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Study on concrete structure's durability considering the interaction of multi-factors

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HIGHLIGHTS

- The experiment method considering crossed influence of multi-factors and bracket-type loading device is proposed.
- Carbonation model which includes influence coefficients of multi-factors is set up.
- The carbonation rate is not constant but grows fast in the former period and slows gradually in the later.
- The tensile stress facilitates the concrete carbonation, while the compressive stress inhibits the concrete carbonation.

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ABSTRACT

The durability of concrete's material and structure is affected by the combined action of multiple factors, and in particular, the effect of stress on the durability should be treated seriously. The quick carbonation experiment of concrete's material is conducted based on bracket-type loading device and appropriate experimental program in comprehensive consideration of the factors including external loads, environmental corrosion medium, material properties and ages, from which representative factors such as stress levels, CO_2, water-cement ratios and carbonation ages are selected. The experimental result shows that concrete's carbonation rate decreases gradually with time; tensile stress can accelerate the concrete carbonation whereas compressive stress retards carbonation; within a certain range, the greater the water-cement ratio, the faster the carbonation rate is. Carbonation model is presented based on the crossed influence of multi-factors by regression fitting and analysis of the test data. After validated by engineering example, the model is reasonable.

1. Introduction

The durability of architectural engineering structure is receiving increasing focus in engineering circles and academic circles. At present, the research results on the durability of concrete's structure are mainly limited to the material level, while in actual construction, different kinds of components or structures (especially underground structure) constructed of concrete are often exposed to various complicated stress states, even under crack condition, and for this reason, the durability of components (or structures) are necessarily different from that of materials free of external force, but research in this area is insufficient; furthermore, although concrete materials have different types, admixtures and ratios and are affected by various external medium conditions, the research work has rarely carried out to address the effect of load, material, environmental corrosion medium, age and other factors on durability, and therefore, the author conducted the carbonation test considering various stress's states and levels and comparing different concrete's water-cement ratios based on different ages for the purpose of finding the pattern in which the above several factors affect concrete's durability and establishing appropriate carbonation model formula.

In order to determine concrete's carbonation depth, many scholars at home and abroad have conducted lots of research work and established a variety of mathematical models. From the perspective of modeling approach, there are two main ways: one refers to the theoretical deduction based on Fick's first law; the other one mainly refers to experimental regression and empirical analysis.

Theoretical models mainly include the mathematical model [1] $X = \sqrt{\frac{2D_{CO_2}C_{CO_2}}{M_{CO_2}}}\sqrt{t}$ proposed by the Soviet scholar Oleksandr Aliyev

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et al., and the analytical model [2] $X = \sqrt{\frac{2D_{CO_2}C_{CO_2}}{C_{CH}+C_{CSH}+3C_{C_3S}+2C_{C_2S}}}\sqrt{t}$ by Greek scholar Papadaki. (Note: in the above formulae, X represents for carbonation depth and t for time; D_{CO_2}, C_{CO_2} and M_{CO_2} are diffusion coefficient, concentration of CO_2 and Coefficient of absorptive capacity to CO_2 per unit volume respectively; C_{CH}, C_{CSH}, C_{C_3S} and C_{C_2S} mean the concentrations of $Ca(OH)_2$, CSH, C_3S and C_2S, respectively.)

Many types of empirical models have been developed based on carbonation test, such as Lesage-de-Contenay C model [3]: $X = K_{CO_2}K_TK_w\sqrt{t}$ (Note: here, k_{CO_2} is the influence coefficient of density of CO_2 in the environment, and k_T and k_w represent the influence coefficients of temperature and water cement ratio respectively), Zhu Anmin model [4]: $X = \gamma_1\gamma_2\gamma_3(12.1W/C-3.2)\sqrt{t}$ (here, γ_1, γ_2 and γ_3 are influence coefficients of cement types, fly ash and weather conditions respectively; W/C is ratio of water to cement), Chen Liting model [5]: $X = \sqrt{2k_\sigma k_{RH}k_Tf(f_{cuk})C_0/m_0}\sqrt{t}$ (here, K_σ, K_{RH} and K_T are influence coefficients of stress, humidity and temperature in the environment respectively, m_0 represents the absorptive capacity to CO_2 per unit volume concrete, and C_0 is concentration of CO_2 in environment), Smolczyk model [6]: $X = 250(1/\sqrt{F_C} - 1/\sqrt{F_g})\sqrt{t}$ (here, F_c is compressive strength of concrete and F_g is ultimate strength when assuming no carbonizing), Niu Ditao model [7]: $X = K_{el}K_{ei}K_t\left(\frac{24.48}{\sqrt{f_{cuk}}} - 2.74\right)\sqrt{t}$ (here, K_{el}, K_{ei} and K_t are influence coefficients of region, indoor and outdoor environment and curing time respectively; K_t is the standard value of concrete cubic compression strength), and Zhang Haiyan model [8]: $X(t)=K(T/10)^{0.713}(H_t^2-1.98H_t+1.896\times\sqrt{C_0/0.03}\left(\frac{15.806}{f_{cuk}}+0.215\right)t^{0.42}$ (here, K is influence coefficients of indoor or outdoor concrete, H_t, T and C_0 are relative humidity, temperature and concentration of CO_2 in environment respectively), etc.

The above models are the same in essence and agree that carbonation depth is in direct proportion to the square root of time, namely, $X = K\sqrt{t}$, but the formula fails to consider the features and patterns of carbonation coefficient k changing with time; in addition, none of the above models discuss the crossed influence of multi-factors on carbonation, and multiple coefficients in some of model formulae are merely superimposed based on the single influence of each factor; furthermore, most of the current carbonation models neglect the degree to which change on mechanics and structure affects the rate of carbonation, and some of empirical models concerning stress factor mainly focus on the analysis on the influence and pattern of stress's state and intensity in the absence of study on the influence of stress level. In view of the problems and disadvantages of the above research work, this article conducts an in-depth study to describe the effect of stress level and the crossed action of multiple factors on concrete's carbonation model based on the experiment.

2. Experimental design

2.1. Experimental material and mix proportion

General 425 grade cement, admixture fly ash FII, Kao superplasticizer SK-1, sand and gravel of medium grade. Cement: sand: gravel: admixture: superplasticizer = 130:213:319:24:1, water-cement ratios of specimen are 0.4, 0.48 and 0.55 respectively.

Experimental condition [9]: CO_2 concentration $(20 \pm 5)\%$, temperature $((20 \pm 5)°C$, humanity $(70 \pm 5)\%$.

2.2. Specimen production and specimen types

The experiment is carried out by the way of accelerating carbonation and uses the specimen with a dimension of $100 \times 100 \times 400\ mm^3$ and the bracket-type design. It adopts the stress application mode in post-tensioning method and installs threaded rod and screw cap in the reserved hole to apply tensile stress and compressive stress with different intensities in combination with a stress sensor. The specimen has a built-in steel bar with a diameter of 16 mm, and based on calculation, a row of reinforcing steel bar (3 pieces) with a diameter of 10 mm are embedded in the cross section of the unsubstantial part where the bracket is connected with the specimen for security when stress is applied. Fig. 1 is the design diagram of specimen and Fig. 2 is the photo of specimen.

The experiment is performed respectively when tensile stress is applied, compressive stress is applied and no stress is applied, and different stress levels are taken into consideration in each state.

As shown in Fig. 1, according to the Saint-Venant principle, when the load P applied to the bracket is equivalently transferred to the main body of the specimen, the result is equivalent to the addition of load P with the same direction and intensity to the bending moment M. The stresses in tensile stress area and compressive stress area can be calculated in the method of mechanics of materials.

The experiment uses 6 groups of specimens (3 for each group), apart from specimens in stress-free group, specimens in all other groups are applied with a load of 0.3, 0.7, 1.0 and 2.0 KN respectively, and the calculation shows tensile stress of 0.15, 0.36, 051 and 1.02 Mpa and compressive stress of 0.21, 0.49, 0.7 and 1.4 Mpa are generated respectively (see Table 1); the result is largely the same as that of finite element modeling calculation using MARC software (see Fig. 3 Stress Nephogram for Specimen). The

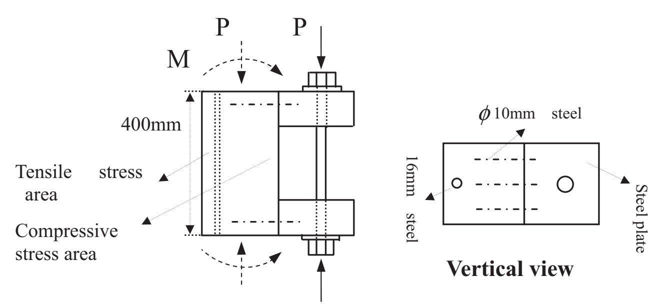

Fig. 1. Design diagram of specimen.

Fig. 2. Photo of specimen.