



Predicting carbonation depth for concrete with organic film coatings combined with ageing effects



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HIGHLIGHTS

- A new concrete carbonation depth prediction model considering the ageing of coating is established.
- Carbonation resistance is greatly improved when the equivalent concrete thickness of coating is denser.
- The carbonation resistance of an organic film coating gradually decreases with its ageing.
- Effective coating repainting prolongs the service life of concrete against carbonation.

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ABSTRACT

A new time-dependent model for concrete carbonation depth prediction combining with the ageing effects of a coating was established to predict the carbonation depth of concrete with organic film coatings under practical service environmental conditions. This model could be solved by introducing a function about the equivalent concrete thickness of a coating with ageing time. Three coated concrete specimens with epoxy, polyurethane, and chlorinated rubber coatings were fabricated and subjected to natural outdoor experiments of exposure degradation for one year. The coated specimens were collected and subjected to accelerated carbonation experiments with different corresponding ageing periods. Based on these experiments, development models of the coatings' equivalent concrete thickness with exposure time were obtained through regression analysis, and the carbonation depths of concrete with organic film coatings combined with the ageing of the coatings and repainting effects were obtained through numerical calculation. Results indicated that organic film coatings could improve concrete carbonation resistance effectively, and a coating with denser equivalent concrete thickness could better improve the carbonation resistance of concrete compared with a thinner application. However, this protection would gradually decrease and reach zero because of coating degradation. Coatings would not affect the development of concrete carbonation after reaching the desired service life. The carbonation resistance of concrete could be improved again through effective coating repainting, which could prolong its service life against carbonation.

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1. Introduction

Carbonation is one of the main causes of the corrosion of steel bars in concrete; inferring the carbonation depth of concrete is significant for evaluating the reliability and predicting the service life of reinforced concrete structures [1,2]. Mortars, ceramic tiles, or paintings are often used on concrete surface for decoration or dura-

bility protection. The carbonation speed of concrete is generally reduced by the protection of finishing materials. However, varied finishing materials affect the speed of concrete carbonation differently.

Cement and lime mortars usually contain carbonatable materials, which can absorb CO₂, thus reducing the risk of concrete carbonation. Roy et al. [3] and Huang et al. [4] found that the cement mortar on concrete surface could reduce concrete carbonation depth significantly. They also found that the concrete would not be carbonated for a significantly long time if the thickness of the mortar layer was sufficiently thick; however, decorative paintings did not almost affect concrete carbonation. Ceramic tiles and

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mosaics do not contain carbonatable materials compared with cement and lime mortars; however, ceramic tiles and mosaics can also improve the carbonation resistance of concrete effectively because of their denser texture [5].

Organic film coatings have been widely used in the field of concrete durability protection for the convenience of application, strong protection and good decoration effects [6–12]. These coatings can form a considerable dense membrane after hardening, thus hindering CO₂ diffusion into concrete, which can also improve the carbonation resistance of concrete. The experimental results obtained by Zafeiropoulou et al. [10], Ahmed et al. [11], and Li et al. [12] showed that epoxy (EP), polyurethane (PU), and acrylic resin in organic film coatings could control concrete carbonation effectively; and different coating categories and film thicknesses, and different concrete substrates would correspond to different improvements. However, the ageing of organic film coatings [13–15] could result in considerable coating defects and decline in coating protection. Ho and Harrison [13], and Park [14] found that the effectiveness of coating would diminish once exposed to natural weathering. The experimental results acquired by Li et al. [15] indicated that the development of carbonation depth of coated concrete exhibited an S-shape curve with the ageing of the coating.

Numerous models have been established for predicting the carbonation depth of ordinary concrete [16–20], in which a typical model was established by Papadakis et al. [16], as shown in Eq. (1a), which is usually simplified as Eq. (1b).

$$x = \sqrt{\frac{2D_0C_0t}{m_0}} \quad (1a)$$

$$x = k \cdot \sqrt{t} \quad (1b)$$

where x is the depth of concrete carbonation/mm, D_0 is the effective diffusion coefficient of CO₂ in concrete/m²·s⁻¹, C_0 is the CO₂ concentration at concrete surface/mol·m⁻³, m_0 is the amount of CO₂ that is completely absorbed by per unit volume of concrete/mol·m⁻³, t is the time of concrete carbonation, and the units of t in Eqs. (1a) and (1b) are “s” and “year”, respectively, and k is the comprehensive coefficient of concrete carbonation/mm·year^{-0.5}.

Zhang [5], Park [14], and Wang et al. [21] established several prediction models of concrete carbonation depth combined with the hindering effects of surface layers on concrete carbonation by introducing a coefficient of surface layer effects R or carbonation delay effects β , as shown in Eqs. (2a) and (2b).

$$x_c = \sqrt{\frac{2D_0C_0}{m_0\beta}} \cdot \sqrt{t} \quad (2a)$$

$$x_c = R \sqrt{\frac{2D_0C_0}{m_0}} \cdot \sqrt{t} \quad (2b)$$

where x_c is the carbonation depth of concrete with a surface layer/mm, and R and β are constants which reflect the hindering effects of surface layers on concrete carbonation.

Eq. (2) indicates that the coefficient of surface layer effects R and carbonation delay coefficient β are essentially the modification on the carbonation model for ordinary concrete, in which influences of surface layers on concrete carbonation are assumed to be unrelated with time. Liu et al. [22] developed a carbonation model for concrete with a surface layer based on the assumption of the linear distribution of CO₂ concentration in coating and concrete, as shown in Eq. (3).

$$x_c = \sqrt{\left(\frac{D_0}{D_c} \cdot \frac{d}{2}\right)^2 + \frac{2D_0C_0t}{m_0}} - \left(\frac{D_0}{D_c} \cdot \frac{d}{2}\right) \quad (3)$$

where D_c is the effective diffusion coefficient of CO₂ in coating/m²·s⁻¹, and d is coating thickness/mm. D_c and d reflect the influence of a surface layer on concrete carbonation.

The effects of surface layer on concrete carbonation are considered in Eqs. (2) and (3); however, these equations can only be applied for surface layers without degradation because all the parameters about surface layer effects are constant. The performance of organic film coating, as a surface layer, is easily affected by its ageing; thus, Eqs. (2) and (3) are not suitable for concrete with organic film coatings. In this paper, the objective is to build a new time-dependent prediction model for the carbonation depth of concrete combined with the ageing influences of organic film coatings, which can make accurate predictions under practical natural environment conditions.

2. Theoretical analysis and equation derivation

2.1. Differential equation of carbonation prediction for coated concrete

A few assumptions are made before establishing a time-dependent prediction model for concrete carbonation. For example, the influence of partial carbonation zone is not considered, and the distribution of CO₂ concentration is bi-linear in coated concrete [22,23]. Fig. 1 presents a sketch of the carbonation process for concrete with coating.

CO₂ diffusion in a coated concrete meets the following differential relationship according to the assumption above:

$$\frac{d^2C}{dx^2} = 0 \quad 0 \leq x \leq d \quad (4a)$$

$$\frac{d^2C}{dx^2} = 0 \quad d \leq x \leq d + x_c \quad (4b)$$

where C is CO₂ concentration/mol·m⁻³.

Boundary conditions occur on the coating surface and the interface between carbonated and uncarbonated concrete zones, which are as follows: $x = 0$, $C = C_0$; and $x = d + x_c$, $C = 0$. CO₂ concentration C is unknown at the interface between coating and concrete, and is assumed to be C_1 : $x = d$, $C = C_1$.

Thus, the function of the distribution of CO₂ concentration in the coating and concrete can be obtained based on the assumption above, which is as follows:

$$C = (C_1 - C_0) \frac{x}{d} + C_0 \quad 0 \leq x \leq d \quad (5a)$$

$$C = (d - x) \frac{C_1}{x_c} + C_1 \quad d \leq x \leq d + x_c \quad (5b)$$

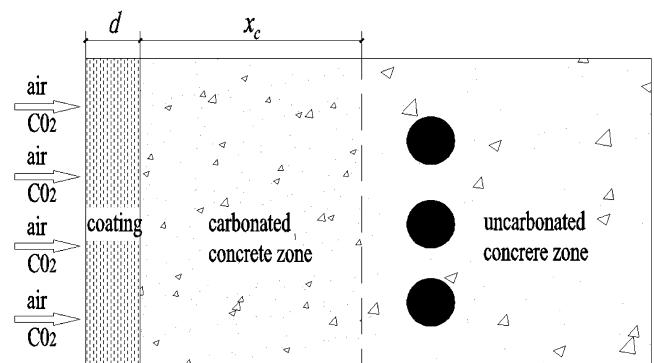


Fig. 1. Schematic of the carbonation process in concrete with coating.

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