

콘크리트의 탄산화로 인해 탈착된 염소이온의 재확산에 대한 해석 연구

Mathematical Modeling of Re-Diffusion Response of De-Sorbed Chloride Ions in Concrete Due to Carbonation

윤인석* 성재덕**
Yoon In-Seok Sung Jae-Duck

Abstract

Many concrete structures have suffered from carbonation or chloride ion diffusion induced reinforcement corrosion, and a number of studies have been done on these topics. Many studies were mostly confined to the single deterioration of carbonation or chloride ion, although the environment actually presents a combined condition.

This paper tried to develop the approach to compute re-diffusion of de-sorbed chloride due to carbonation of concrete. This is a key for successful combined deterioration model of carbonation and chloride. It is thought that this paper can contribute to express mathematically chloride enrichment and re-diffusion of chloride at front of carbonation.

요약

대부분의 콘크리트 구조물은 탄산화 및 염소이온의 침투에 의하여 철근부식을 겪고 있으나, 대다수의 콘크리트 구조물은 염소이온과 탄산화로 인한 복합열화를 겪고 있음에도 불구하고, 대다수의 연구들은 단일열화만을 다루고 있다.

본 연구는 탄산화로 인하여 탈착된 염소이온의 재확산을 추정하기 위한 접근방법을 개발하고 하였다. 이는 탄산화와 염소이온의 복합열화에 대한 성공적인 모델을 정립하는데 핵심적인 요소이다. 본 연구결과는 향후 복합열화 모델식에 반영되어 염소이온의 탈락으로 인해 탄산화 경계영역에서 염소이온의 농축 및 재확산을 효과적으로 표현할 수 있을 것으로 생각된다.

1. Introduction

In this study, we suggest fundamental approach the combined deterioration due to carbonation and chloride ion. Incidentally, the purpose of this study is to develop a practical strategy considering the process and synergy effect of combined deterioration. The synergy effect should be occurred, along with; (a) production of Friedel's salt and ettringite due to the compound reaction of cement and chloride ions, (b) carbonation of Friedel's salt and ettringite, (c) dissociation of Friedel's salt in pore solution, (d) increased chloride content in the pore solution, and the enrichment of chloride at the carbonation front. The purpose of this study is to develop new strategy for fact that dissociated chloride ions migrates into the noncarbonated area which can lead to the enrichment of chloride ions at the noncarbonated concrete.

* 정회원, 인덕대학 건설정보공학과 교수

** 정회원, 대림대학 토목환경과 교수

2. Mathematical Approach

While initial source of chloride is sea water in case of single deterioration of chloride, de-sorbed chloride can be regarded as an additional source of chloride for combined deterioration with carbonation, as shown Fig. 1. De-sorbed chloride ions, which are decomposed by carbonation, migrate to the insider of concrete by diffusion. A source of the released chloride is normally originated from the surface, however, re-diffusion of released chloride content is generated at surrounding space around carbonation front. Released chloride content, $[Cl(aq)]_{rel}$, can impact on diffusion to bilaterally. In this study, instantaneous planar diffusion in an infinite medium is considered to solve re-diffusion, diffusion phenomena at carbonation depth. De-sorbed chloride is allowed to spread to bilaterally into the two adjacent concrete occupying the half-spaces. The location of 0 “zero” means carbonation front. The application of the Laplace transform procedure to Fick’s second law gives the solution as Eq. (1).

$$\frac{p}{D}[\tilde{Cl}](x, p) - \frac{d^2[\tilde{Cl}](x, p)}{dx^2} = \frac{[Cl](x, 0)}{D} \quad (1)$$

In the case of the initial condition at time $t = 0$, $[Cl](x, 0) = 0$ for all $x \neq 0$ and the boundary condition $[Cl](\pm\infty, t) = 0$, so the finite concentration of de-sorbed chloride $[Cl(aq)]_{rel}$ cannot alter the composition of this infinitely long bar of material far away from the source’s location. The diffusion process is overall subject to the integral mass constant

$$\int_{-\infty}^{\infty} [Cl](x, t) dx = [Cl(aq)]_{rel} \quad (2) \quad \frac{p}{D}[\tilde{Cl}](x, p) - \frac{d^2[\tilde{Cl}](x, p)}{dx^2} = 0 \quad (3)$$

Now the initial condition above reduce the Laplace-transformed Fick’s second law, Eq.(1) for this problem to Eq. (3). Because the right-hand side of Eq.(1) vanishes at $t = 0$ for all x , except for the source plane itself at $x = 0$. Eq. (3) is a well-known linear ordinary differential equation with the general solution as Eq. (4). The boundary condition specified above indicates that both terms appearing in the solution, Eq. (5), will be needed to provide well-behaved piecewise solutions for the left-going and right-going diffusion field. Specifically, on-going re-diffusion is

$$[\tilde{Cl}(aq)] = Ae^{x\sqrt{p/D}} + Be^{-x\sqrt{p/D}} \quad (4) \quad [\tilde{Cl}(aq)] = Be^{-x\sqrt{p/D}}, \quad x > 0 \quad (A = 0) \quad (5)$$

Symmetry required that de-sorbed chloride flows left and right equally, so the global concentration constraint for the half-space $x > 0$ can be formulated by the Laplace transform of the concentration constraint as Eq.(6) which provides the following integral statement as Eq.(7).

$$\int_0^{\infty} e^{-pt} \int_0^{\infty} [Cl(aq)](x, t) dx dt = \int_0^{\infty} \frac{[Cl(aq)]_{rel}}{2} e^{-px} dx \quad (6) \quad \int_0^{\infty} [\tilde{Cl}(aq)](x, p) dx = \frac{[Cl(aq)]_{rel}}{2p} \quad (7)$$

Response of re-diffusion can be summarized and this can be re-expressed by inversed term of Laplace transform (L^{-1}), as shown in Fig. (9).

$$[Cl(aq)]_{r-diff}(x', t) = \frac{[Cl(aq)]_{rel}}{2\sqrt{D_{Cl}^{ncb}}} L^{-1} \frac{e^{-a\sqrt{p}}}{\sqrt{p}}, \quad 0 < x' < x_c \quad (8) \quad [Cl(aq)]_{r-diff}(x'', t) = \frac{[Cl(aq)]_{rel}}{2\sqrt{D_{Cl}^{cb}}} L^{-1} \frac{e^{-a\sqrt{p}}}{\sqrt{p}}, \quad x \geq x'' \quad (9)$$

in which, t_c denotes a subsequent time after concrete is carbonated by the level of carbonation depth x_c . Instantaneous depth x' and x'' are in range of carbonated concrete, and noncarbonated concrete, respectively.

3. Concluding Remarks.

This study could be regarded as key module for released chloride enrichment and its re-diffusion response and be expanded into simultaneous deterioration model.

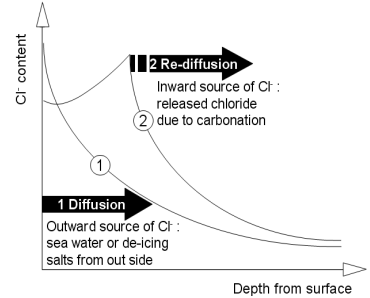


Fig. 1 Chloride diffusion response with various original sources

The application of the Laplace transform procedure to Fick’s second law gives the solution as Eq. (1).