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Experimental Study on Corrosion Rate in Concrete

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The corrosion of reinforcement is a very important factor on the serviceability and safety of reinforced concrete structures. The corrosion rate influences directly the cover failure time of reinforced concrete structures because the corrosion rate is used to estimate the amount of corrosion and thus expansive pressure due to corrosion. In this study, several series of experiments are performed considering the chloride concentration in artificial pore solution. The potentials are measured according to the applied current density and then corrosion current densities are obtained from the Tafel plot for various chloride concentrations. The measured corrosion rates show good correlation with those of other researchers.

Keywords : *corrosion rate, chloride concentration, concrete, pore solution*

1. Introduction

Concrete is effective in protecting embedded steel corrosion. However, it is well known that the corrosion of steel reinforcement in concrete can be easily induced by the presence of chloride ions. When the chloride concentration in the concrete reaches a certain level, the threshold chloride concentration, the protective environment in the concrete is destroyed, and the corrosion process starts. The corrosion rate rapidly increases after concrete cover cracks. The corrosion rate of steel in concrete is a function of the relative humidity of concrete, availability of oxygen, and temperature, etc.[1]

The corrosion rate of steel in artificial pore solution depends on concentration of chloride ion, as previously mentioned in the work of Verbeck. Verbeck states that the threshold and rate of corrosion are affected by the alkalinity and chloride concentration.[2] This can be used to explain the phenomena of non-uniform corrosion of steel in concrete exposed to chloride invasion.

The purpose of present study is to propose a realistic relation between corrosion current density and chloride content in concrete, which can be used to estimate the corrosion amount and thus the time to cover cracking in reinforced concrete structures.

2. Experimental

2.1 Tests setup

The test variables are designed for showing the effects of chloride concentration on corrosion rate. The working electrode specimen is made with reinforcement bar (diameter 11.5 mm, area 1.03 cm^2) and Formica using teflon mold. A 1 litter of electrolyte is used per one experimental process to the exclusion of oxygen availability. The corrosion current density of steel in simulated pore solution is measured from Tafel plot curves acquired by using Potentiostat / Galvanostar Model 273A.

2.2 Tests variables

The main variable is the chloride concentration (0.05 mol/L, 0.1 mol/L, 0.3 mol/L, 0.5 mol/L and 0.7 mol/L) in pH 12.5 ± 0.1 artificial pore solution. The chloride concentration is set using sodium chloride(NaCl) and pH is controlled using calcium hydroxide($Ca(OH)_2$). A concentration of 0.7 mol/L is approximately equals to the concentration of chloride in seawater. And it is supposed that artificial pore solution is similar to the environment in fully saturated concrete.

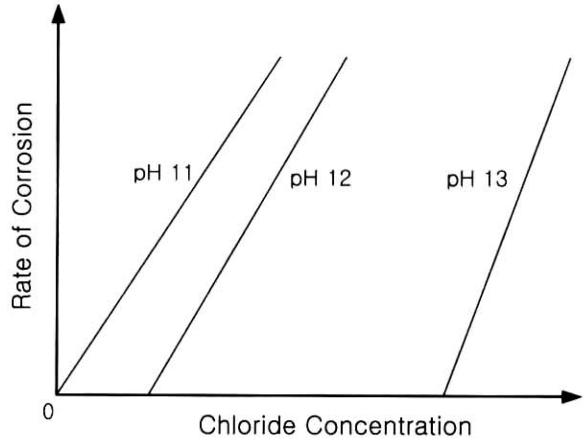

Fig. 1. Threshold chloride ion concentration required to occur increase as the alkalinity, pH of the cement paste liquid increases [2)]

Table 1. Tests Variables

Series No.	Chloride concentration (mol/L)	pH
1	0.05	12.53
2	0.1	12.60
3	0.3	12.44
4	0.5	12.50
5	0.7	12.51

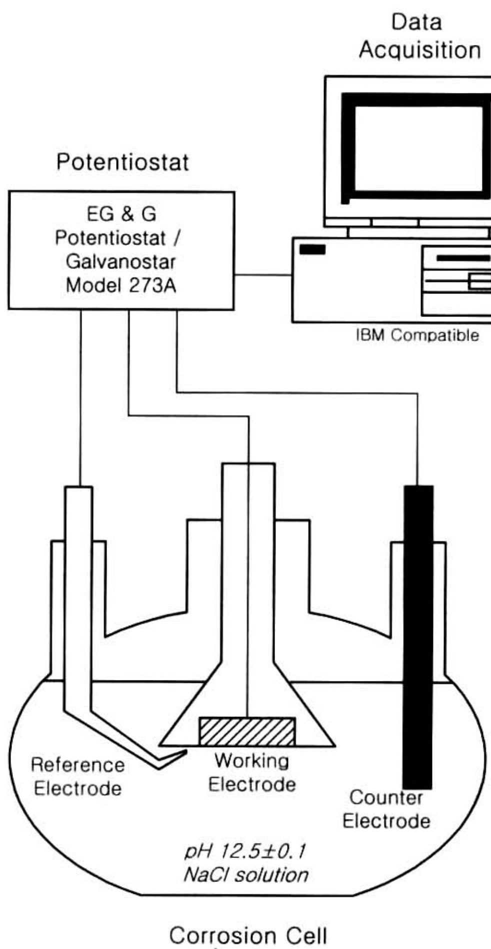

Fig. 3. Experiments setup

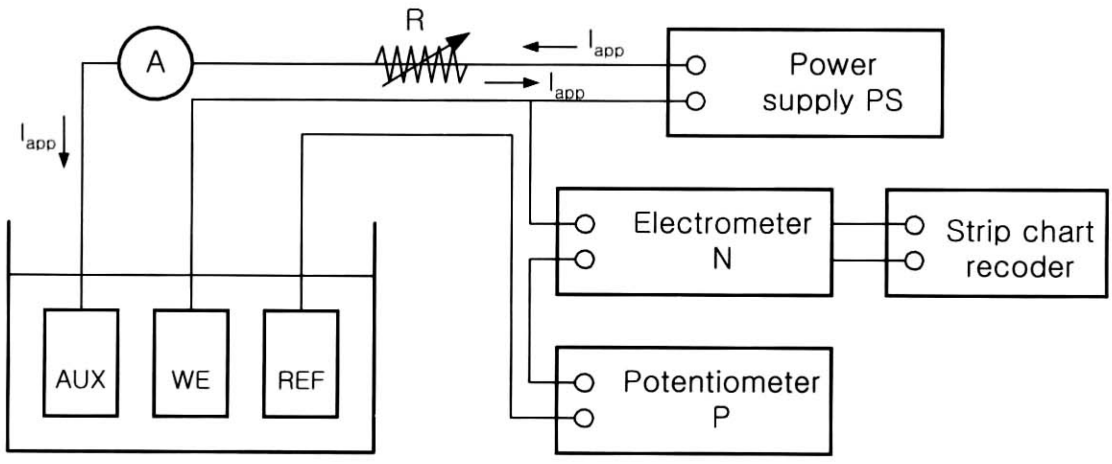

Fig. 2. Galvanostatic, constant-current circuitry for determination of corrosion rate by polarization methods

3. Test results and discussion

3.1 Test results

From the measured Tafel plot curve, the current density is determined. Each Tafel plot curve is illustrated in Fig. 4 ~ Fig. 8. Fig. 4 shows the Tafel plot curve of steel in artificial solution having 0.05 mol/L chloride concentration and pH 12.5±0.1. Fig. 5 shows the Tafel plot curve of steel in artificial solution having 0.1 mol/L chloride concentration and pH 12.5±0.1. Fig. 6 shows the Tafel plot curve of steel in artificial solution having 0.3 mol/L chloride concentration and pH 12.5±0.1. Fig. 7 shows the Tafel plot curve of steel in artificial solution having 0.5 mol/L chloride concentration and pH 12.5±0.1. Fig. 8 shows the Tafel plot curve of steel in artificial solution having 0.7 mol/L chloride concentration and pH 12.5±0.1.

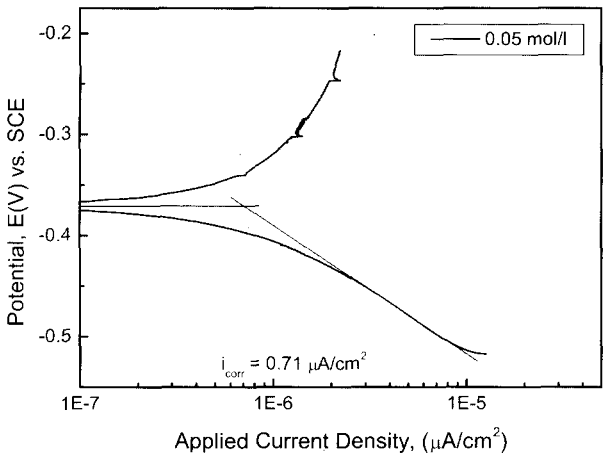

Fig. 4. Tafel plot (0.05 mol/L)

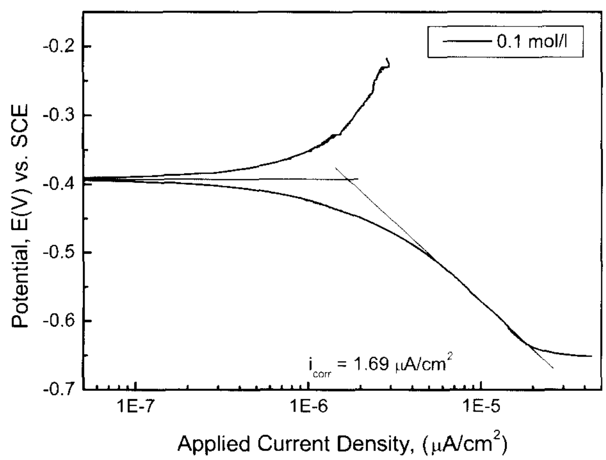

Fig. 5. Tafel plot (0.1 mol/L)

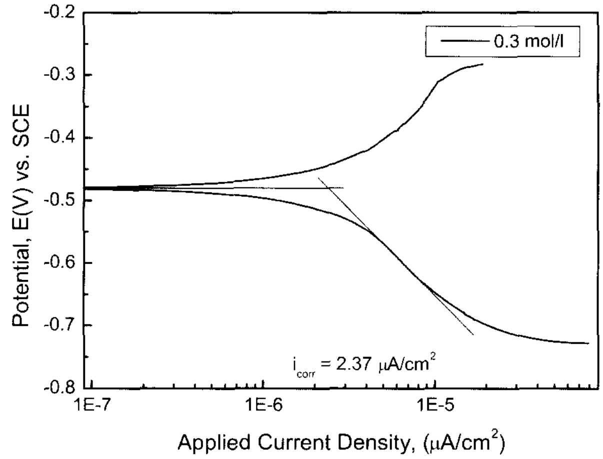

Fig. 6. Tafel plot (0.3 mol/L)

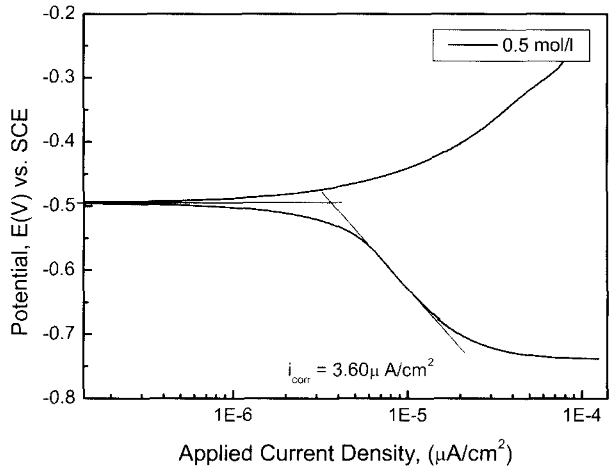

Fig. 7. Tafel plot (0.5 mol/L)

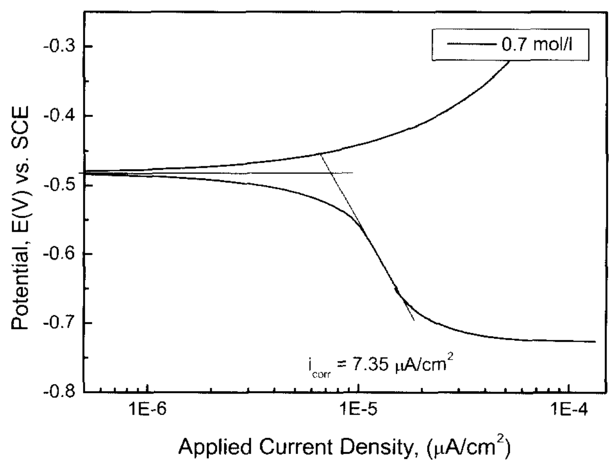

Fig. 8. Tafel plot (0.7 mol/L)

Table 2. Corrosion current density

Series No.	Chloride concentration (mol/L)	Corrosion current density ($\mu A/cm^2$)	pH
1	0.05	0.71	12.53
2	0.1	1.69	12.60
3	0.3	2.37	12.44
4	0.5	3.60	12.51
5	0.7	7.35	12.50

As shown in Fig. 4 ~ Fig. 8, the corrosion current density obtained from experiments is 0.71 $\mu A/cm^2$, 1.69 $\mu A/cm^2$, 2.37 $\mu A/cm^2$, 3.60 $\mu A/cm^2$ and 7.35 $\mu A/cm^2$ for chloride concentration of 0.05 mol/L, 0.1 mol/L, 0.3 mol/L, 0.5 mol/L and 0.7 mol/L, respectively. (see Table 2)

3.2 Relationship between corrosion rate and chloride concentration

Fig. 9 shows that the corrosion current density increases as the chloride concentration in pore solution increases. This shows a good coincidence with the work of Verbeck. Corrosion current density can be estimated from Fig. 9 according to chloride concentration in the solution. The corrosion current density equation was obtained through linear fitting of the result of experimental data.

$$i_{corr} = 6.135 + 4.559\log(c_{sol}) \qquad (1)$$

where i_{corr} is the corrosion current density($\mu A/cm^2$), c_{sol} is the chloride concentration in solution(*mol/L*).

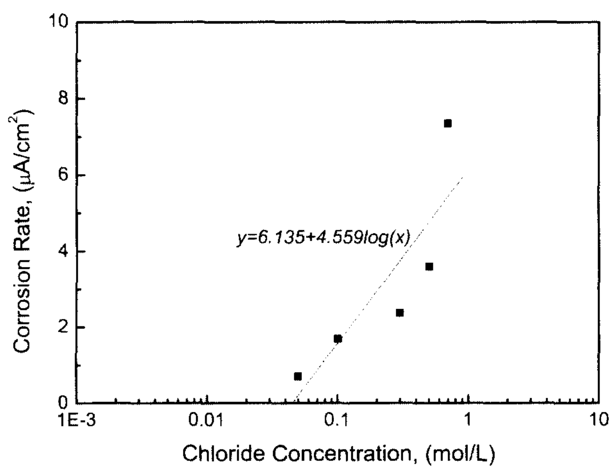

Fig. 9. Corrosion current density according to chloride concentration in solution

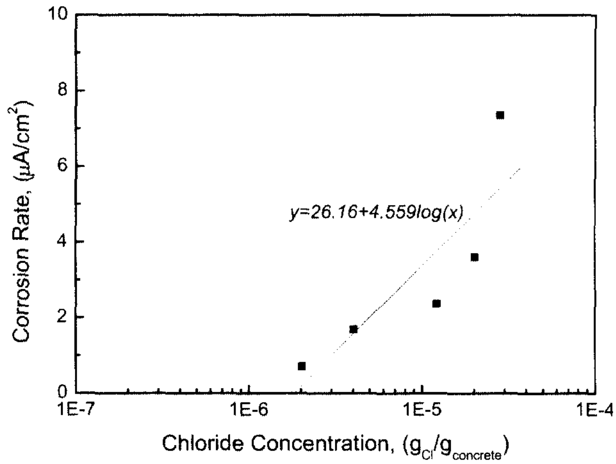

Fig. 10. Corrosion current density according to chloride concentration in concrete

Fig. 10 alters c_{sol} in scale of axis (chloride concentration in solution). If the concrete is saturated, the scale of axis changes from *mol/L* to $g_{cl} / g_{concrete}$ using the characteristics of β_{sol} which is the ratio of pore solution to concrete, in liters of the pore solution per gram of the concrete ($L_{pore\ solution} / g_{concrete}$).[3)-6)] Modified Power's model[7)] is adopted to derive β_{sol} which is function of mix property, age, cement type and et al.
Then equation (1) transforms to equation (2)

$$i_{corr} = 26.16 + 4.559\log(C_{sol}) \qquad (2)$$

where c_{sol} is the chloride concentration in grams of chloride weight per grams of concrete weight (g_{cl} / $g_{concrete}$).

Experimental result shows that the relationship between chloride concentration and corrosion current density of steel in artificial pore solution. Therefore we need some assumptions to apply this relationship to the reinforcement in concrete considering the real condition.

This study assumes that the chloride concentration at the start point of corrosion, that is, the corrosion current density which starts from zero, equals the threshold concentration of chloride in concrete. The relationship between the free chloride concentration in concrete and the corrosion current density of steel in concrete is presented in equations (3) and Fig. 11.

$$i_{corr} = 26.16 + 4.559\log\left(\frac{C_f}{820.7}\right) \qquad (3a)$$

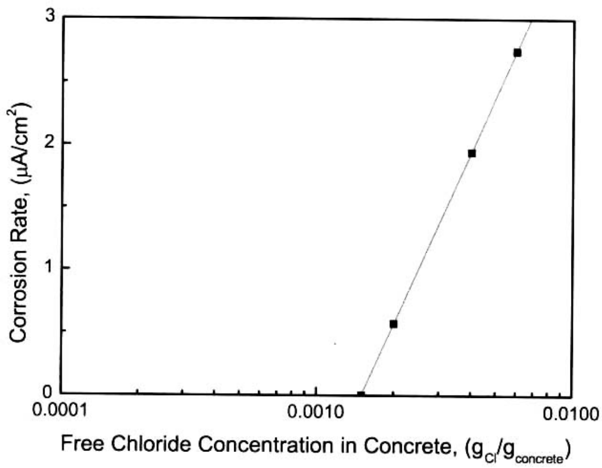

Fig. 11. Relationship between C_f and i_{corr}

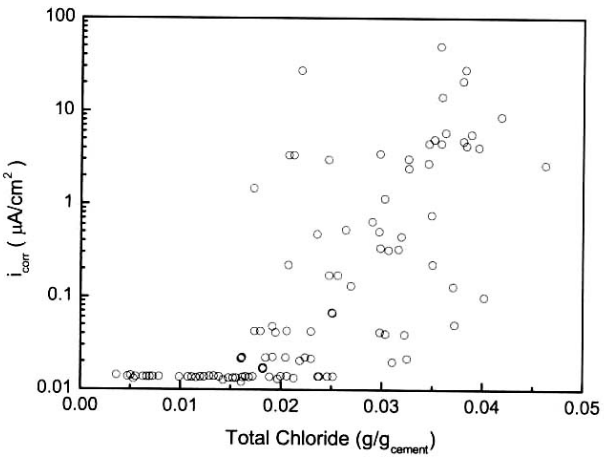

Fig. 12. i_{corr} according to total chloride concentration[11)]

$$i_{corr} = 12.87 + 4.559\log(C_f) \quad (3b)$$

where C_f is the free chloride concentration in grams of free chloride weight per grams of concrete weight (g_{cl} / $g_{concrete}$). This study assumes that the threshold concentration of chloride is 0.0015 g_{cl} / $g_{concrete}$.[8)-10)]

4. Conclusions

Following conclusions were drawn from this study,

(1) A suggested relationship between corrosion rate and chloride concentration has good agreements with tendency of others paper.

(2) The proposed equation for corrosion rate can be efficiently use through estimate the corrosion amount of steel bar and eventually the time to cover cracking of concrete structures.

(3) The relationship between corrosion rate and chloride concentration in concrete is suggested. However, more complementary experimental data and site measurement data are necessary for realistic application.

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