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Long-age wet curing effect on performance of carbonation resistance of fly ash concrete

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HIGHLIGHTS

- We examined the carbonation resistance of fly ash concrete cured under A and B conditions.
- The influence mechanism of wet curing for 90 days on the fly ash concrete carbonation resistance ability was analyzed by a variety of microscopic analysis.
- Wet curing for 90 days had the positive effect of dense interfacial zone and the negative effect of calcium hydroxide consumption.
- It is different of 90 days wet curing for the concrete carbonation resistance with different content of fly ash and water-binder ratio.

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ABSTRACT

To investigate the carbonation regularity in concrete of 100 mm × 100 mm × 400 mm, in the environment, (20 ± 3)% (volume fraction) concentration of CO_2, (70 ± 5)% relative humidity and (20 ± 2) °C temperature. The concrete specimens were divide into two parts: curing 28 days with temperature of (20 ± 2) °C and the relative humidity ⩾95% (named wet curing), and then curing for 3 years (named A condition) with the relative humidity of (60 ± 5)% and the temperature of (20 ± 2) °C (named dried curing) and long-age wet curing for 90 days (named B condition). The water-binder ratio was 0.37, 0.45 and 0.53, the content of fly ash substituting for the equal quality of cement by mass was 0%, 30% and 60%, respectively. Based on the scanning electron microscope (SEM) morphology of the interfacial transition zone of concrete's coarse aggregate and X-ray diffraction (XRD) analysis, the influence mechanism of wet curing for 90 days on the fly ash concrete carbonation resistance ability was analyzed. The results show that the wet curing for 90 days had the positive effect of dense interfacial zone and the negative effect of calcium hydroxide consumption on the concrete carbonation resistance ability. In the case of high fly ash content with low water-binder ratio or low fly ash content with high water-binder ratio, the dense effect of the interfacial transition zone of concrete's coarse aggregate occupied a dominant position, and the carbonation resistance ability was greatly improved after wet curing for 90 days. The average increment value of carbonation depth of fly ash concrete in each group decreased by 53.5% compared with the specimens cured under A condition. When the water-binder ratio and the fly ash content were either higher or lower, the positive effect of dense interfacial zone and the negative effect of calcium hydroxide consumption had little significant effect on the concrete carbonation resistance ability, and the wet curing for 90 days had no obvious influence on improving the carbonation resistance ability. At present, the average increment value of carbonation depth of fly ash concrete in each group decreased only by 11.5% of that under A condition.

1. Introduction

The durability of concrete structures was a major concern of building owners as it was related to safety, economy and sustain-ability. The most relevant issue affecting the durability of concrete structures was anti-carbonation ability [1–2]. In resent years, with the development of the concrete technology, fly ash had become one of the main components of modern concrete [3]. The secondary hydration of fly ash would consume the $Ca(OH)_2$, which reduces anti-carbonation of concrete, and leads to steel corrosion in concrete, and then affects the durability of concrete [4].

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Therefore, anti-carbonation was the key factor which restricts the development of fly ash concrete.

Fly ash content and water-binder ratio were two important parameters that influence the carbonation resistance of fly ash concrete [5–6]. The carbonation resistance of fly ash concrete was decreased with the increased of water-binder ratio and fly ash content [7–8]. Nevertheless, the carbonation resistance of concrete with low fly ash content would increase. For the concrete that have the low volume fly ash mixtures (less than 30%) the carbonation coefficients of concrete was approximately equal to those of the concrete of cement-only mixtures, and the carbonation depth of the specimens containing 20% of fly ash was only 77.6% of specimens with cement-only mixtures [9–10]. Based on the above analysis, it could be obtained that these studies did not consider the carbonation resistance of fly ash concrete under different curing conditions.

Early curing period had important effect for the anti-carbonation of fly ash concrete [11]. The incorporation of fly ash postpones the development of both wave velocity and attenuation coefficient, and achieves lower one-day wave velocity values [12]. This would slow down the rate of hydration of cement. Thus, extending the early curing time would promote the hydration of gelled material, and improve the anti-carbonation of fly ash concrete, especially for the concrete with large content of admixture which should be more appropriate to extend the early curing period [13–14]. The anti-carbonation ability of concrete could be improved by extending the wet curing age. Under wet curing for 28 days, there was no obvious difference in the anti-carbonation of concrete with different content of fly ash, and the carbonation depth of concrete standard curing for 3 days was about 2.35 times for standard curing 28 days [15–18]. Curing temperature and humidity changes would affect the anti-carbonation ability of fly ash concrete [19–22]. Li [19] had studied the carbonation resistance of fly ash concrete which were curried for 3 days, 7 days, 14 days, 28 days in the water with the temperature of 20 °C, 30 °C and 40 °C respectively. The results showed that extend the initial curing time and increasing the curing temperature was beneficial to improve its resistance to carbonation. And the concrete cured at 60 °C hot water for 24 h could promotes changes in the pore size distributions and generates certain modifications in the C–S–H gels formed, and increase the carbonation resistance of concrete [20–21]. The anti-carbonation of concrete was greatly improved when the curing relative humidity increased from 60% to 100% according to Li Xuebin's study [22]. For the concrete with different water-binder radio and different curing conditions, the studies found that the early standard curing time less than 3 days compared with the standard curing for 28 days of concrete carbonation depth increased by 50–100% and the longer standard curing the stronger anti-carbonation of concrete would be [23–24]. Above these studies, they did not consider the influence of curing age for the concrete carbonation resistance with different content of fly ash and water-binder ratio at the same time. In addition, concrete carbonation test was used with a standard carbonation test in the study of the past [25–26], this method was the standard curing 28 days after the specimens shape, then carried out the carbonation experiment of 28 days in the carbonation chamber. Through the carbonation depth of concrete showed the anti-carbonation of concrete. This method could intuitively and conveniently reflect the influence factors in the anti-carbonation of concrete and their influence degree. But for the fly ash concrete, studies [27–28] showed that the secondary hydration of fly ash mainly happened between the 28 days and 90 days, and the hydration reaction of fly ash was accompanied by the rapid carbonation of concrete. And the carbonation of hydrated cement paste caused a change in porosity and pore size distribution, the pore structure and morphology of hydrated products would have an effect on the carbonation resistance of concrete [29–30]. These would affect the carbonation of the uncertainty.

Based on the above researches, the carbonation regularity in concrete of 100 mm × 100 mm × 400 mm was studied, in the environment, (20 ± 3)% (volume fraction) concentration of CO_2, (70 ± 5)% relative humidity and (20 ± 2) °C temperature. The concrete specimens were divide into two parts: curing 28 days with temperature of (20 ± 2)°C and the relative humidity ⩾95% (named wet curing), and then curing for 3 years (named A condition) with the relative humidity of (60 ± 5)% and the temperature of (20 ± 2) °C (named dried curing) and long-age wet curing for 90 days (named B condition). The water-binder ratio was 0.37, 0.45, 0.53, the content of fly ash substituting for the equal quality of cement was 0%, 30% and 60%. The purpose of setting A condition was to close to the engineering practice and the purpose of setting B condition is to make the secondary hydration of fly ash concrete more fully and reduce the secondary hydration of fly ash of uncertain influence on carbonation during accelerated carbonation. According to the scanning electron microscope (SEM) morphology of the interfacial transition zone of concrete's coarse aggregate and X-ray diffraction (XRD) analysis, the influence mechanism of wet curing for 90 days on the fly ash concrete carbonation resistance ability was analyzed.

2. Experimental

2.1. Raw materials

The cementitious materials used in the experiment were Portland cement and fly ash, whose chemical components and specific surface area were shown in the Table 1. Fine aggregate was river sand with the fineness modulus of 2.8 and the apparent density of 2650 kg/m^3. Coarse aggregate was crushed lime stone with the size of 5–20 mm and the apparent density of 2660 kg/m^3. The polycarboxylic water reducer with a water-reducing rate of 21% was used to achieve target workability.

2.2. Experimental methods

2.2.1. Preparations of specimens and accelerated carbonation experiment

In the concrete mix design, the equivalent mass substitution method of fly ash was taken in this article according to the GBJ146-90 《Technical specification for fly ash concrete application》. Reference the literature [31–35], this article directly determined the uniform water-binder ratio was 0.37, 0.45 and 0.53. The concrete specimens with 100 mm × 100 mm × 400 mm, by using the ratio of Table 2. The slump of each mixture was controlled within (100 ± 10) mm by adjusting the dosage of superplasticizer. In the specimens, one part of the 3 years concrete specimens were the wet curing for 28 days and dry curing for 3 years (condition of A), the rest of specimens were wet curing for 90 days (condition of B). Stop curing after reaching a predetermined age. The initial carbonation depth of concrete under two curing conditions were measured before the experiment in the environment of the relative humidity of (60 ± 5)% and the temperature of (20 ± 2) °C, and then the specimens were sealed with a heated paraffin wax. One part of the specimens which content of fly ash was 60% left one side without paraffin wax, the other sides were sealed. One part of the specimens which content of fly ash was 0% and 30% left two sides without paraffin wax, the other sides were sealed. Accelerated carbonation experiment of concrete specimens under two curing conditions referring to the Chinese standard GB/T 50082-2009 《Ordinary concrete long-term performance and durability test method standard》. When the carbonation time (3 days, 7 days, 14 days and 28 days) reached, the specimens were cut from the set position. Drop the phenolphthalein with the concentration of 1% (mass fraction) on the split surface. When the color of