Carbonation of surface protected concrete

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HIGHLIGHTS

- The carbonation of concretes with surface protection was evaluated.
- The concretes were protected with systems based in siloxane, acrylic and epoxy resins.
- The surface protected concretes presented lower carbonation diffusion coefficients than the non-protected concretes.
- The prescriptive methodology is not a guarantee to obtain the desired service lives of 50 or 100 years.
- The desired services lives were only obtained with the use of surface protection treatments.

ARTICLE INFO

ABSTRACT

Concrete structures are exposed to carbonation that may cause rapid decay, shortening their service life and raising maintenance and repair costs. Carbonation lowers the alkalinity of the concrete depassivating the steel reinforcement. Two limit states can be identified with regard to service life. The first limit state ends when the steel is depassivated. The second limit state is based on cracking of the concrete cover due to oxides generated during corrosion. The service life includes a certain propagation period of corrosion during which the cross-sectional area of steel is progressively decreased, the bond between steel and concrete is reduced and the effective cross-sectional area of concrete is diminished due to spalling of the cover.

Surface treatment is commonly used to improve the resistance of concrete to carbonation. A barrier is formed retarding the carbonation reactions in the interior of the concrete. In this study surface protected concretes were compared with non-protected concretes. The used surface protected concretes presented generally lower carbonation diffusion coefficients than the non-protected concretes. The use of epoxy resin showed better protection than the use of acrylic and siloxane resins. The composition of the concretes is an important factor affecting the diffusion of carbonation. The influence of the water–cement ratio was very important. The carbonation diffusion coefficients increased with the water–cement ratio. The prescriptive methodology is not a guarantee to obtain the desired service lives of 50 or 100 years. The desired services lives were only obtained with the use of surface protection treatments.

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1. Introduction

According to Eurocode EN 1992-1-1 [1] a durable structure shall meet the requirements of serviceability, strength and stability throughout its intended working life, without significant loss of utility or excessive maintenance. There is often a need for supplementary measures to protect concrete in aggressive environment. Surface treatment is commonly used to improve the resistance of such concrete against the penetration of aggressive substances, both in new and existing structures [2]. Various generations of surface protection materials have been developed to counteract the aggressive actions of the environment against concrete. Between the most used we can find siloxane, acrylic and epoxy resins.

Natural concrete carbonation is a chemical reaction that involves the dissolution of atmospheric carbon dioxide in the pore water and the formation of a weak carbonic acid which dissociates and reacts with the calcium hydroxide resulting calcium carbonate and water [3]. The reactions are given in Eqs. (1) and (2), and a simplified graphic illustrating the reactions in Fig. 1.

$$CO_2 + H_2O \rightarrow H_2CO_3 \tag{1}$$

$$Ca(OH)_2 + H_2CO_3 \rightarrow CaCO_3 + 2H_2O \tag{2}$$
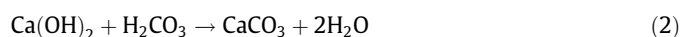
However, in addition to these reactions the carbon dioxide also reacts with C–S–H in concrete to form additional calcium carbonate [4]. Carbonation starts at the concrete surface including the surfaces of any cracks throughout the life of the concrete [5]. After,

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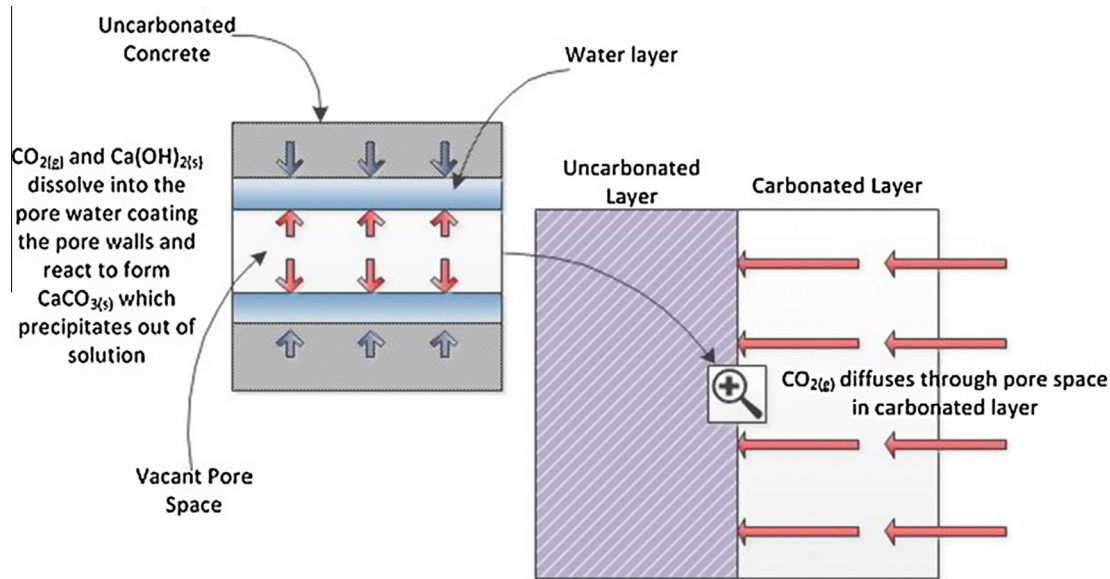 *E-mail address:* aguiar@civil.uminho.pt (J.B. Aguiar).

Fig. 1. Carbonation schematic [4].

carbonation penetrates inside of the concrete. This reaction lowers the alkalinity of the concrete depassivating the steel reinforcement [6].

Park [7] asserted that one-half of carbon dioxide in concrete reacts with calcium hydroxide while the other half reacts with C–S–H. This assertion was further supported by Glasser and Matschei [8] who showed that the reaction would occur in sequence, with calcium hydroxide first being consumed and then C–S–H reacting thereby densifying the microstructure.

Based on reference documents [9,10] the Portuguese standard NP EN 206-1 [11] for the design of concrete compositions includes two alternative specifications – prescriptive [12] and performance-based [13] – in view of environmental exposure.

The prescriptive methodology LNEC E464 [12] sets the limits of the concrete constituents (maximum w/c ratio, minimum cement dosage and cement type), the minimum compressive strength and the concrete cover thickness for a design working life of 50 years (target period) under the environmental exposures classes in issue. Eurocode 2 [1] defines and describes environmental exposure classes in view of the aggressive agent. For carbonation induced corrosion four classes are defined and described: XC1, XC2, XC3 and XC4 (Table 1).

The performance-based specification makes no restriction concerning constituents and dosage. The criterion is related to the modeling lifetime result (service life) based on testing results of accelerated carbonation on concrete samples of the designed concrete composition [6].

Two limit states can be identified with regard to service life (Fig. 2). This ends when the steel is depassivated. The limit state is based on cracking of the concrete cover due to oxides generated during corrosion. The service life includes a certain propagation
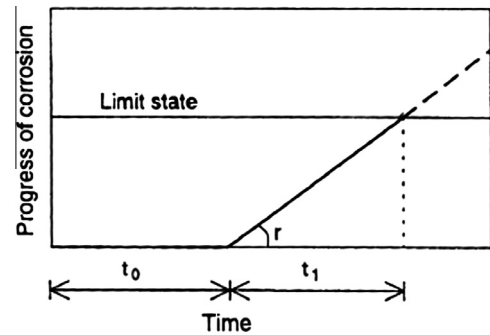

Fig. 2. Determination of service life with respect to corrosion of reinforcement [9].

period of corrosion during which the cross-sectional area of steel is progressively decreased, the bond between steel and concrete is reduced and the effective cross-sectional area of concrete is diminished due to spalling of the cover [9].

The initiation period concerning the penetration of carbon dioxide is based on the model of CEB [10] which the specification LNEC E465 [13] adopted considering the Portuguese environment. This model expresses the diffusivity of hardened concrete and it relates the concrete carbonation with time as follows:

$$x = \sqrt{\frac{2h}{R_{C65}}}\sqrt{k_0 k_1 k_2}\left(\frac{t_0}{t}\right)^n \qquad (3)$$

where due to carbonation, steel depassivation starts when a depth x equals the concrete cover c of the reinforcement steel. R_{C65} ((kg/m^3/

Table 1
Environmental exposure classes for carbonation induced corrosion [1].

Exposure class	Description	Informative examples where exposure classes may occur
XC1	Dry or permanently wet	Concrete inside buildings with low air humidity
		Concrete permanently submerged in water
XC2	Wet, rarely dry	Concrete surfaces subject to long-term water contact
		Many foundations
XC3	Moderate humidity	Concrete inside buildings with moderate or high air humidity
		External concrete sheltered from rain
XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2