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Corrosion of Steel Reinforcement in Rc Structures –Effect And Method Of Repair

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ABSTRACT:

Reinforced concrete structures have the potential to be very durable and capable of withstanding a diversity of adverse environmental conditions. However, failures in structures still occur as a result of variety of defects among which premature reinforcement corrosion isone.In the case of concrete structures, the main effect of the reinforcement corrosion is its section decreases due to the corroding process. Reduction of reinforcement thickness then leads to loss of mechanical strength and structural failure or breakdown.In this thesis, the chemistry of corrosion in concrete is briefed. The damages caused by corrosion of steel in concrete, corrosion detection measurement in built structures and corrosion consideration in developed countries are alsodiscussed.Since much attention is not being given to corrosion effect in India construction industry, some sample pictures are collected from construction sites and is attempted to show the corrosion consideration in our country.Poor construction methods and workmanship could attribute to the failure of structures. The poor construction methods and workmanship is caused due to negligence and inadequate quality control at construction sites. The study discloses that labor and money could be saved by means of repair and rehabilitation; and serious accidents could be avoided if the corrosion of reinforcements is well understood, detected and monitored at earlystage.

1.INTRODUCTION

1.1.BACKGROUND

For thousands of years, humans have taken advantage of ductile materials with high tensile strength in the reinforcement of brittle materials having high compressive strength. The ductile reinforcement transfers tensile loads in the structure, allowing the brittle material to crack without causing failure of the structure. During the last two centuries, concrete has been developed into a construction material with ever increasing potential to support compressive forces. As the compressive capacity of concrete increased, the demand to support larger and taller structures becomes eminent and hence, stronger, more ductile and more tensile reinforcement has beenrequired[1].

Reinforced concrete structures have the potential to be very durable and capable of withstanding a variety of adverse environmental conditions. However, failures in the structures do still occur as a result of variety of defects among which premature reinforcement corrosion is one.

As a modern construction material, steel has been used to reinforce concrete since it provides tensile strength, ductility and chemical bond for the structure. It comes in round and plain forms. Unfortunately, steel is subject to corrosion in wet and salty environments. Due to this, the steel become weak and lose some of its important properties. Many issues pertaining to the corrosion of steel in such a medium are unsolved and most scientists and engineers are still unfamiliar to corrosion, and hence need a thorough investigation. In addition, concrete is quite different from the traditional aqueous corrosion media, some theories and techniques used in the traditional corrosion field may not be directly applicable to the study of corrosion of reinforcedconcrete.

Steel has the ability to bond with the surrounding concrete. This formation of bond is a significant property of reinforcing steel allowing forces to be transferred and distributed evenly to the surrounding concrete material. The physical interlocking of the concrete aggregate, the quality and strength of concrete in tension and compression, bar deformations, the anchorages within the concrete at the reinforcement ends are the products of bond strength between steel and concrete. Much of the research and development on rebar throughout its history attempted to determine and increase the bond strength of reinforcing elements inconcrete.

Reinforced concrete structures were considered to be highly resistant to corrosion due to the presence of concrete cover. However, practically, reinforced concrete structures usually do not perform so well, and their service lives are sometimes much shorter than what they were designed for. The steel in concrete is always attacked by corrosion. This leads to become at a reasonable explanation that the cover concrete is not free of defects.

Corrosion of reinforcement has been established as the predominant factor causing widespread premature deterioration of concrete construction worldwide, especially of the structures located in the coastal marine environment and in areas of subsoil possessing salinity. After the ingression of chloride ions and carbon dioxide to the steel surface, the corrosion process continues and the corrosion products (iron oxides and hydroxides) deposit around the steel and develop expansive stresses and cause the concrete cover to crack and spall. This results in progressive deterioration of the concrete.

Figure 1.1 Buildup of corrosion products, spalling of concrete cover and exposure of reinforcements

Consequently, the repair costs nowadays constitute a major part of the current spending on infrastructure. 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. Quality control, maintenance and planning for the restoration of these structures need non-destructive inspections and monitoring techniques that detect the corrosion at an earlystage.

Corrosion loss consumes considerable portion of the budget of the country by way of either restoration measures or reconstruction. There have been a large number of investigations on the problems of deterioration of concrete and the consequent corrosion of steel in concrete. Properly monitoring the structures for corrosion performance and taking suitable measures at the appropriate time could affect enormous saving. 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,[5].

2.LITERATUREREVIEW

2.1.GENERAL

Steel, like most metals except gold and platinum, is thermodynamically unstable under normal atmospheric conditions and will release energy and revert back to its natural state—iron oxide, or rust. This process is calledcorrosion.

Corrosion is the deterioration of metallicmaterials by chemical interaction with their environment. The term corrosion is sometimes also applied to the degradation of plastics, concrete and wood, but generally refers to metals. The most widely used metal is iron (usually as steel) and the following discussion is mainly related to its corrosion, [6].

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1.1. CORROSION PROCESS – CHEMISTRY OFCORROSION

Corrosion is an electrochemical process involving the flow of charges(electrons and ions). At active sites on the bar, called anodes, iron atoms lose electrons and move into the surrounding concrete as ferrous ions. This process is called a half-cell oxidation reaction, or the anodic reaction, and is representedas:

$$2Fe \rightarrow 2Fe^{2+} + 4e^{-} \qquad (2.1)$$

The electrons remain in the bar and flow to sites called cathodes, where they combine with water and oxygen in the concrete. The reaction at the cathode is called a reduction reaction. A common reduction reaction is:

$$2H_2O + O_2 + 4e- \rightarrow 4OH^{-} \qquad (2.2)$$

To maintain electrical neutrality, the ferrous ions migrate through the concrete pore water to these cathodic sites where they combine to form iron hydroxides, or rust:

$$2Fe^{2+} + 4OH^{-} \rightarrow 2Fe(OH)_2 \qquad (2.3)$$

This initial precipitated hydroxide tends to react further with oxygen to form higher oxides. The increases in volume as the reaction products react further with dissolved oxygen leads to internal stress within the concrete that may be sufficient to cause cracking and spalling of the concrete cover.

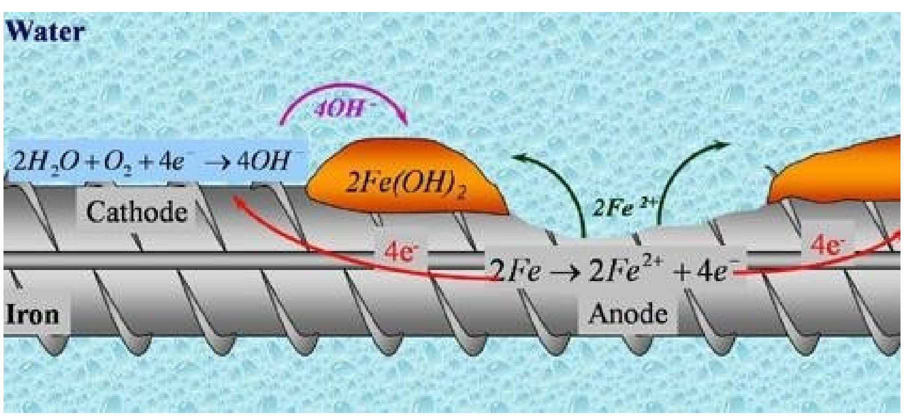

Figure 2.1 Oxidation process of reinforcing steel

1.2. CORROSION PROCESS OF REINFORCING STEEL INCONCRETE

Generally, corrosion of metal in any environment consists of the following basic processes:[6]

- Depolarization reagent arrives at the surface of metal through the medium surrounding it. Commonly the depolarization reagent is oxygen dissolved in the medium or proton (H+) naturally existing in the aqueousmedium.
- Electrochemical (anodic and cathodic) reactions occur at the interface between the metal and the surrounding medium, i.e. most probably, the oxidization of metal and the reduction of O_2 orH^+.
- Reaction products (corrosion products) are accumulated at the surface of metal or removed away from the surface into the medium. For example, passive film or iron rust is formed at the surface of metal; or generated hydrogen gas, OH- and Fe^{2+} during the corrosion process move away from the surface of metal intosolution.

It should be borne in mind that these three basic processes are essential for any corrosion of metal. The absence or stopping of any one of the processes will end the progress of corrosion.

Due to the porosity of concrete, O_2 can easily diffuse into concrete, becoming dissolved in the pore solution and finally reaching the surface of steel. At the surface (cathodic area), oxygen is reduced into hydroxide ion via an electrochemical cathodicreaction.

$$O_2 + 2H_2O + 4e \rightarrow 4OH^- \quad (2.4)$$

This is a very common cathodic reaction associated with most corrosion of steel in concrete. However, in some special cases, the cathodic reaction may be in the form of hydrogen evolution:

$$2H_2O + 2e \rightarrow H_2 + 2OH \quad (2.5)$$

Equation (2.5) might occur in two cases:

1) At a very negative potential or a very high cathodic currentdensity;
2) In a carbonated concrete in which the pH value of the pore solution has become verylow.

Even in these two cases, reaction by equation (2.4) still has some contribution to the corrosion of steel, but the effect of reaction (2.5) prevails over reaction (2.4). No matter which process is taking place, the cathodic reactions always produce hydroxide ion and increase the pH value of pore solution in the vicinity of cathode.

The anodic reaction occurring at the anodic area on the steel surface can be basically described as a reaction:

$$Fe \rightarrow Fe^{2+} + 2e \quad (2.6)$$

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With this anodic reaction proceeding, the cross section of steel bar is reduced and finally the rebar could break down. So reaction (2.6) is a very important process responsible for the corrosion damage of reinforcement.

The intermediate corrosion product, $Fe^{2+,}$ could be further transformed into Fe^{3+} under oxidizing conditions, and be accumulated at the surface of steel rebar; or be dissolved into the pore solution and move away from the steel reinforcement, under reducingconditions.

Normally, the pore solution is rich in oxygen with a high pH value. So Fe^{2+} can stay in the form of $Fe(OH)_2$ or $Fe(OH)_3$ due to hydrolysis or oxidation of Fe^{2+}, forming a thin passive film on the steel surface, which consequently retards reaction (2.6). In this case, the steel can be well protected in concrete, and there will be no detectable corrosiondamage.

However, at the initial stage after concrete is casted and subjected to moist-curing, the passive film cannot be formed so quickly if the concrete is completely immersed in water. It was suggested that the formation of passive film on reinforcement might take a significantly long time even when the concrete is not completely immersed in water after casting. This is understandable, because in a very basic solution, steel cannot be passivated as easily as stainless steel; also the supply of oxygen which is necessary for the passivation of steel in concrete is usually a few orders of magnitude lower than that in a normal aqueous solution.

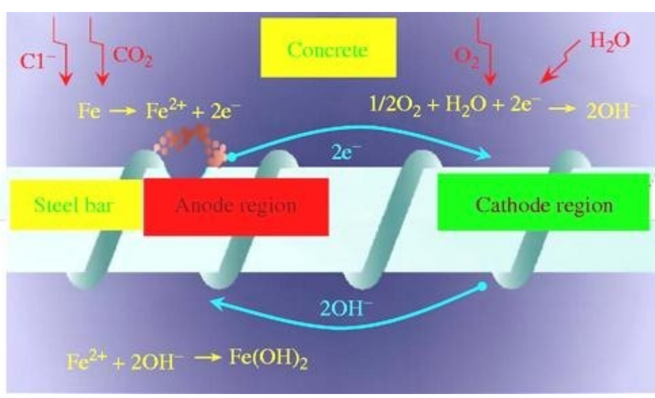

Figure 2.2 Corrosion process of reinforcing steel in concrete

1.3. TYPES OF CORROSION OF REINFORCING STEEL IN CONCRETESTRUCTURES

Corrosion in steel reinforcement may take the following forms:[4]

2.4.1.CREVICECORROSION

Crevice corrosion is a localized form of corrosion usually associated with a stagnant solution on the micro-environmental level. Such stagnant micro environments tend to occur in crevices (shielded areas). Oxygen in the liquid which is deep in the crevice is consumed by reaction with the metal. Oxygen content of liquid at the mouth of the crevice which is exposed to the air is greater, so a local cell develops in which the anode, or area being attacked, is the surface in contact with the oxygen-depleted liquid.

2.4.2.PITTING

Theories of passivity fall into two general categories, one based on adsorption and the other on presence of a thin oxide film. Pitting in the former case arises as detrimental or activator species, such as Cl^-, compete with O_2 or OH- at specific surface sites. By the oxide film theory, detrimental species become incorporated into the passive film, leading to its local dissolution or to development of conductive paths. Once initiated, pits propagate auto-catalytically according to the generalizedreaction,

$$M+3 + nH2O + nCL- \rightarrow M(OH)n+ nHCL, \qquad (2.7)$$

resulting in acidification of the active region and corrosion at an accelerated rate (M+n and M are the ionic and metallic forms of the corroding metal).

1.4. FACTORS AFFECTING CORROSION OF REINFORCING STEEL IN CONCRETE STRUCTURES

The corrosion behavior of reinforcement steel in concrete is a function of parameters of steel and concrete as well as the properties of their interfacial zone. That is, it is determined by the composition of the pores solution of the concrete and chemical properties of the steel. The other parameters of concrete would affect corrosion of steel through their influences on the pore solution.

Environmental factors can not affect the corrosion processes directly, but they cause the deterioration of the cover concrete and accelerate the ingress of aggressive species, making the pore solution in contact with the steel more corrosive. Among all the environmental factors, chloride ions and carbon dioxide have been responsible for most corrosion of steel in concrete structures. In Addition to these two factors, temperature and moisture, as well as some other factors that cause deterioration in concrete, also play important roles in corrosion of steel in concrete. What makes the influence of those factors so complicated is that the corrosion of steel in concrete is not determined by a single factor. The interaction among these factors plays an important role in the corrosion process of the steel reinforcement,[6].

2.5.1. REINFORCINGSTEEL

Different types of steels have different microstructures and compositions so different types of steel usually have different corrosion behaviors in concrete.

The steel surface can directly affect the bond between the reinforcement and the concrete, and further influence the failure of structures. It was found that the rust which was well adhered to the underlying steel helped the bond between steel and concrete. The surface of steel treaded with water to form a coating before incorporation of the steel in concrete could increase the bond strength. Slight corrosion could increase the bond strength, whereas severe corrosion decreasedit.

2.5.2. PORE SOLUTION OFCONCRETE

The pore solution in concrete is an electrolyte which is physically absorbed in the pores of the concrete due to the capillary force produced by absorption resulting from molecular force. It reacts with the steel reinforcement and under certain conditions can lead to the corrosion damage at the steelsurface.

2.5.3. PERMEABILITY OFCONCRETE

Higher porosity and larger pre sizes lead to more severe corrosion damage in the steel. The pores can facilitate the ingress of Cl^-, CO_2, O_2, H_2O and some other detrimental species from the environment. They also greatly affect the removal of corrosion products from the steel surface. Therefore, the permeability directly affects two of the basic corrosion processes, the supply of depolarization reagents and the removal or accumulation of corrosion products and has significant influence on the corrosion of reinforcement.

For a normal concrete structure, it is believed that oxygen is very easily able to access the reinforcement but it is quite difficult for corrosion products to move from the reinforcement surface. In effect, resistivity of concrete can be partially ascribed to the permeability as well, so the permeability of concrete also exerts an influence on the galvanic corrosion rate through its influence on the ion flowing process in the cover concrete.

If the concrete has low permeability, then the aggressive species would be difficult to access the reinforcement, and the possibility of corrosion of the reinforcement would be low.

The permeability of concrete is mainly determined by the porosity of concrete and its pore size distribution, which are dependent on the ratio of water/cement (w/c) in the concrete. Therefore, the permeability of concrete increases with an increase in w/c ration, especially when w/c >0.55 . Sometimes, the permeability of concrete could vary by as much as two orders of magnitude as w/c increases from 0.4 to more than 0.7.

Other factors can also significantly affect the permeability of concrete. For example, hydration process of cement also influences porosity and permeability. It was found that the porosity for hardened cement paste changed from 29% at age 40 days to 25.8% at age 296 days. The use of mineral admixture (fly ash) also had significant effect on the chloride diffusion than on the oxygen diffusion in concrete.

Low w/c, better compaction and use of mineral admixtures etc, could lower the permeability of the cover concrete, therefore they are the options to improve the corrosion resistance of reinforced concrete.

2.5.4. MOISTURE

The influence of concrete moisture content on the rate of corrosion of steel in concrete is well known. If there is no water in concrete, there should be no corrosion problem with the reinforcement. Since electro chemical reactions are mainly responsible for the reinforcement corrosion, moisture should be an essential substance in the corrosion of steel in concrete, [6].

The moisture of concrete has a complicated influence on the corrosion of steel in the concrete. The resistivity of concrete is first affected by the moisture, which can influence the galvanic corrosion rate. However, increasing moisture has contrary effects on anodic and cathodic reactions. The anodic reaction rate increases and the cathodic reaction rate decreases with the increasing humidity. This is due to the fact that the increase in moisture makes the departure of rust or corrosion products easier, but it decreases the diffusion coefficient of oxygen and makes the supply of oxygen more difficult.

In recent years, research interest has been increasing in the rate of water absorption into cover concrete. The water absorption into concrete from outside environment can rapidly increase the rate of corrosion of depassivated reinforcing steel to the levels that will cause cracking and spalling. The absorption is also an important transport mechanism for the ingress of chlorides into concrete. It was found that the internal relative humidity (RH) of concrete behaved differently to the external RH; but no direct relationship was found between corrosion rate and internal RH or temperature.

3.CONCLUSION

This thesis provides a comprehensive description of issues and solutions involved in reinforcing concrete structures with steel rebar.

The economic loss caused by corrosion damage of reinforced concrete structures and risks associated with the corrosion of steel in concrete have been recognised in developed countries. But much has to be done in Indian practice since professionals and practitioners in the construction industry are not aware of corrosion effects and damages.

As it is attempted to illustrate corrosion in built structures, many structures in our country are suffering from corrosion and factors related to corrosion such as cracks, leakage, moisture, spalling of cover concrete, rebar exposure and others. Therefore, it is evidence that corrosion is a risk to our country civil engineering structures.

In our country practice, it is advantageous to know the extent of corrosion in reinforced concrete structures using resistivity meter and corrosion analyzing instrument. As a result, the available corrosion control measures can be used at an early stage. In addition, it is desirable to monitor the condition of structures right from the construction stage by carrying out periodic corrosion surveys and maintaining a record of data. Furthermore, the design should also be done with great care.

Inaccessible details that do not allow for inspection and maintenance are poor design practices and must be avoided. Moreover, concrete placing, curing, rebar placement, grouting procedures and materials should be properly done. The poor reinforcement bar storage, handling and installation trends should be avoided and the inadequate quality control and negligence which in turn cause poor construction methods and workmanship should be improved. Since there are many repair options available; cost, technical feasibility and reliability must be considered. Professionals need to understand all the relevant material, structural and environmental issues associated with concrete repairs in order to make intelligentchoices.

In our country, many civil engineering structures are constructed and under construction. A lot of money is being spent on those projects and others. Hence, it is better to think about the damages that result due to negligence and unawareness at early stages. It is going to be very disappointing if the structures fail and lose the lives of many while a lot can be done from the design stage to the final stage of construction. Therefore, properly monitoring the structures for corrosion performance and taking suitable measures at the appropriate time could help enormous saving in life and also costaspect.

As long as metallic materials are used in concrete, and as long as the concrete is not free of defects, corrosion problems will not be avoided.Consequently, much attention must be given in developing awareness on the problem. Detailed information on corrosion education must be given in higher education institutes and some short term trainings in construction site to all workers.Otherwise, it is going to cause a great damage to the whole country economic system.

3.1.RECOMMENDATION

Future study may be made on the following:

- Assessment study on life of corrosion caused failure structures inIndia.
- For most structures, laboratory and field tests must be conducted to determine corrosion rate in service lifeestimation.
- Cost comparison should be made for the available corrosion control measures putting into account our environmental condition, workmanship, maintenance techniques and expected exposure of the structure to corrosive elements over itslifetime.
- The use of admixtures and sealers can be evaluated to different bridge decks. Testing of sealers and admixtures in the field can be expanded. In addition, a long-term study on the use of admixtures and sealers should beimplemented.
- Calculations and estimates can be done to determine construction and repair costs for bridge decks and times to repair and/orreplacement.

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