



Evaluation of carbonation resistance of paint coated concrete for buildings



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HIGHLIGHTS

- Carbonation depth of C35 standard cured concrete is 56% smaller than that of C25.
- Accelerate curing increases carbonation depth of C25 concrete by 61%.
- Paint coating can reduce 28-day carbonation depth of concrete by 46% at least.
- Carbonation suppression ratio varies with exposure time and quality of substrate.
- Exterior paint coating has a longer blockage time and a smaller carbonation rate.

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ABSTRACT

When evaluating the carbonation resistance of paint coated concrete, the effects of both the strength grade and the curing conditions (standard curing and accelerated curing) of concrete substrate on carbonation resistance of paint coated concrete were investigated. The concept of the carbonation suppression ratio of paint was presented for evaluation of the anti-carbonation performance of the two types of paints (exterior and interior paints) when applied to a reference concrete substrate. The test results showed a good linear relationship between the carbonation depths of the paint coated concrete and the square root of exposure times. Concrete with higher strength grade exhibited greater carbonation resistance. The carbonation depth of the C35 standard cured concrete was reduced by 56% in comparison with that of the C25 standard cured concrete. It was found that concrete substrate prepared by accelerated curing method displayed lower carbonation resistance than standard cured concrete. Compared with the standard cured specimen, the carbonation depth of the accelerated cured specimen increased by 61% for the control C25 concrete and by 56% for the control C35 concrete. This phenomenon was attributed to the formation of a higher volume of capillary pores in concrete prepared by accelerated curing. Additionally, the exterior paint had a higher carbonation suppression ratio than the interior paint. The suppression ratios of the exterior and interior paint coatings applied on C25 standard cured concrete were 71% and 56%, respectively. The exterior paint coated concrete had a better carbonation resistance with longer effective blockage time and smaller carbonation rate.

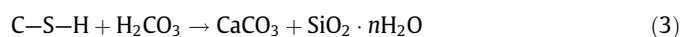
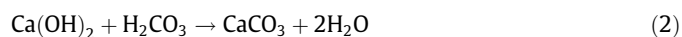
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1. Introduction

1.1. Carbonation theory

Natural concrete carbonation is a chemical reaction between the carbon dioxide (CO₂) in the air and cement hydration products

of the concrete. Atmospheric carbon dioxide dissolves in the pore water, and it produces a weak carbonic acid (see Eq. (1)) which dissociates and reacts with calcium hydroxide (see Eq. (2)) and then with calcium silicate hydrates (C–S–H) (see Eq. (3)), to form calcium carbonate and water [1,2]. Without doubt, these reactions decrease the alkalinity of concrete.



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Carbonation is a diffusion process involving the transportation of CO_2 from one area to another by way of random molecular motion. Under steady state conditions, the diffusion process follows Fick's first law, set out in Eq. (4) [3–5].

$$D = kt^n \quad (4)$$

where D is carbonation depth, k is a constant carbonation coefficient, t is time duration of exposure in years, and n is an exponent smaller than 1.0 (usually taken as 0.5).

Carbonation is a long-term durability problem of reinforced concrete, predominantly because it is the most significant cause of steel bar corrosion which, in turn, leads to concrete structural degradation [1,6]. Under normal conditions, steel reinforcement embedded within ordinary concrete is usually protected from corrosion by the high alkalinity of the surrounding concrete. Hobbs [7] suggested that 9.5 was the pH threshold value for the depassivation of steel. Nevertheless, the carbonation phenomenon leads to a lowering of the alkalinity of the concrete from approximately 12 to less than 9, which depassivates the steel reinforcement and exposes steel reinforcing bars to corrosion [8]. Neves et al. [9] presented a simple indirect assessment model of carbonation resistance which works by way of measuring concrete air permeability. This simple on-site non-destructive test assessment could provide useful and realistic information, upon which estimations of the service life of newly built concrete structure may be calculated.

1.2. Surface protection and carbonation of concrete

According to the research of Bara and Senbu [10], the surface protection of concrete could be classified into three groups: a cementitious finishing layer (such as organic paint coatings), surface improvement (such as barrier penetrants) and a non-cementitious finishing layer (such as mortar screeding); curve illustrations of the carbonation depth of the corresponding surface protected concrete were also proposed (see Fig. 1). This suggested that the carbonation depths of cementitious materials were linear to the square root of the exposure times, while the carbonation rate of concrete with a non-cementitious paint coating increased along with the square root of the exposure time.

Anti-carbonation paints, and some other high quality acrylic and vinyl-acrylic coatings, have proved effective in preventing the carbonation of concrete in tropical environments, with the support of laboratory test results [11]. Park [12] reported that acrylic paint coating had a diffusion coefficient of $6.15 \times 10^{-12} \text{ m}^2/\text{s}$ and a permeation coefficient of $63.8 \times 10^{-17} \text{ kmol/s m kPa}$ for CO_2 , and when applying the paint to concrete substrate; the carbonation depth of concrete after ten years was reduced by 40%, from

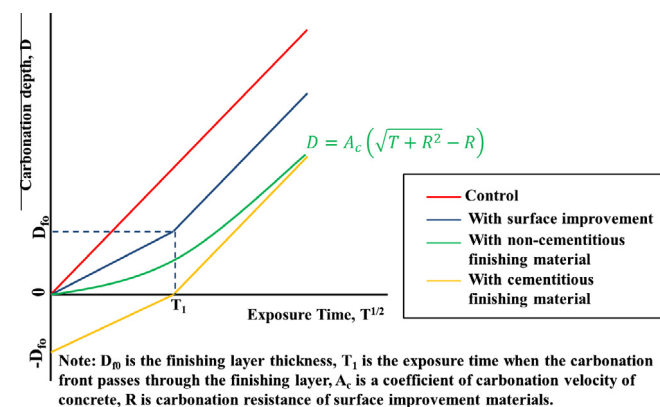


Fig. 1. Carbonation depth development model of concrete with different surface protections [10].

12.5 mm to 7.5 mm. Franzoni et al. [13] selected inorganic ethyl silicate and sodium silicate paints as the surface coating materials of concrete. The test results of their accelerated carbonation test showed that, after a 60 day exposure in a carbonation chamber (at a concentration of $\text{CO}_2 = 20 \pm 2\%$, $T = 25 \pm 5^\circ\text{C}$ and $\text{RH} = 70 \pm 5\%$), the carbonation depth of the concrete varied from 11.1 to 3.9 mm in concrete coated with ethyl silicate and from 5.7 to 1.9 mm in concrete coated with sodium silicate. This meant that these two surface treatments both effectively limited the penetration of CO_2 .

The contribution of concrete strength to carbonation rate has been studied in a number of previous studies [14–16]. Rabehi et al. [17] proved that carbonation depth was a decreasing function of compressive strength and proposed an exponential function ($D = 80e^{(-0.08 \times C_{s28\text{days}})}$) correlation between the compressive strength $C_{s28\text{days}}$ (MPa) and the carbonation depth D (mm) at 180 days, by way of an accelerated carbonation test conducted at a CO_2 concentration of 50%, $T = 20 \pm 2^\circ\text{C}$ and $\text{RH} = 66\%$.

Typically, the rate of carbonation depends on how fast CO_2 and/or carbonate ions can move into the concrete and react with the cement paste, a process which is affected by the permeability of the concrete, water/cement (w/c) ratio, curing conditions, cement type, concentration of CO_2 in the atmosphere and other environmental conditions. Additionally, inadequate concrete cover, cracking of the concrete, and low strength grade and poor quality concrete will also result in the high permeability of CO_2 for concrete [BRE 18, 19]. Therefore, the use of surface protection, like paint coating, and a higher strength grade of the concrete substrate should enhance the durability of concrete against carbonation [20,21].

For paint, a current standard (BS EN 1062-6, 2002) used to evaluate the anti-carbonation performance of paint, namely the equivalent air thickness (R -value) method, is based on the diffusion resistance of the paint membrane itself, which is not a direct measurement of the concrete carbonation. The R -value, expressed as an equivalent air layer thickness, is always quoted, which allows the air thickness to be quantified so as to specify both the barrier performance of a coating and how thick a layer of air with the same diffusion resistance would be required to be.

The accelerated carbonation test provides a fast standardized direct measurement method with which to assess the carbonation protection of different paint coatings for concrete substrate.

1.3. Research significance

The service lives of most of paints that are commonly marketed are less than 15 years, while the designed life of residential building is much larger than that. In this case, reapplication of paint is needed in order to maintain the anti-carbonation capacity of buildings when the paint coating is about to be out of function. Meanwhile, the time interval of reapplication of paints should be adjusted with thickness of concrete cover and designed service life of buildings. So, a better understanding of the development of accelerated carbonation depth of paint coated concrete is required when predicting natural carbonation depth of concrete after paint coating.

The durability of a paint coated concrete structure against carbonation is dependent on the cooperative effect of the paint coating and the quality of the concrete substrate, but the effect of quality of concrete substrate was less studied in the existing literatures. A measurement model to evaluate the anti-carbonation performance of paint applied to different qualities of concrete substrates is therefore necessary. Accelerated cured concrete specimens are more sensitive to carbonation because the pores of steam cured concrete are normally larger in size than those found in standard cured concrete. The use of accelerated cured concrete

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