Corrosion Assessment of Reinforced Concrete using different Steel Grades with or without Epoxy-Coating

P. Damle[1]

Ms **T Visalakshi** Dept. Of Civil Engineering, Amity School Of Engineering and Technology, India[1]

Abstract-*Corrosion in reinforced concrete occurs either because of ingression of chloride ions onto the embedded steel or because of carbonation which leads to reduction in alkaline environment at the level of the embedded steel. Often, the two processes complement each other and initiate corrosion. The money spent on the repair of corroded reinforced structures amounts to hundreds of millions worldwide. This research aims at detection of corrosion in RC samples using electrochemical techniques employed in the past. The principle used is that the probability of corrosion is the function of the potential difference measured between the reinforcement and the surface of concrete. The samples are subjected to accelerated corrosion using impressed current technique to cause corrosion to an extent that would occur in several decades. Also in this research, it is intended to apply this technique for on-field detection of corrosion so as to plan the repairing procedure effectively.*

Keywords - corrosion, half-cell potential, impressed current, epoxy

1. Introduction

Reinforced cement concrete is one of the most widely used building material because of its durability. There are many factors because of which the durability of concrete is reduced, but one of the major and very disastrous issue that leads to the failure of a reinforced concrete structure within its service life is corrosion of the reinforcing steel. There are numerous examples where cracks develop on the concrete surface and the reason behind this is bulging of the reinforcement because of corrosion. The use of 'disastrous' is justified as the process of corrosion in reinforcing steel is not very easily detected primarily because the reinforcing steel cannot be physically examined.

In this research, the half-cell potential measurement technique for the detection of corrosion is put in practice for various samples of different steel grades and different exposure conditions. The two exposure conditions used in this research for the embedded steel is with and without a layer of red-oxide epoxy coating. The corrosion detection technique is applied for all the samples and the reliability of the technique is observed.

Also, the process of causing accelerated corrosion is put in practice. It is intended to device the impressed current technique as a standard procedure on-site for newly cast concrete. If a standard process of accelerated corrosion is established to test the concrete for its tendency to allow the ingression of chloride ions, it can be used as a criteria for checking the quality of

concrete right after the casting has been done and so the necessary measures to prevent corrosion can be taken according to the environmental conditions.

2. Corrosion

Steel, like most metal, except gold and platinum is thermodynamically unstable under normal atmospheric conditions. The stable form of metals is the respective iron ore from which they are extracted. After the extraction process, any metal is at a very high energy level. Hence metals ty to attain stability by releasing energy and reverting back to metal oxide. In case of iron they form iron oxides which is known as rust. This process is known as corrosion.

Generally, the process of corrosion occurs if three following conditions are satisfied:
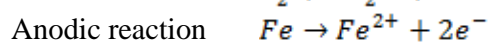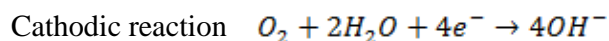
1) Depolarizing agent arrive at the surface of metal
2) Electrochemical reactions occur at the interface between the surface of the metal and the surrounding medium
3) Reaction products are accumulated at the surface of the metal or are removed away from the surface into the medium.

2.1 Process of corrosion in concrete

In concrete the above three conditions are satisfied as follows:

1) As concrete is porous, depolarizing agent i.e. oxygen easily diffuses into it with time and arrives at the surface of the reinforcement
2) Following electrochemical reactions occur at the interface between reinforcement and surrounding medium i.e. concrete
Reactions involved
Cathodic reaction $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$
Anodic reaction $Fe \rightarrow Fe^{2+} + 2e^-$
3) The reaction product i.e. iron oxide are removed from the reinforcement into the concrete. Concrete acts as an electrolyte and transmits the reaction product to another point in the reinforcement where it accumulates.

2.2 Identification of real problem

The process of corrosion initially leads to the formation Fe_3O_4 i.e. Black rust. Black rust is not a threat to the stability of the structure, on the contrary according to the **Concrete Reinforcing Steel Institute (CRSI)**"Rust actually improves bond because it increases the roughness of the surface. However - and this is the exception - *if there is so much rust that the weight of the bar is reduced or the height of the deformation is reduced, then the rust is considered harmful.*"

But at a later stage, the corrosion product formed is $Fe(OH)_3.3H_2O$ i.e. Red rust, which is of major concern. The following figure explains the reason
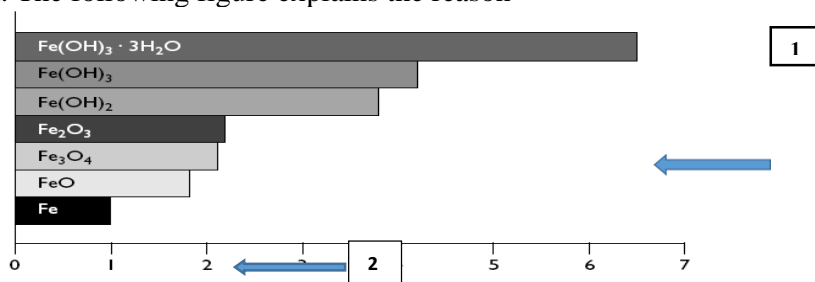
Relative volume of iron and its oxides from Mansfield *Corrosion*, 1981, 37(5)

Figure 1

As it can be seen from the above figure, (2) i.e. black rust takes up twice as much volume as occupied by the original steel. Whereas (1) i.e. red rust takes 6-7 times as much volume as occupied by the original steel. This increase in the volume of the reinforcement has disastrous consequences over the durability of concrete. The reinforcement exerts pressure on the concrete to such an extent that it leads to formation of cracks in the concrete and leaves the RC structure unusable and necessitates its repair.

2.3 Carbonation and Chloride Ingression inter-relationship

Carbonation is the process in which the atmospheric CO_2 diffuses into the porous concrete to react with hydroxides as follows:

➢ $CS + H \rightarrow CSH + Ca(OH)_2 (Lime)$

➢ $Ca(OH)_2(Lime) + CO_2 \rightarrow CaCO_3 + H_2O$

The formation of CaCO_3 is not harmful until it reaches the level of the embedded steel. In fact it increases the strength of the hardened concrete. Once it reaches the steel, it reduces the pH value of the concrete-steel interface and leads to depassivation of the steel.

Although, the carbonation of concrete changes the pore structure of concrete which is observed to facilitate chloride ion ingression into the concrete.

3. Accelerated Corrosion Using Impressed Current Technique

For the purpose of causing corrosion in the reinforced concrete samples to an extent that would occur after several years, the samples were subjected to accelerated corrosion using the impressed current technique.

3.1 Impressed Current Technique

In this technique, the samples were placed in an electrolytic solution (the solution used here is NaCl dissolved in water). The samples were connected to each other in series and the positive terminal of a 12V DC battery, and a copper-rod (counter-electrode) was connected to a negative terminal of the same battery. Current was allowed for a duration of 20 hours. Intention of this procedure was to allow an electrolytic reaction where the cathodic reaction would take place in RC samples.

It was observed that if the bare reinforcement was connected to the cathode, the metal starts to decay and enter the solution as iron oxide. So, in an RC sample connected to the cathode, the concrete acts as an electrolyte and both cathodic and anodic reactions occur within the concrete itself. Thus satisfying all the three conditions essential for corrosion as stated earlier and it leads to the formation of iron oxide (rust) within the concrete.
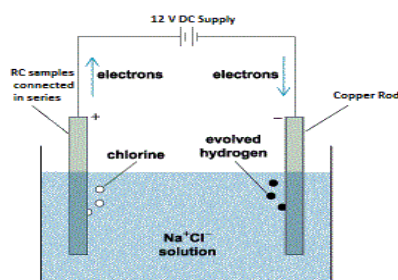
3.2 Set-up

Figure 2 : Accelerated Corrosion Set-Up

4. Detection of Corrosion

4.1 Half-Cell Potential measurement

The RC samples, after being subjected to accelerated corrosion, were tested for corrosion using the half-cell potential measurement technique and following results were obtained:

1) **Samples with no epoxy coating**

S no.	Type of reinforcement	Potential difference (in mV)
1)	Fe 500	-395
2)	Mild steel square	-403
3)	Fe 500	-390
4)	Mild steel circular	-495
5)	Mild steel square	-357
6)	Fe 500	-256
7)	Mild steel circular	-416

Table-1

2) **Samples with epoxy coating**

S no.	Type of reinforcement	Potential difference (in mV)

1)	Fe 500	-757
2)	Mild steel square	-710
3)	Fe 500	-736
4)	Mild steel circular	-726
5)	Mild steel square	-730
6)	Fe 500	-643
7)	Mild steel circular	-602

Table-2

The above results were obtained using the following set-up:
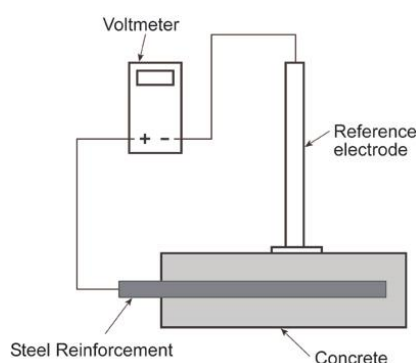
Figure 3- Half-Cell measurement

The following are the values of potential difference with the associated corrosion probability based on past researches:

Measured Potential v/s reference electrode (in mV)(x)	Corrosion probability
x > -200	Low, less than 10%
-200 > x > -350	Uncertain
x < -350	High, more than 90%

4.2 Inferences:

1) The samples before being subjected to accelerated corrosion showed no probability of corrosion. Hence the impressed current technique is useful in assessing durability of any concrete from corrosion point-of-view in a very short duration.

2) The half-cell potential technique does not yield reliable results with epoxy coated rebars. As it was observed from the testing, the epoxy coated reinforcements, which were expected to not corrode at all, showed potential difference in a range where corrosion is believed to be fairly certain.

   Therefore the half-cell potential measurement technique has its limitations when used for reinforcements with some coating. The reason could be that a complete electrical circuit could not be established because of the non-conducting epoxy coating.

5. Applications on-field

The necessity of using this technique is generally for the detection of corrosion in structures that are already in place therefore it is essential to develop this technique as an on-site testing procedure.

5.1 Potential mapping

Potential mapping is the representation of the half-cell potential measurements to show the profile of corrosion. The single point measurements of the half-cell potential data are plotted and the points with same potential are joined to form contours. This procedure is particularly helpful for assessing corrosion in relatively large surfaces. The potential mapping is a handy technique which proves to be very helpful in planning the repair of a corroded structure. The reliability of this technique is directly dependent on the reliability of the half-cell potential measurement technique.

6. Conclusion and future work

The following conclusions were made in this research project:

1) Repair work can be planned based on the mapping of potential.

2) Half-cell potential measurement does not yield reliable results in case of surface coated reinforcement.

In future the following work is intended to be carried out:

1) Study of the interference of epoxy coating with the half-cell potential measurements. Alternative testing methods for epoxy coated reinforcements are to be studied.

2) The use of fly-ash as binding material instead of cement could be a good alternative from the corrosion point of view. Therefore, it is intended to test the samples with fly-ash blended concrete.

3) A closer research is intended to be done for the accelerated corrosion procedure using impressed current technique, so that it can be used to identify the tendency of concrete to corrode, in limited time.

7. References

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