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Cover cracking of reinforced concrete due to rebar corrosion induced by chloride penetration

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ABSTRACT

Cracking of concrete cover due to corrosion induced expansion of steel rebar is one of the major causes of the deterioration of reinforced concrete (RC) structures exposed to marine environments and de-icing salts.
This paper presents two models that deal with the chloride-induced corrosion and subsequent cracking of concrete cover in RC structures. The former analyses the chloride diffusion within partially saturated concrete. A comprehensive model is developed through the governing equations of moisture, heat and chloride-ion flow. Nonlinearity of diffusion coefficients, chloride binding isotherms and convection phenomena are also highlighted. The latter describes the internal cracking around the bar due to expansive pressures as corrosion of the reinforcing bar progresses. Once a certain chloride concentration threshold is reached in the area surrounding the bar, oxidation of steel begins and oxide products are generated, which occupy much greater volume than the original steel consumed by corrosion. An embedded cohesive crack model is applied for cracking simulation.
Both models are incorporated in the same finite element program. The models are chained, though not explicitly coupled, at first instance. Comparisons with experimental results are carried out, with reasonably good agreements being obtained. The work is a step forward for the integration of the two traditional phases (initiation and propagation) widely used in the literature and usually analysed separately. The estimation of the service life of the structure needs to evaluate the associated time for each one.

1. Introduction

Corrosion of reinforcement bars is a primary cause in the deterioration of concrete structures which may lead to failure and even collapse. In any case, the cost of the associated repair and maintenance is enormous (for example, Kirkpatrick et al. [1]). Chloride induced corrosion of the reinforcing steel is known to be a major cause of premature rehabilitation of reinforced concrete structures.

Hence, research relating to the durability assessment of concrete structures has shown a substantial increase in recent years. However, many factors involved in the chloride induced corrosion process remain poorly understood. In spite of significant progress in predicting models, the estimation of service life of reinforced concrete (RC) structures is yet to be satisfactorily defined.

Present work is focused on chloride attack and distinguishes the two distinct phases traditionally adopted in the literature [2]: the initiation stage, until aggressive species concentration around the reinforcement bar reaches a threshold value, necessary to trigger active corrosion; and the propagation stage, in which rust generation induces tensile stresses in the concrete cover. This work sets out to integrate the two phases (initiation and propagation) widely cited in the literature and usually analysed separately. An overview of the previous proposals leads the reader to the general conclusion that service life ends when steel depassivates (the initiation phase) [3]. In this work, the above models are chained though not explicitly coupled. On a first calculation the chloride ingress and transportation are studied. When the chloride concentration around the reinforcement bar reaches a threshold value, the concrete cracking cover is then examined, through the second model.

Depending on the scale, the modelling of the concrete can be performed with different levels of abstraction, from a detailed representation of the concrete components (aggregates, cement paste, voids, among others), based on a micro-modelling approach, to a global analysis as a continuum. This paper presents a meso-modelling procedure for analysis of the chloride ingress and transportation and concrete cracking. The model does not make any distinction among individual components of concrete, averaging the effect of the composite material through the formulation of a fictitious continuous material. The material is assumed to be homogeneous and isotropic. The meso-scale approach has been successful for chloride

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