Numerical Modelling of Degradation of Reinforced Concrete Structures Exposed to Cracking and Chlorides

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Summary

The paper provides a brief overview of recently developed fully coupled 3D chemo-hygro-thermo-mechanical model for simulation of chloride induced corrosion, before and after depassivation of steel as well as its consequences on degradation of reinforced concrete structures. The applications of the model are illustrated on three numerical examples. The aim of the first numerical example is to demonstrate the influence of cracks in concrete on transport processes and on depassivation time. In the second and the third numerical examples processes after depasivation of reinforcement are analyzed in order to study the influence of concrete quality, water saturation and cracks in concrete on corrosion current density of a macro cell; influence of rust transport into the concrete cracks and pores on damages in concrete as well as influence of corrosion on bond resistance. The numerical results are in good agreement with the available experimental observations, what leads to the conclusion that the model is able to realistically predict corrosion of reinforcement in concrete.

Keywords: Reinforced Concrete, Pitting Corrosion, Modelling, Finite elements, Cracking, Chlorides, Corrosion Rate, Bond Resistance.

1. Introduction

Chloride-induced corrosion of steel bars in reinforced concrete (RC) is one of the major causes of deterioration of reinforced concrete structures, especially those exposed to de-icing salts and aggressive maritime environment condition and de-icing salts. The 3D fully coupled chemo-hygro-thermo-mechanical model is developed to realistically simulate pitting corrosion, before and after depassivation of steel, and its consequences for the structural safety.

2. 3D transient model for steel corrosion in concrete

To predict service life of RC structures it is necessary to model following physical, electrochemical and mechanical processes: (1) transport of capillary water, oxygen and chloride through the concrete cover; (2) immobilization of chloride in the concrete; (3) cathodic and anodic polarization; (4) transport of OH^- ions through electrolyte in concrete pores; (5) calculation of corrosion rate, current density and electrical potential; (6) transport of corrosion products in concrete and cracks and (7) concrete cracking due to mechanical and non-mechanical actions [1-4]. In the model the results of corrosion, such as the expansion of the corrosion product or the reduction of the cross-section of reinforcement, have an effect on the mechanical response of concrete structures. On the other hand, the mechanical properties, such as strength or fracture energy, also influence the corrosion process [5]. The model is formulated in the framework of continuum mechanics following basic principles of irreversible thermodynamics. The mechanical part of the model is based on the micro-plane model for concrete with relaxed kinematic constraint [9].

3. Application of the model

The aim of the first numerical example (Fig. 1) is to demonstrate the influence of cracks in concrete

https://doi.org/10.2749/222137813806735534

on transport processes and on depassivation time. In the second (Fig. 2) and the third (Fig. 3) numerical examples processes after depasivation of reinforcement are analyzed in order to study the influence of concrete quality, water saturation and cracks in concrete on corrosion current density of a macro cell; influence of rust transport into the concrete cracks and pores on damages in concrete as well as influence of corrosion on bond resistance.

Cracked concrete cover significantly reduces depassivation time of reinforcement bar, however, within assumed conditions crack does not remarkably influences corrosion rate. Corrosion rate is much higher in poor than in good quality concrete. The maximal values of corrosion rate, achieved at critical water saturation, are within the limits for concrete in splash zone, as one of the most critical areas for corrosion of steel in concrete. Corrosion induced cracks strongly reduces pull-out capacity of reinforcement. Transport of rust through cracks reduces unfavorable effects of corrosion induced cracks of concrete cover, but it must be included in numerical model in order to more precisely simulate corrosion effects on reinforced concrete structures. Further development of the model is in progress.

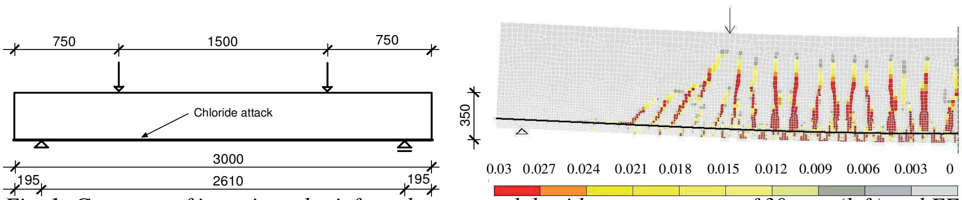

Fig. 1: Geometry of investigated reinforced concrete slab with concrete cover of 30 mm (left) and FE discretization and distribution of cracks with red zones as maximal principal strains in the slab (right)

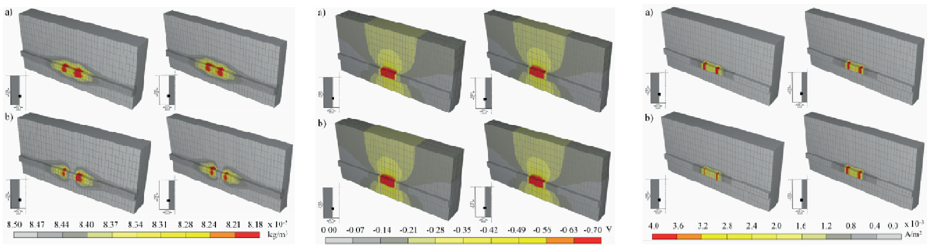

Fig. 2: 3D distribution of oxygen (left), electric potential (middle) and current density (right) for good quality concrete at saturation of 45% after 10 minutes of corrosion process for: a) un-cracked and b) cracked concrete

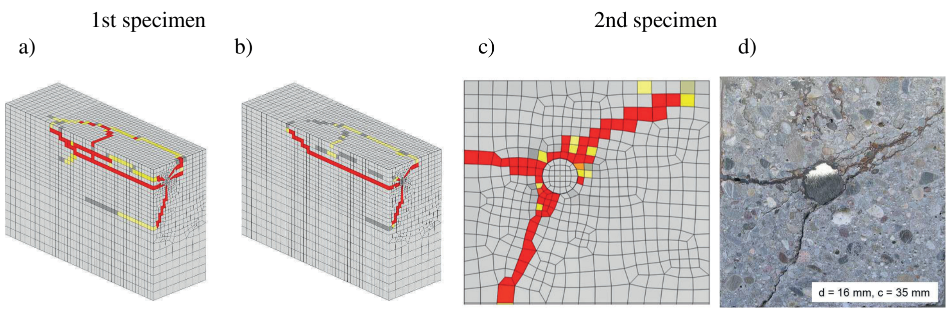

Fig.3: Cracks 7 years after depassivation: (1) in the 1st specimen: without (a) and with rust transport (b); and (2) in the middle of the 2nd specimen: (c) numerical study , (d) experimental results by Fischer [13]