nylon brush or cloth and it will completely neutralize the acid contents.

6. Air dry for 12 min.

V. ANOTHER PREVENTION METHODS

1) Keep concrete always dry, so that there is no H2O to form rust. Also aggressive agents cannot easily diffuse into dry concrete. If concrete is always wet, then there is no oxygen to form rust.

2) Stainless steel or cladded stainless steel is used in lieu of conventional black bars.

3) A portion of the chloride ions diffusing through the concrete can be sequestered in the concrete by combining them with the tricalcium aluminate to form a calcium chloro-aluminate (Friedel's salt). It can have a significant effect in reducing the amount of available chlorides thereby reducing corrosion.

4) Electrochemical injection of the organic base corrosion inhibitors, ethanolamine and guanidine, into carbonated concrete.

5) The rougher the steel surface, the better it adheres to concrete. oxidation treatment (by water immersion and ozone exposure) of rebar increases the bond strength between steel and cement paste to a value higher than that attained by clean rebars. In addition, surface deformations on the rebar (such as ribs) enhance the bond due to mechanical interlocking between rebar and concrete.

VI. CONCLUSION

1. This paper helps us to know that corrosion of reinforcement is very serious problem and caused due to oxygen and water permeability also due to chlorides ingress.2. It is widely accepted the corrosion of embedded bars in concrete can be controlled by simply improving the concrete properties by use of special steel and by metallic and organic coating.3. This will not only allow structure to last it's designed service life but will also save a large amount of resources being used to day for repair and rehabilitation of reinforced concrete structure.5. The development of integrated monitoring systems for new and existing reinforced concrete structures could reduce costs by allowing a more rational approach to the assessment of concrete structures.6. The ability to continuously monitor the cover concrete and steel *in real time* could thus able to provide more information of the current and future performance of the structure.7. Corrosion monitoring can be a vital part of planned maintenance and life prediction by giving quantitative information about the development of corrosion as aggressive conditions develop in the concrete due to chloride ingress or carbonation. It can also be used to assess the effectiveness of rehabilitation systems such as coatings or corrosion inhibitors. 8. The presented system was developed to allow a simple but permanent evaluation of the corrosion potential in reinforced concrete structures. Combining measurements of corrosion currents on dummy rebars, resistivity measurements and temperature measurements, it becomes possible to follow the propagation of the conditions that allow initiation of corrosion, form the surface to the depth where the

real rebar are installed.9. Epoxy coated rebar can easily be identified by the light green color of its epoxy coating. Hot dip galvanized rebar may be bright or dull grey depending on length of exposure, and stainless rebar exhibits a typical white metallic sheen that is readily distinguishable from carbon steel reinforcing bar. More techniques like Cathodic protection and ECE are also employed. Use of Fly Ash too delays the effect of chlorides and carbon dioxide.

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