경화중 콘크리트의 염해 침투성능에 관한 연구

Prediction of chloride penetration into hardening concrete

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Abstract

In marine and coastal environments, penetration of chloride ions is one of the main mechanisms causing concrete reinforcement corrosion. Currently, most of experimental investigations about submerged penetration of chloride ions are started after the four weeks standard curing of concrete. The further hydration of cement and reduction of chloride diffusivity during submerged penetration period are ignored. To overcome this weak point, this paper presents a numerical procedure to analyze simultaneously cement hydration reaction and chloride ion penetration process. First, using a cement hydration model, degree of hydration and phase volume fractions of hardening concrete are determined. Second, the dependences of chloride diffusivity and chloride binding capacity on age of concrete are clarified. Third, chloride profiles in hardening concrete are calculated. The proposed numerical procedure is verified by using chloride penetration test results of concrete with different mixing proportions.

키 워 드 : 염화물 침투, 수화, 강화중 콘크리트, 확산 계수, 결착력
Keywords : Chloride penetration; hydration; hardening concrete; diffusion coefficient; binding capacity

1. Introduction

The ingress of chloride ions constitutes a major source of durability problems affecting reinforced concrete structures which are exposed to marine environments. Once a sufficient quantity of chloride ions has accumulated around the embedded steel, pitting corrosion of the metal is liable to occur unless the environmental conditions are strongly anaerobic. In the design of concrete structures, the influence of chloride ingress on service life must be considered [2].

2. Cement hydration model

The shrinking-core model, which was originally developed by Tomosawa [2], is used in this study to simulate the development of cement hydration. This model is expressed as a single equation consisting of three coefficients: k_d the reaction coefficient in the induction period; D_e the effective diffusion coefficient of water through the C-S-H gel; and k_{ri} a coefficient of the reaction rate of mineral compound of cement as shown in eqs. (1) and (2) below:

$$\frac{d\alpha_i}{dt}=\frac{3(S_w/S_0)\rho_w C_{w-free}}{(v+w_g)r_0\rho_c}\frac{1}{(\frac{1}{k_d}-\frac{r_0}{D_e})+\frac{r_0}{D_e}(1-\alpha_i)^{\frac{-1}{3}}+\frac{1}{k_{ri}}(1-\alpha_i)^{\frac{-2}{3}}} \quad (1)$$

$$\alpha=\frac{\sum_{i=1}^{4}\alpha_i g_i}{\sum_{i=1}^{4} g_i} \quad (2)$$

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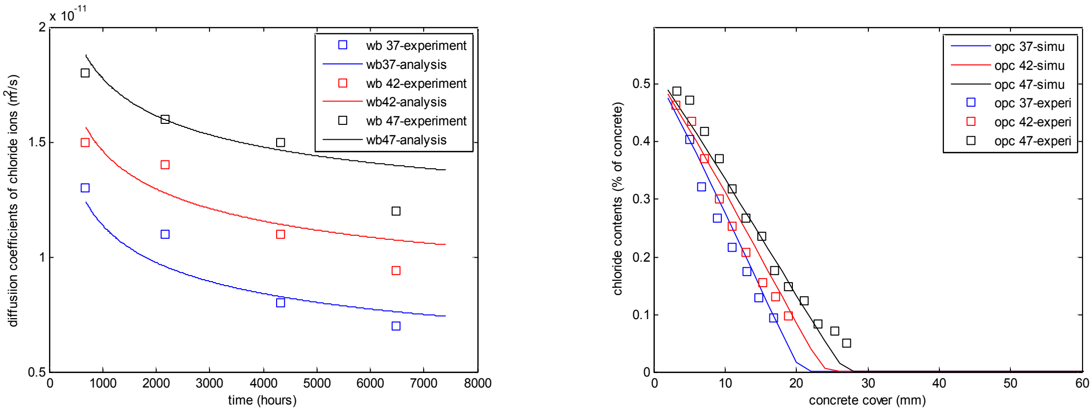
3. Chloride penetration model

The following modified Fick's second law equation can be obtained, as equation (3) :

$$\frac{\partial C_f}{\partial t}=\frac{\partial}{\partial x}\left(\frac{\frac{D_c}{V_4}}{1+\frac{1}{V_4}\frac{\partial C_b}{\partial C_f}}\frac{\partial C_f}{\partial x}\right) \qquad (3)$$

As shown in equation (2), $\frac{\partial C_b}{\partial C_f}$ is the binding capacity of the concrete binder (m^3 of pore solution/m^3 of concrete), D_c is the effective diffusion coefficient when the concentration is expressive in kilograms per cubic meter of pore solution (m^2/s). The analyzed results about chloride diffusion coefficients and chloride profiles are shown in figure 1. as shown in this figure, the analyzed results generally agree with experimental results.



(1-a)chloride diffusion coefficients (1-b)chloride profiles

Figure 1. evaluation of chloride ions penetrations

4. Conclusions

This paper presents a numerical procedure to analyze chloride penetration into hardening concrete. The simultaneous cement hydration reaction and chloride ion penetration process are modeled. The proposed numerical procedure is verified by using chloride penetration test results of concrete with different mixing proportions.

참 고 문 헌

1. Xiao-Yong Wang, Han-Seung Lee. Modeling the hydration of concrete incorporating fly ash or slag. Cement and Concrete Research 40, pp.984~996, 2010
2. Xiao-Yong Wang and Ki-Bong Park. Modeling of hydration reactions to predict the properties of slag blended concrete. Can. J. Civ. Eng. 41: pp.421~431, 2014