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Effect of crack openings on carbonation-induced corrosion

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ABSTRACT

Reinforced concrete is widely used in the construction of buildings, historical monuments, infrastructures and nuclear power plants. For a variety of reasons, many concrete structures are subject to unavoidable cracks that accelerate the diffusion of atmospheric carbon dioxide to the steel/concrete interface. Carbonation at the interface induces steel corrosion that could cause the development of new cracks in the structure, a determining factor for its durability. The aim of this article is to study the effect of existing cracks on the development of carbonation-induced corrosion. The results indicate that, after the initiation phase, the corrosion kinetics decreases with time and the free corrosion potential increases independently of the crack opening. In addition, the corroded zone matches the carbonated one. The interpretation of these results allows the authors to conclude that, during the corrosion process, corrosion products seal the crack and act as a barrier to oxygen and water diffusion. Consequently, the influence of crack opening on corrosion development is masked and the corrosion development is limited.

1. Introduction

Corrosion of the reinforcing steel is the main pathology affecting reinforced concrete structures and is a determining factor for their durability. These structures are subject to unavoidable cracks which create a pathway for atmospheric carbon dioxide, oxygen, water and chlorides to the steel/concrete interface and subsequently reduce the time to corrosion initiation. Both laboratory studies [1–6] and in situ observations [7–11] have noted earlier corrosion initiation in cracked concrete structures. Load-induced cracking is accompanied by interfacial slipping and separation between concrete and steel [12–15]. It has also been shown that both chloride- and carbonation-induced corrosion start and develop for a few millimeters around the rebar at its interception with the preexisting crack [16,17]. While there is a general consensus in the scientific community on the deleterious effects of cracks and steel/mortar interface quality on the initiation of reinforcement corrosion, the effects of such phenomena on the propagation of reinforcement corrosion induced by carbonation are still open to debate.

Tuutti [18] proposed a corrosion model for cracked and carbonated concrete, which supposes that steel repassivation is possible due to the sealing properties of the corrosion products and to a potential realkalization of carbonated mortar. In the same study, results of experiments exposing cracked and carbonated specimens to different relative humidities, validate the repassivation assumption. Tremper [19] investigated cracked specimens after 10 years of outdoor exposure and identified the presence of corrosion near the cracks and their immediate surroundings. He also added that the corrosion detected did not have deleterious consequences because of its minor degree. Additionally, Vesikari [20] investigated the corrosion development in the cracked concrete of 50 year old bridges and found that very few cracks had given rise to serious corrosion damage. This observation supports the idea that a reduction of corrosion kinetics occurs after the initiation phase, due to the corrosion products developed deep in the crack.

On the other hand, Dang et al. [21], studying carbonation-induced corrosion propagation, used ring-shaped mortar specimens with preexisting cracks induced mechanically by internal pressure (expansive core method). After accelerated carbonation (50% CO_2 - 65% RH), the specimens were subjected to humidification/drying cycles to accelerate corrosion development. It was observed that the CO_2 spread along the total length of the steel/mortar interface and induced corrosion initiation on the entire circumference of the rebar. Thereafter, new cracks were detected in the concrete cover characterized by a low tensile strength [22]. Nevertheless, because corrosion was initiated on the entire length of the rebar, it was not possible to conclude whether carbonation-induced corrosion in cracked structures would lead to corrosion cracks and thus to corrosion propagation.

In the field of nuclear energy, reinforced concrete is used for structures that have an impact on safety (containment buildings, cooling

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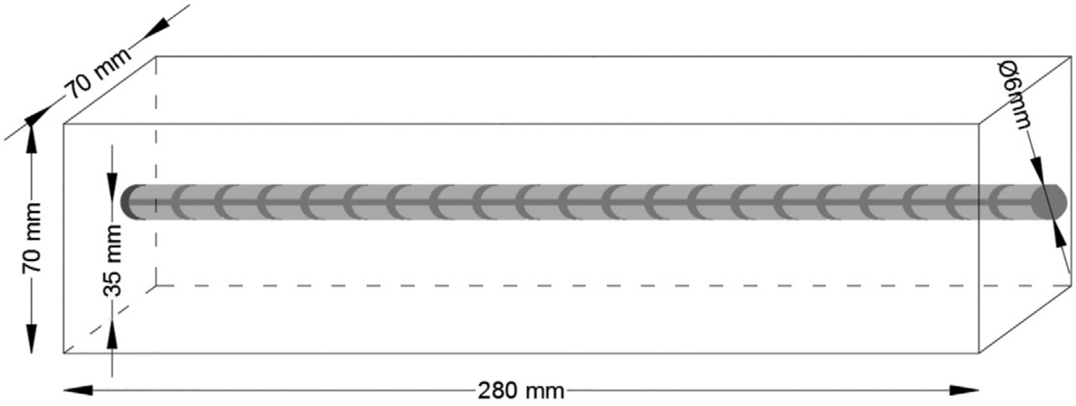


Fig. 1. Schematic representation of the reinforced mortar specimen.

towers), it is therefore important to complete the literature and understand the effect of cracking and steel/concrete interface damage, in terms of both corrosion initiation and corrosion propagation in cracked specimens. In this project, specimens were exposed to raining/drying cycles to simulate the outside environment and accelerate corrosion naturally. The ultimate goal was to find answers to the following questions:

- Does crack opening influence the kinetics of carbonation-induced corrosion?
- Will carbonation-induced corrosion deep in the crack induce the development of corrosion cracks and threaten the durability of the structure or it will seal the cracks and slow down corrosion propagation?

In the following sections, the experimental protocols developed to provide answers to the above questions are detailed and then the results obtained are discussed.

Table 1
Mechanical characteristics of the mortar mix.

Compressive strength f_c (MPa)	55
Tensile strength f_{ctk} (MPa)	3.5
Young's Modulus E (GPa)	33.3
Poisson's ratio ν	0.21

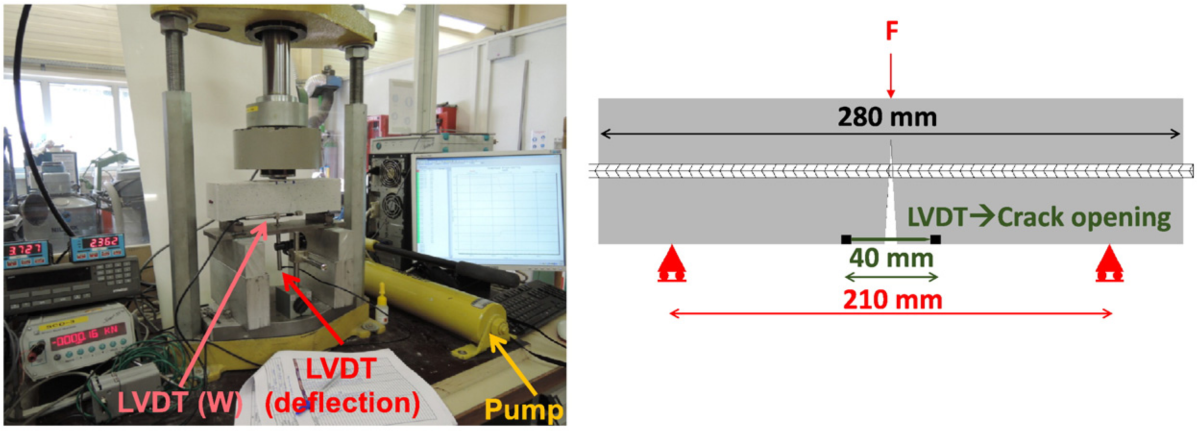
2. Experimental program

2.1. Materials and specimens

The specimens tested were 70 × 70 × 280 mm prisms. A 6 mm corrugated rebar was positioned in the middle of each specimen as shown in Fig. 1. All the specimens were prepared with a mortar mix containing three parts sand, two parts cement and one part water. Ordinary Portland cement (CEM I 52.5) and siliceous sand (according to CEN EN 196-1) were used. The yield strength of the steel used was 500 MPa. Mortar was poured in prismatic molds in two layers, each of them being vibrated to eliminate air bubbles. After 24 h, the specimens were unmolded and then cured for 28 days in water with calcium hydroxide. The mechanical properties of the mortar mix measured following current standards and recommendations are shown in Table 1. The specimens tested in this study were made from 2 consecutive batches of 60 l each.

2.2. Cracking

Immediately after curing, cracks of different widths were generated at mid-span of the prismatic specimens using a three-point bending test. The cracking protocol consisted in applying the load at the mid span of the simply supported specimen using a hydraulic pump as shown in Fig. 2(a). The crack was usually obtained in the cross section subjected to the maximal tensile stress (mid-span). In order to quantify



(a) (b)

Fig. 2. Three-point bending test on 70 × 70 × 280 mm specimens.