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A numerical study on chloride migration in cracked concrete using multi-component ionic transport models

Qing-feng Liu [a,b,*], Jian Yang [a,b,e], Jin Xia [c], Dave Easterbrook [d], Long-yuan Li [d], Xian-Yang Lu [a,b]

[a] State Key laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai 200240, PR China
[b] School of Naval Architecture, Ocean & Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, PR China
[c] Institute of Structural Engineering, Zhejiang University, Hangzhou, PR China
[d] School of Marine Science and Engineering, University of Plymouth, PL4 8AA, UK
[e] School of Civil Engineering, University of Birmingham, B15 2TT, UK

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ABSTRACT

This paper presents a numerical study on the mechanism of chloride migration in cracked concrete. Unlike most of existing work, this study utilises multi-component ionic transport models to reflect the influence of ionic interactions by coupling the mass conservation and Poisson's equations. To provide a better understanding of the influences caused by multi-component migration and concrete cracking, two categories of geometry samples are displayed and discussed respectively. Finally, through a comparatively overall numerical exploration, which includes external voltage, ionic interactions, heterogeneous nature, binding effect and multiple cracks arrangement, a series of important transport features, which cannot be revealed previously from existing cracked concrete models, are highlighted.

1. Introduction

Nowadays, durability problem has received more and more attention in the concrete industry. It is well known that the performance of reinforced concrete (RC) structures will be significantly influenced by the penetration of ions, especially chloride ions. This deterioration caused by chloride-induced corrosion of reinforcing steel is even serious when the concrete has cracks. Cracking is an inevitable phenomenon for RC structures and can be generated due to various reasons, i.e., plastic and restrained shrinkage, thermal and mechanical loading, expansive degradation reactions, improper design, etc.

To assess the effect of cracking characteristics on chloride diffusion in concrete, a number of studies [1–12] have been reported, in which traditional approaches including analytical and/or experimental methods were used. However, note that concrete is a heterogeneous material with complicated microstructure organisation. For analytical studies, the main shortcoming is that they could only focus on the transport of ions in a 1-D single-phase medium (i.e., the cement or mortar matrix), neglecting the impact of other meso- or micro-structures in concrete. Moreover, due to the high nonlinear level of the problem of multi-component ionic transport, almost all existing analytical models consider the transport of only a single-species, i.e. the chloride ions. For experimental studies, though they can provide wider and valuable data, it is still very difficult for them to reveal individual effects of different factors because of the interactions between different factors. Also, most of testing methods are expensive and time-consuming, especially for the high-performance concrete specimens.

Hence, with respect to the abovementioned issues, as well as the fast advance of computer science and progress of computational mathematics, today's researchers tend to adopt the numerical technique to gain a better understanding of the mechanism of chloride transport in cracked concrete [13–18]. For example, Leung and Hou [13] developed a 2-D single-phase concrete model with cracks for investigating the chloride-induced reinforcement corrosion. Marsavina et al. [14] examined the influence of artificial

* Corresponding author at: School of Naval Architecture, Ocean & Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, PR China. Tel.: +86 1394 2035 131.
E-mail addresses: henrylqf@163.com, liuqf@sjtu.edu.cn (Q.-f. Liu).

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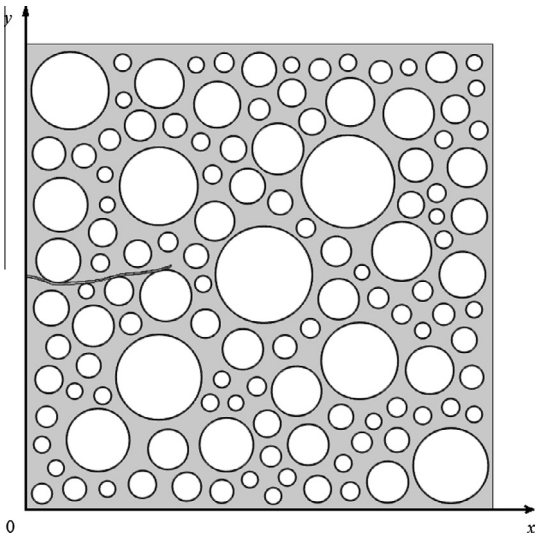

Fig. 1. Geometry of 3-phase heterogeneous concrete model with mesocrack.

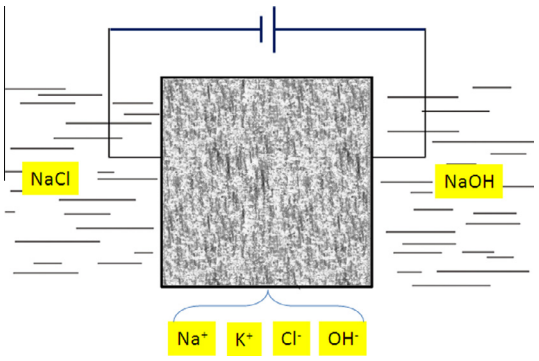

Fig. 3. Schematic representation of 2-D plain concrete specimen in a RCM test.

Table 2
Initial and boundary conditions of individual species.

Field variables		Potassium	Sodium	Chloride	Hydroxide	Electrostatic potential
Concentration boundary conditions, mol/m^3	$x = 0$	0	520	520	0	0
	$x = L$	0	300	0	300	24 V
Flux boundary conditions	$y = 0$	$J = 0$	$J = 0$	$J = 0$	$J = 0$	$\partial\Phi/\partial y = 0$
	$y = L$	$J = 0$	$J = 0$	$J = 0$	$J = 0$	$\partial\Phi/\partial y = 0$
Initial conditions, mol/m^3	$t = 0$	200	100	0	300	0

cracks on the chloride penetration in concrete using a 3-D finite element analysis model. However, the model developed was based on a single phase for which the concrete was treated as a homogenous material. Wang and Ueda [15] proposed a 2-D mesoscale transport model for investigating chloride diffusion in cracked concrete, in which the concrete was treated as a three-phase composite, consisting of aggregate, mortar, and interfacial transition zone (ITZ). It was found that chloride ions can penetrate into cracks with a much higher speed than they do into other phases. Šavija et al. [16] presented a further simulation with a 3-D geometry based on lattice fracture model [19–22] to emphasise that cracked concrete is highly inhomogeneous and their transport properties would show significant local variations. Mesoscale finite element models, originally developed for the stress analysis of concrete [23,24], have recently been applied to predict the transport

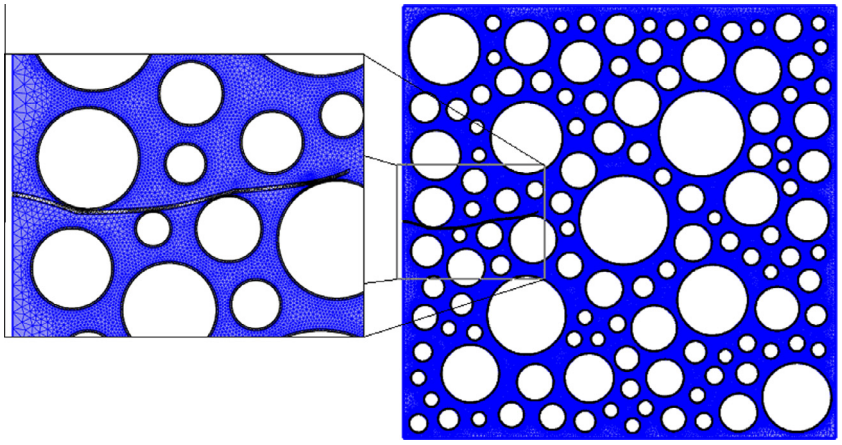

Fig. 2. Finite element mesh.

Table 1
Ionic transport properties in different phases.

Field variables	Potassium (mol/m^3)	Sodium (mol/m^3)	Chloride (mol/m^3)	Hydroxide (mol/m^3)
Charge number	1	1	−1	−1
Diffusion coefficient in aggregates, D_A	0	0	0	0
Diffusion coefficient in bulk mortar, $D_B \times 10^{-10}$ m^2/s	3.914	2.668	4.064	10.52
Diffusion coefficient in ITZs, $D_I \times 10^{-9}$ m^2/s	1.174	0.800	1.219	3.156
Diffusion coefficient in crack, $D_C \times 10^{-8}$ m^2/s	2.348	1.601	2.438	6.312
Diffusion coefficient in damage zone, $D_D \times 10^{-8}$ m^2/s	0.783	0.534	0.921	2.104