DEVELOPMENT OF SIMULATION METHOD FOR CRACK PROPAGATION AND CORROSION PRODUCTS MOVEMENT DURING REBAR CORROSION PROCESS

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1 INTRODUCTION

Corrosion products movement has a big role in the cracking process. Therefore, some experimental observations concerning the corrosion products movement have been conducted. For example, Wong et al (2010) observed the migration of corrosion products using image analysis. They found that the corrosion products can accumulate at the steel-concrete interface and pores. The corrosion products movement to the pores influences on crack initiation and the movement to cracks influences on long-term crack width development.

The aim of this paper is to develop the simulation method for the corrosion-induced cracking process with corrosion products movement by RBSM combined with Truss Network Model. Moreover, the applicability is evaluated by comparing with crack width development from test results and the effect of corrosion products movement is discussed.

2 OUTLINE OF DEVELOPED SIMULATION METHOD

2.1 Concept of proposed method

RBSM is one of the discrete models to simulate concrete cracking behavior accurately. Tran et al (2011) succeed to simulate concrete cracking due to rebar corrosion by using RBSM with introduced three phases material model. Their model assumed local corrosion and penetration of corrosion products through cracks. However, their model is time independence. A number of time-dependent analysis of RBSM have been proposed. Srisoros et al (2007), analyzed mass transfer by using RBSM combined with truss network model. In this model, truss elements are generated at both internal and boundary of the Voronoi element. Internal truss element is used to carry out mass transfer into the concrete bulk and boundary truss element is used to carry out mass transfer through cracks.

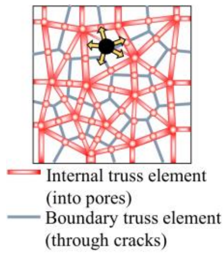

Fig. 1 Concept of proposed model

This proposed model combined the concept of Srisoros et al (2007) and Tran et al (2011), that is cracking behavior is simulated by considering corrosion products movement into pores and through cracks as shown in Fig.1.

2.2 Outline of simulation flow

Fig. 2 shows the simulation flow of the proposed model, which combines diffusion analysis for corrosion products movement by using truss network model and corrosion expansion and cracking analysis for structural evaluation by RBSM. Initially, the increment of mass loss Δm_i was determined by Faraday's Law, and current efficiency N_i based on local crack width w was introduced (Qiao, (2016)). Corrosion products consist of solid and liquid phase and both phases are important in the corrosion process.

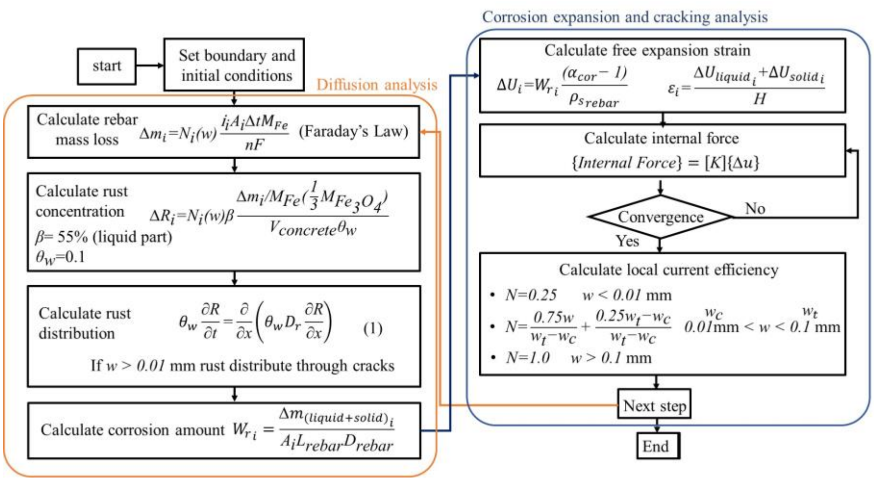

Fig. 2 Simulation flow.

In the diffusion analysis, only liquid parts β join the diffusion process, which is assumed as 55% (Gebreyouhannes et al (2016)). Subsequently, liquid corrosion products concentration was calculated with the assumption of corrosion products type as Fe_3O_4. Calculated corrosion product concentration was distributed using one-dimensional diffusion equation in Eq (1), where R, D_r, and θ_w are corrosion products concentration, the diffusivity of the corrosion products, and volume fraction of pore water, respectively. Diffusion coefficient into the pores is assumed as $2.2x10^{-6}$ mm^2/s. When crack larger than 0.01 mm occurs, corrosion products can move through the cracks and diffusion coefficient in cracked part is assumed as $2.2x10^{-2}$ mm^2/s which is quite larger values than one of the pores.

In the corrosion expansion and cracking analysis, expansion of corrosion products due to corroded rebar was modeled by internal expansion pressure on the boundary between rebar and corrosion products layer. Based on the mass loss considering the effect of local current efficiency, corrosion amount Wr_i was calculated. The current efficiency for rebar area near concrete surface increase if a sufficient crack w appears (Qiao, (2016)). The increment of initial strain was calculated based on the free increase of rebar radius ΔU_i which was obtained by using corrosion amount and the ratio of

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volume expansion α_{cor} assumed as 2.5. Based on predicted crack width obtained by RBSM, local current efficiency was updated to calculate mass loss and initial strain for the next step.

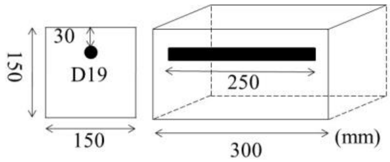

Fig. 3 Specimen geometry

3. VALIDATION OF THE MODEL

3.1 Analytical model

In this study, a single rebar specimen shown in Fig. 3 was simulated. This specimen was also tested by electric corrosion test with current density 900 μA/cm^2. Surface crack width was observed in the test.

3.2 Analytical result and discussion

Simulations were performed for three cases, without corrosion products movement, with the movement only into the pores, and with the movement both into the pores and through the cracks. Fig. 4 presents surface crack width propagation against the time. Corrosion products movement into the concrete pores delay the crack initiation and when the cracks appear, corrosion products move through the cracks and reduce the expansion pressure near rebar, then the cracking speed become slower. It is confirmed that most of the liquid parts moved through the cracks and solid parts contribute to expansion pressure. It can be deduced that corrosion products movement affect the cracking process. Fig. 5 shows cross section of specimen and corrosion products distribution. It can be seen clearly that corrosion products are distributed gradually as the crack develops within the time. Corrosion products concentration is higher near the vertical cracks in concrete cover. This model can simulate severer corroded part of rebar. The effect of some parameters is also investigated. Fig. 6 shows the effect of diffusion coefficient in the crack. It shows that smaller diffusion coefficient give higher cracking speed, but the difference between this diffusion coefficient is not so obvious. Therefore, the diffusion coefficient does not really affect the cracking process. Fig. 7 shows the effect of solid/liquid phase of corrosion products. It shows that higher percentage of liquid phase delays crack initiation and cracking speed is smaller. Therefore, the portion of liquid and solid parts in corrosion products strongly influence the cracking process.

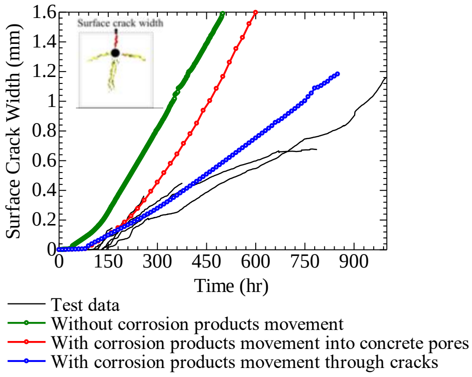

Fig. 4 Surface crack width and time relationship.

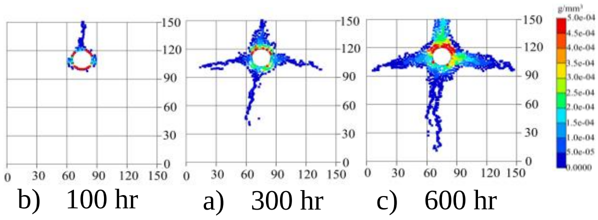

Fig. 5 Corrosion products distribution through cracks.

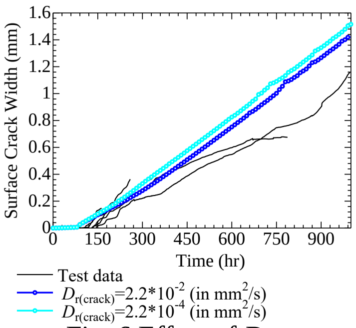

Fig. 6 Effect of *Dr*.

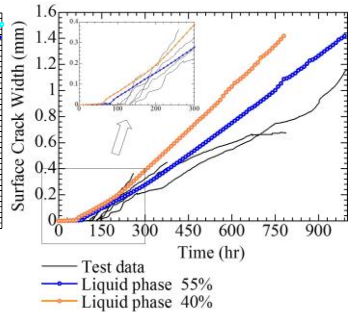

Fig. 7 Effect of β.

4. CONCLUSION

Simulation method to simulate crack propagation and corrosion products movement during rebar corrosion process is developed. From simulation results, it shows that:

1) Corrosion products movement into concrete pores and through cracks have a strong influence on the cracking process. The movement of corrosion products into the pores influences crack initiation and the movement of corrosion products through the cracks influences long-term surface crack width development.
2) Solid/liquid phase of corrosion products affect surface cracking development. Solid part portion directly contributes to expansion pressure. Liquid part portion influences the amount of corrosion products that can be moved into the pores and through cracks, thus release the pressure and reduce cracking speed consequently.

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