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MODELLING CONCRETE CRACKING DUE TO REBAR CORROSION USING FINITE ELEMENTS

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ABSTRACT

Reinforcing steel bar corrosion is one of the most important pathologies of reinforced concrete structures. Oxidation occurring at the bar surface when depassivating agents find their way through the cover produces a decrease of the net cross-sectional area of the bar, thus reducing its strength, and, for deep corrosion attack, decreasing the overall structure safety. However, long before a significant decrease of net cross-sectional area is produced, the volumic expansion of the oxide induces internal pressure and cracking of the concrete surrounding the bar with, eventually, full spalling of the concrete cover [1,3].

The study of the evolution of the whole process requires the analysis of the transport of the aggressive species through the cover, the determination of the kinetics of the complex electrochemical phenomena occurring at the steel-concrete interface, and the prediction of the mechanical effects of the expansive oxide layer on the surrounding concrete.

The present work concentrates on the last part of the process, and thus assumes that the expansive oxide layer is already forming and that its mechanical effect is not explicitly time dependent, but depends only implicitly on time through the corrosion depth. The paper intends to provide numerical tools to investigate concrete cracking induced by the oxide expansion including the influence on it of the mechanical (fracture) properties of the concrete and of the geometrical pattern of the system, and, most importantly, the influence of the mechanical properties of the oxide layer on the evolution of cracks.

The cracking of concrete is assumed to follow the basic cohesive crack model proposed by Hillerborg et al in 1976 [2]. The numerical simulation of the cracking process is carried out by the finite element method by means of elements with embedded adaptable cohesive cracks [4]. The corrosion layer is simulated with an interface element, with zero initial thickness, which incorporates both the expansive behavior and the mechanical behavior; we call it an *expansive joint element*.

The application of the method to a simple experimental set up, a single bar unsymmetrically embedded in a concrete prism, disclosed some essential features of the oxide layer. It was first verified that if one assumes perfect elastic behavior of the oxide layer, with high bulk and shear moduli, a nearly perfect adherent behavior is achieved, which implies that crack localization is in fact prevented: a cloud of finely

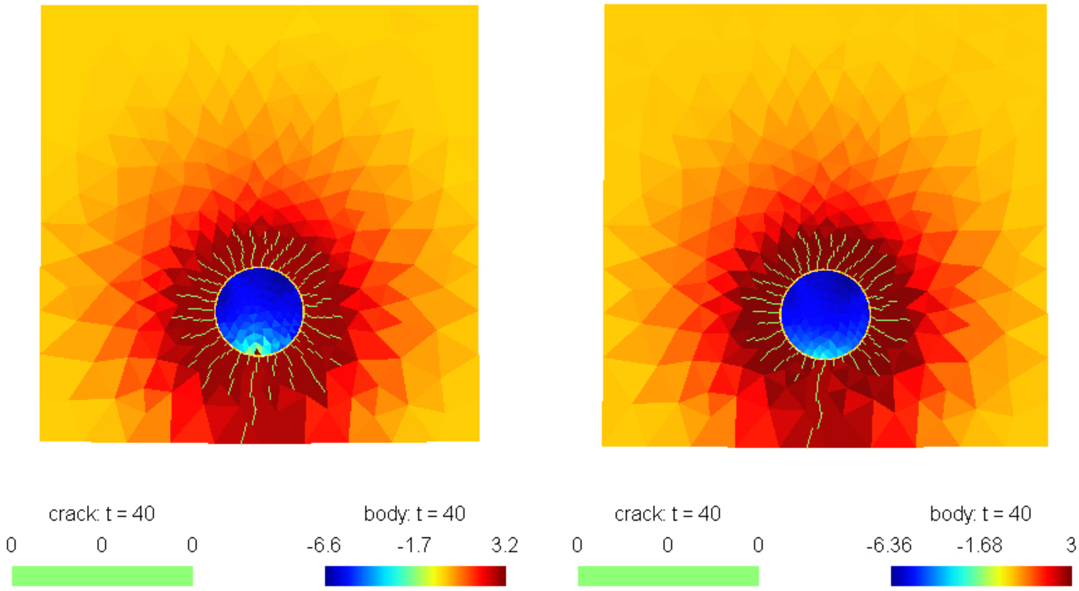

Figure 1: Maximum principal stress and crack pattern for an outside oxide expansion of 4μm. Left: High normal tensile stiffness. Right: Reduced normal tensile stiffness

spaced radial cracks spreads though the concrete. Reducing the shear stiffness of the layer improves the result, since a localized crack jumping to the surface is obtained at relatively early stages of corrosion (4μm radial expansion); however, a closer look at the solution, shown in Figure 1, left, shows that the root of the main crack is “clamped” at the steel surface, which manifests itself by the red, highly stressed element in the steel bar. This is due to the normal stiffness being large both in tension and in compression. Therefore, it is essential to introduce a strongly reduced stiffness in tension, simulating a kind of debonding; as shown in Figure 1, right, this relieves the stress lock-in completely.

Similar conclusions were reached for a concrete slab with uniformly distributed bars. For such a case, a main crack appears parallel to the concrete surface across the bar layout, thus producing the spalling of the concrete cover.

The paper describes the formulation of the expansive joint element and the basic features required for the mechanical behavior of the oxide layer. Parametric studies disclose the conditions for numerical stability and the influence of the basic mechanical properties of the oxide layer on the cracking behavior.

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