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Effect of Cathodic Protection on the State of Steel Reinforcement

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Damage of reinforced concrete structures is mainly caused by chloride or carbonation induced corrosion of steel. Cathodic protection is a very effective measure for corrosion control of steel in concrete, especially in chloride contaminated concrete.

In this paper, effect of cathodic protection on the state of steel reinforcement is presented. Cathodic polarization of reinforcements in concrete was done under different submerged conditions. Cyclic potentiodynamic tests were used to determine the effect of cathodic protection on the behavior of the steel. Pitting appeared on the non-protected steel, but was not observed on the cathodically protected steel. Microscopic photographs show that a close film exists on the protected steel, while the non-protected steel 's film is loose. Investigated results have proved the effect of cathodic protection in restoring or strengthening passive film on the steel reinforcement.

Keywords : *cathodic protection, reinforced concrete, steel reinforcement, submerged reinforced concrete, corrosion control.*

1. Introduction

For assessing a cathodic protection system of reinforced concrete, the following criteria are considered: 300mV potential shift, protection potential and 100mV decay. Besides, it can be used in combination with other additional methods to have more information about effect of cathodic protection.

This paper deals with cathodic protection of steel in concrete in water environment. Use of electrochemical and non-electrochemical methods for investigation of effect of cathodic protection of steel in concrete are concerned. Information about effect of cathodic protection on the state of steel reinforcement in submerged concrete is presented.

2. Experimental

Specimen preparation: Cylindrical mortar specimens made of with reinforcement centered were used. The mortar consisted of 1/3/0.5 parts by weight of Portland cement / sand / water. The reinforcement was made of a mild steel rod with an exposed surface area of 10 cm^2. In order to activate the reinforcement, 2% sodium chloride by weight of cement was added. Specimens were cast and kept in the mould for 24 hours, then removed from the mould and cured for 28 days in wet condition.

Submerged conditions: There are three series of specimens

- Continuously submerged
- Partly submerged
- Cyclically submerged (4 hour wet and 20 hour dry)

Testing solutions are 0.3% NaCl and 3.5% NaCl solutions.

Cathodic protection test: In each submerged condition, some specimens were unprotected and others were cathodically protected with the current densities ranged from 3 mA/m^2 to 15 mA/m^2. Half-cell potential measurement was carried out vs. a saturated calomel electrode (SCE) during exposure time.

Cyclic potentiodynamic polarization: The potentiodynamic polarization tests were carried out on the specimens with and without cathodic protection. The scan rate was 0.2 mV/s.

Visual test: After exposure period, the specimens were broken to determine whether the reinforcements were corroded. SEM photographs were taken for unprotected and protected specimens. Microscopy was used to observe their cross sections.

X-ray diffraction analysis: X-ray was used to analyze corrosion product on the steel surface. The steel reinforcement surface film was analyzed as soon as the specimen was broken.

3. Results and discussion

3.1 Cathodic protection criteria investigation

Study of cathodic protection of steel in concrete in water environment was carried out by impressing specimens with current densities ranged from 3 mA/m^2 to 15 mA/m^2. During test, cathodic protection criteria were investigated.

In order to assess cathodic protection of specimens, the following criteria have been considered: 300 mV potential shift, protection potential (-800 mV vs. SCE for continuously and partly submerged specimens, -720 mV vs. SCE for cyclically submerged specimens) and 100 mV decay for cyclically submerged specimens.

Received results say that application of above criteria to cathodic protection of steel in concrete in water environment is suitable. Basing on such criteria, minimum current densities for cathodic protection of steel in concrete in studied solutions were set up as follows:

2 to 7 mA/m^2 for continuously submerged reinforced concrete

3 to 7 mA/m^2 for partly submerged reinforced concrete

11 to 15 mA/m^2 for cyclically submerged reinforced concrete

It is also indicated that reinforcing steel in concrete in a high chloride water environment needs the higher protected current density than the one in the less chloride environment.

From the studied results, it is drawn that in order to assess and operate cathodic protection system, it should be used a combination of -800mV vs. SCE protection potential and 300mV potential shift for continuously submerged reinforced concrete, and a combination of -720mV vs. SCE protection potential and 100mV decay for cyclically submerged reinforced concrete.[1-4]

3.2 Cyclic potentiodynamic polarization

The potentiodynamic polarization tests were performed on all the specimens with and without cathodic protection. It is found that whenever the impressed current densities are less than the above minimum current densities then the cyclic potentiodynamic curves show pitting on steel reinforcements. But it is shown no pitting on cyclic potentiodynamic curves for higher impressed current densities. From the experimental results, a good correlation between cathodic protection criteria and cyclic potentiodynamic curves is found. An example of potentiodynamic curves is presented in Fig. 1 and 2.

Fig. 1 shows the cyclic potentiodynamic curve of unprotected reinforcement submerged cyclically in 3.5% NaCl solution. This is also the form of cyclic potentiodynamic curves for unprotected specimens in water environment. The curve indicates that the current density is higher for the same values of potentials during the reverse scan period, which means that the unprotected reinforcement is undergoing pitting corrosion. Form of cyclic potentiodynamic curves for cathodically protected specimens is shown in Fig. 2. If the impressed current is not

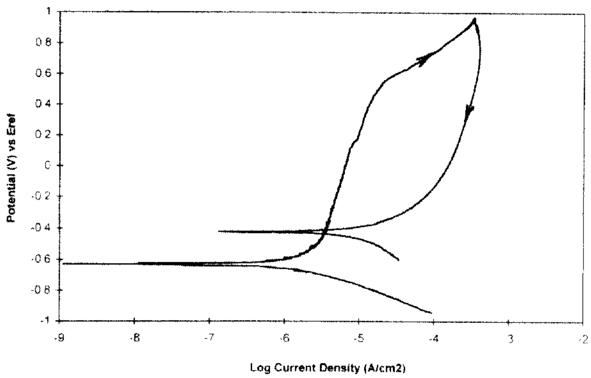
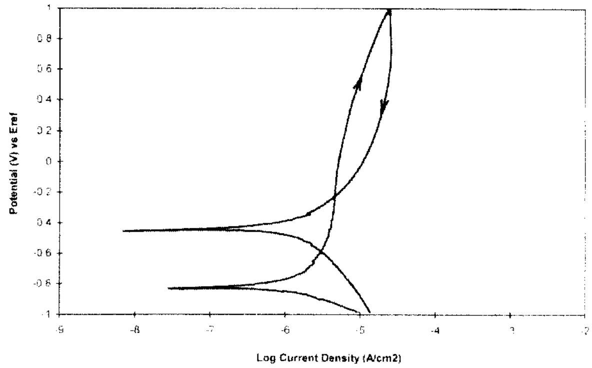
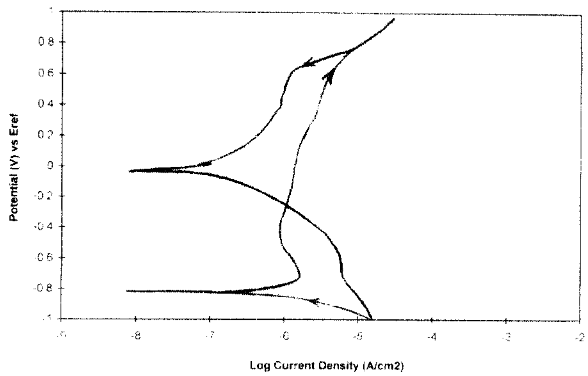


Fig. 1. Cyclic potentiodynamic curve of unprotected reinforcement submerged cyclically in 3.5% NaCl solution



(a)



(b)

Fig. 2. Cyclic potentiodynamic curves of protected-at-13 mA/m^2 reinforcements
(a) submerged cyclically in 3.5% NaCl solution
(b) submerged cyclically in 0.3% NaCl solution

high enough to protect the reinforcement then pitting is existing but the loop is smaller than for the unprotected one, such as cyclic potentiodynamic curve of protected-at-13 mA/m^2 reinforcement submerged cyclically in 3.5% NaCl solution in fig. 2a (compared to fig. 1). If the impressed current is high enough then the curve exhibits the smaller current density for the same values of potentials during the reverse scan period, which means that no pitting is occurred. This case is the cyclic potentiodynamic curve of protected-at-13 mA/m^2 reinforcement submerged cyclically in 0.3% NaCl solution (Fig. 2b).

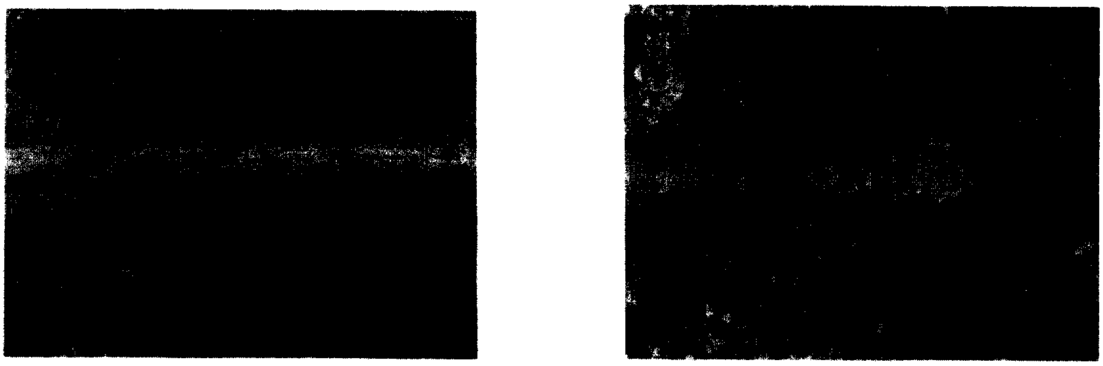
From the investigated results, it can be said that there is a good correlation between the cathodic protection criteria and analysis of cyclic potentiodynamic curves for determining protection current density.

3.3 Visual examination

Visual test after breaking specimens showed that all the unprotected reinforcements were locally corroded, while for the well-protected reinforcements no sign of corrosion was observed. Fig. 3 presents suffices of the partly submerged reinforcements with and without cathodic protection. It can be seen that there are black spots (localized corrosion) on the unprotected reinforcement submerged partly in 3.5% NaCl solution (fig. 3a). When the reinforcement in the same solution is cathodically protected at 9 mA/m^2, no localized corrosion occurs on its surface (Fig.3b).

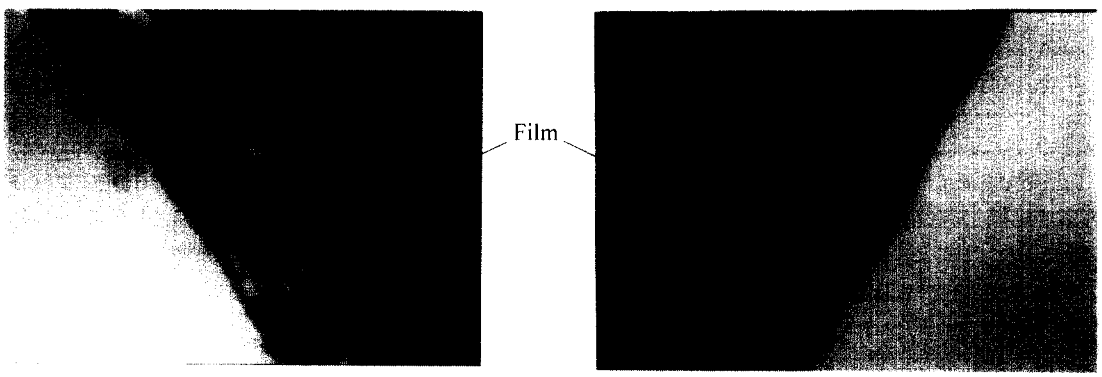
Cross-section of unprotected and protected specimens were cut and magnified by microscope. Fig. 4 shows cross-sections of reinforcements submerged cyclically in 3.5% NaCl solution. A loose film can be observed on the unprotected steel (fig. 4a), while the protected steel has a close film on its surface (fig. 4b). This shows the effect of cathodic protection in maintaining passive film or re-establishing passive film on the steel reinforcement.

Some corrosion product films of steel reinforcements under different submerged conditions were analyzed by X-ray diffraction. The X-ray diffractogram of unprotected reinforcement film presented Fe_2O_3, FeO, Fe_3O_4 and



(a) (b)

Fig. 3. Suffices of unprotected (a) and protected-at-9 mA/m^2 (b) reinforcements submerged partly in 3.5% NaCl solution



(a) (b)

Fig. 4. Cross sections of the unprotected (a) and protected-at-13 mA/m^2 (b) reinforcements submerged cyclically in 3.5% NaCl solution

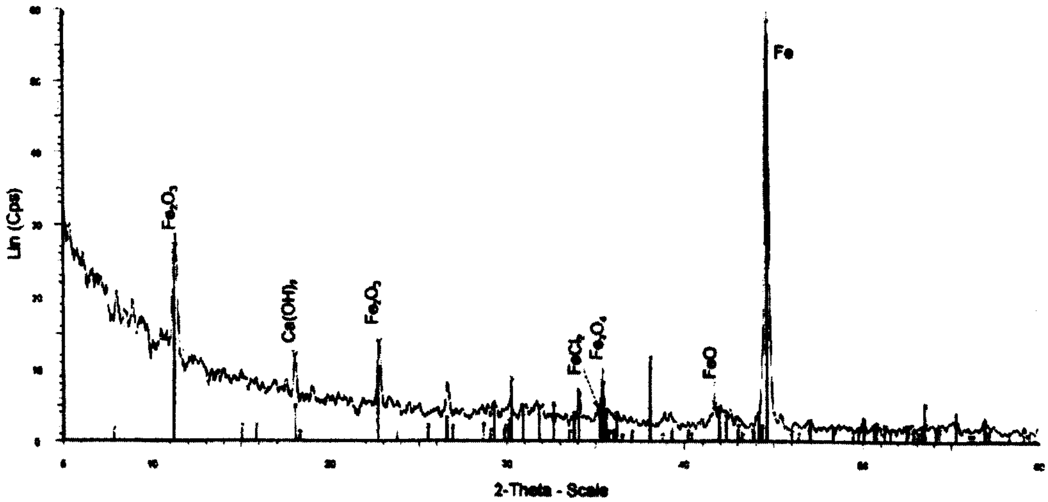


Fig. 5. X-ray diffractogram of unprotected reinforcement submerged continuously in 3.5% NaCl solution

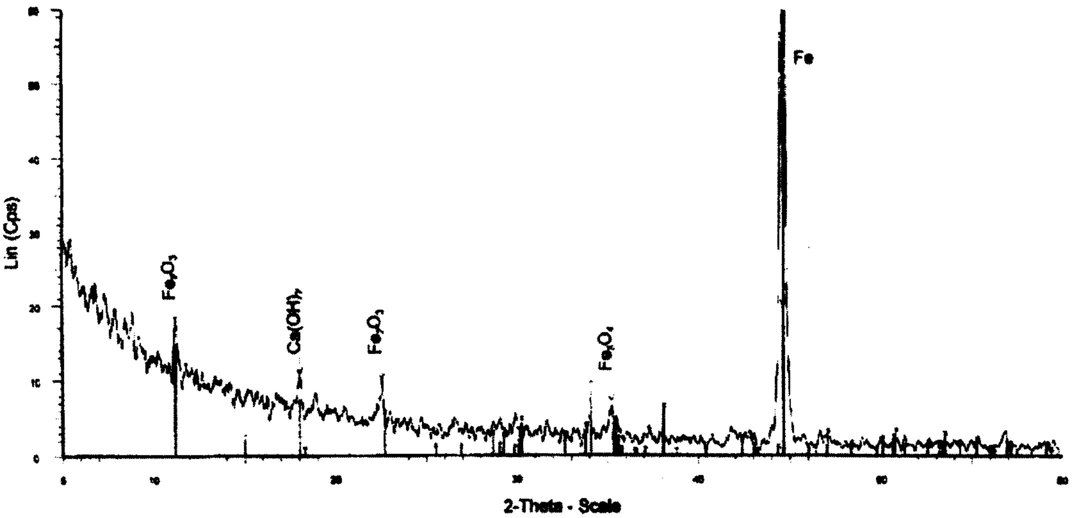


Fig. 6. X-ray diffractogram of protected-at-7 mA/m^2 reinforcement submerged continuously in 3.5% NaCl solution

$FeCl_2$, as shown in Fig. 5. The presence of $FeCl_2$ in the X-ray diffraction spectrum confirms participation of chloride ions in the mechanism of corrosion of steel in concrete. But $FeCl_2$ does not appeared in the diffractogram of protected reinforcement (Fig. 6), which proves the effect of cathodic protection in migration of chloride ions from reinforcement.

4. Conclusions

The following conclusions can be drawn from the investigation:

– Investigated results have proved the effect of cathodic protection in restoring or strengthening passive film on the steel reinforcement. No pitting was observed on well-protected steel.

– There is a good correlation between the used cathodic protection criteria and surface observation, as well as analysis of cyclic potentiodynamic curves in order to assess cathodic protection systems.

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