Reinforcement Corrosion in RC structures-A Review

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Abstract-The reduction in the useful service-life of reinforced concrete structures, mainly due to reinforcement corrosion, is a cause of concern to the construction industry world wide.It not only effects the physical appearance of the structure but it leads to notable effect on structural performance of the RC structures .The present research paper focus on mechanism of corrosion, types of corrosion ,various parameters effecting corrosion and different stratagies to monitor corrosion. It also discusses various effects of corrosion on reinforced concrete structures.

Index Terms- Corrosion;concrete;spalling;damage

1. INTRODUCTION [1]

Reinforced concrete (RC) has been developed and applied extensively in the twentieth century and it continues to be used in this century as well. It combines the good compressive strength of concrete with the tensile strength of steel and has proven to be successful in terms of both structural performance and durability. One major flaw, namely its susceptibility to environmental attack can severely reduce the strength and life of these structures. In humid conditions,atmospheric pollutants percolate through the concrete cover and cause corrosion of steel reinforcements. The resulting corrosion products occupy volumes several times that of the steel. The increased volume induces tensile stresses in the concrete that result in cracking, delamination and spalling. As a result, the reinforcements get exposed to direct environmental attack and the corrosion is accelerated. Along with unpleasant appearance it weakens the concrete structure to a high degree. Moreover, bond between the steel and the concrete is reduced.Pitting corrosion may also reduce the ductility of the steel bar by introducing notches on the surface of the steel bars that leads to a premature necking.A large proportion of damage is caused due to insufficient planning and incorrect assessment of the environmental attack such as carbonation and chloride exposure. Corrosion affected structures are highly susceptible to catastrophic collapse. Unlike other devices and facilities that are renewed periodically with newer ones human endeavor has been to maintain centuries old structures. As a result,structural engineers deal with RC structures of age varying more than hundred years. They are also subjected to a wide range of environmental load regimes. Typically, an RC structure that is subjected to heavy environmental loading requires major restoration work within fifteen years of its construction.
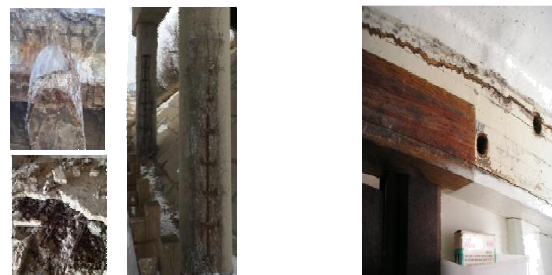
Fig 1 Corrosion in various elements of concrete structures[1]

2. CORROSION MECHANISM

Steel is used in concrete principally as reinforcement. Concrete ordinarily provide an almost ideal environment for protecting steel from corrosion. Its high alkalinity causes the formation of a thin invisible protective passive film of Ferric Oxide (Fe_2O_3) on the steel (thickness approx. 10000 A0). It is expected that when the embedded steel is protected from air by an adequate thick cover of low permeability concrete, the corrosion of steel would not arise. This expectation is not fully met in practice, as is evident from the unusually high frequency with which the RCC structures suffer damage due to steel corrosion. The magnitude of damage is especially large in structures exposed to marine environments. The damage to

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concrete, resulting from corrosion of embedded steel, manifests in the form of expansion, cracking and eventually spalling of the cover concrete.Corrosion of steel is a series of electrochemical reactions.The electrochemical potentials to form the corrosion cells may be generated in two ways:

- concentration cells may be formed due to differences in concentration of dissolved ions in the vicinity of steel,such as, chlorides and oxygen.
- composition cells may be formed when two dissimilar metals are embedded in concrete,such as steel rebars and aluminium conduit pipes or when variation exists in surface characteristics of the steel.

As a result one of the two metals becomes anodic and the other cathodic.the fundamental chemical changes occuring at the anodic and cathodic areas are as follows:
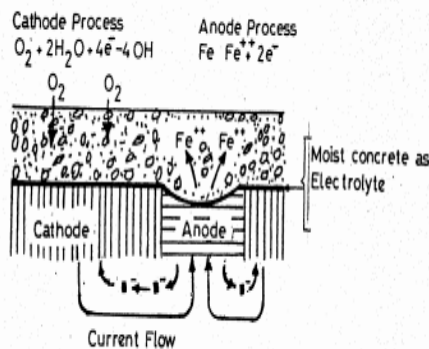

Fig 2 Showing chemical changes occuring during corrosion process[2]

3. PARAMETERS AFFECTING CORROSION

- Presence of impurities in metals: Speed of corrosion increases with the presence of impurities in the metals because these impurities help in setting up the voltaic cells.
- Presence of electrolyte: Electrolytes present in water also increases the rate of corrosion e.g. corrosion of iron in sea water takes place in large extent than in distilled water because sea water contains salts i.e.electrolytes.
- Position of metals in e.m.f. series: Highly reactive metals undergo corrosion faster than least reactive metals. Reactivity of metals can be found from the electrochemical series.
- Presence of carbon dioxide in water: Presence of carbon dioxide in natural water also increases the rusting of iron because it acts as an electrolyte

and increases the flow of electron from one place to another.
- Presence of protective coating: When the iron surface is coated with the metal, which is more reactive than the iron, then the rate of corrosion is retarded e.g. when iron is coated with zinc, iron is protected from rusting.

4 .TYPES OF CORROSION [1]
Pitting corrosion
Pitting corrosion is most likely to occur in concrete with good conductivity, a high content of alkali (i.e. non-carbonated) and a moderate level of chloride (or chloride reaching only isolated areas of the reinforcement). The chloride ion breaks down the passive film locally in those areas where the concentration is high or the passive film is weak. A localized corrosion cell is formed with adjacent areas of passive steel acting as a cathode, where oxygen is reduced, and the anodic dissolution of iron taking place only at the small central anode. Several factors then maintain or aggravate the development of the existing pit rather than to spread the corrosion or nucleate new pits. Acid is produced at the anode (pit site) due to hydrolysis reactions and alkali at the cathode due to the reduction of oxygen. Under the acid conditions present, the corrosion products formed are soluble. Therefore, considerable amounts of corrosion can occur without spalling of the concrete. In pitting corrosion access of oxygen is the major factor in determining the total amount of corrosion. However, with the large cathode/anode area ratio, intense pitting can result even with limited oxygen supply.

General corrosion
General corrosion may result from carbonation or due to the presence of large amounts of chlorides, so a large number of closely situated pits are formed. Both anodic and cathodic processes take place everywhere on the surface, and the pH shifts associated with each of these processes cancel each other.This means that the anodic dissolution takes place in a near neutral or alkaline environment, where oxygen has access. The corrosion product, in this case, is solid rust, which occupies about 4 times the volume of the metal that has been corroded. The buildup of corrosion products on the steel reinforcing bars exerts tensile forces on the concrete cover resulting in cracking and spalling.In practice, general corrosion caused by carbonation or by chlorides has different characteristics. In cases, where carbonation has penetrated deeply, the concrete is likely to be rather permeable and semi-dry, and the rate of corrosion, once it starts, is probably controlled by the relatively high resistivity and lack of water rather than the diffusion of oxygen. The time-of-wetness , known to be an important factor in atmospheric corrosion, is an appropriate measure of corrosion rate under these conditions.Conversely,

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corrosion in chloride-rich concrete is more often found where water is abundant and resistivity of the concrete is low. Under these conditions the diffusion of oxygen through the water- filled pores is the rate determining factor.

Macro-Cell Corrosion

Under certain conditions, it is possible for the anodic and cathodic sites to be significantly remote from each other so that the reaction products from the anode and cathode reactions do not interact. Such conditions can exist if some of the steel is inanaerobic conditions and if the concrete is sufficiently conductive (i.e low resistivity, 12kΩcm or less) to carry the macro -cell corrosion current. Typically this occurs in a concrete member with its lower parts permanently immersed in sea-water and extending upwards through the tidal and splash zones. This may include bridge and wharf piles, and skirting panels for wharves or promenades. Under conditions of macro-cell corrosion, the cathode reaction occurs in the oxygen-rich tidal or splash zones, with no noticeable effect on the concrete.The steel, however, dissolves at the anode which will be the immersed lower part of the member, saturated with sea-water but with little or no available oxygen. The ferrous ions react with anions present in sea-water (chlorides, sulphates, hydroxides) to produce ionic compounds which form a sticky black/green colloidal paste within the concrete, often referred to as "black rust". Since this is not an expansive reaction, the colloidal corrosion products will opportunistically occupy available spaces such as voids and pores, or fracture planes if cracking is present from other causes. The colloid can slowly migrate to the surface where, if oxygen is more abundant, it may form conventional brown/orange rust stains, or it may simply be lost in the sea-water. S ince there are few outward signs of this mechanism, and although this process is generally slow, significant loss of metal can occur over time with subsequent loss of structural integrity and possible sudden, catastrophic failure. Even concrete of high quality and density can corrode by this mechanism

5 REASONS OF CORROSION [4]

The two most common causes of reinforcement corrosion are:

1. Localised breakdown of the passive film on steel by chloride ions and

2. General breakdown of passivity by neutralization of the concrete, predominantly by reaction with atmospheric CO2.

6. EFFECTS OF CORROSION [5]

The reinforcement in concrete structures is harmful in the following ways:

➢ The presence of rust impairs the bond strength of reinforcement because corrosion occurs at the raised ribs and fills the gap between ribs,thus evening out the original deformed shape.In essence the bond between the raised ribs and concrete.the reduction of mechanical locks by corrosion results in the decline in bond strength with concrete.

➢ The corrosion reduces the effective cross sectional area of bar leads to decrease in tensile strength.

➢ The corrosion products occupy about 3 times the original volume of steel from which it is formed.such increase in volume generates significant bursting forces in the vicnity of steel reinforcement.cracks are formed along the bars when the tensile strength of concrete is exceeded.
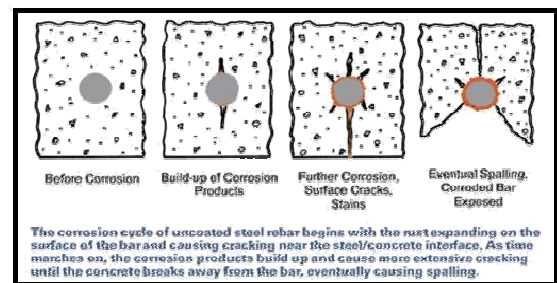

Fig 3 Corrosion cycle[1]

7. PREVENTION [6]

1.Epoxy coating to rebar to protect them from moisture and aggressive agents. The embedded epoxy coating on steel bars provide a certain degree of protection to the steel bars and thereby, delay the initiation of corrosion. These coatings prevent movement of moisture to the steel surface but restrict oxygen penetration.

2. Stainless steel can be used in lieu of conventional reinforcements.

3. Use of fly ash concrete with low permeability which would delay the arrival of carbonation and chlorites at the level of the rebar. They form a calcium silica hydrate (CSH) compound that over time effectively reduces concrete diffusivity to oxygen, carbon dioxide, water and chloride ions.

4.Electro chemical injection of organic base corrosion inhibitors into carbonated concrete.

8. STRATEGIES FOR INVESTIGATION OF A CORRODED RC STRUCTURE [2]

A visual survey was conducted, whether the corrosion of reinforcement bar is really a cause of distress. The survey includes careful investigation of the structure for any sign of distress such as cracking, spalling and rust staining.

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Reinforcement Corrosion Monitoring Techniques
Half – Cell potential
Concrete resistivity
polarization resistance

9. CONCLUSION

Concrete is good combination of compressive and tensile strength but due to corrosion tensile strength of concrete is decreasing.The main cause of reinforcement corrosion is presence of chloride ions and carbonates.It is harmful for the health of concrete in many aspects but a good structural design ,good detailing and a well chosen cement mix which results in a durable concrete may provide sufficient protection for many applications.

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