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Comparison of three and one dimensional attacks of freeze-thaw and carbonation for concrete samples

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HIGHLIGHTS

- Three and one dimensional attacks of freeze-thaw and carbonation are studied.
- The comparison of three and one dimensional attacks is presented.
- Multi-techniques are utilized to analyze the deterioration mechanism behind.

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ABSTRACT

In this work, the influence of water to cement ratio, air-entraining agent and alternative attack cycles of freeze-thaw and carbonation on compressive strength, carbonation depth, weight loss and relative dynamic modulus of elasticity of concrete samples is evaluated. What is more, the preliminary comparisons of weight loss and relative dynamic modulus of elasticity between three and one dimensional alternative attacks of freeze-thaw and carbonation for concrete samples are performed. Besides, air bubble tests and water absorption rate tests, microstructural analysis techniques (X-ray diffraction and thermogravimetric analysis) are adopted to reveal the deterioration mechanism of alternative freeze-thaw and carbonation attacks.

1. Introduction

Nowadays, the prediction of service life of concrete structures has drawn wide attention as the durability of concrete is an important concern in terms of reducing the social cost of new construction and maintenance of infrastructures [1]. However, most theoretical prediction approaches or tools are typically based on one main driving force of deterioration [2], such as loading-carrying, chloride diffusion [3,4], freeze-thaw or carbonation [5].

From the view point of concrete durability, on one side, freeze-thaw action causes a major cost to an ageing infrastructure and responsible for concrete deterioration in cold climates, and usually taken into consideration in structural design [6,7]. On the other side, carbonation can be identified as the most common coupled-deterioration phenomenon affecting the durability of reinforced concrete structures, thus the coupled or alternative deterioration factors should be considered in the material design of concrete. Kuosa et al. in 2014 recommended that the laboratory assessment for freeze-thaw testing should be performed, accompanying by the carbonation attack, in order to accurately simulate natural conditions [2]. However, a limited number of studies on the alternative action of freeze-thaw and carbonation were reported [2]. The main reason is due to the absence of acceptable standards or well-recognized approaches until now.

Besides, the mainstream laboratory assessments for alternative attack of freeze-thaw and carbonation usually adopted the accelerated measures, for instance, all the faces of samples were suffered from the attack of carbon dioxide (CO_2) exposure and freeze-thaw, whereas natural attacks of freeze-thaw and carbonation for concrete structure, for instance, dam structure, often exhibited single-side and/or one dimensional characteristic. The relation between accelerated and natural attacks has not been understood until now. Therefore, it is necessary to compare the differences of three and one dimensional alternative attacks of freeze-thaw and carbonation, and thus, clarify the deterioration mechanism behind.

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Besides, the investigation of alternative attacks of carbonation and freeze-thaw cycles is helpful to provide a guideline of the timing and quality control of concrete construction.

In this study, the influence of water to cement ratio, air-entraining agent and alternative cycles of freeze-thaw and carbonation is evaluated by three dimensional accelerated attacks via the compressive strength, carbonation depth, weight loss and relative dynamic modulus of elasticity. Furthermore, the preliminary comparisons of weight loss and relative dynamic modulus of elasticity between three and one dimensional alternative attacks of freeze-thaw and carbonation are performed based on a serial of fitting equations. Last but not the least, the deterioration mechanism of alternative freeze-thaw and carbonation is further revealed by pore structure analysis techniques (air bubble and water absorption rate tests), X-ray diffraction (XRD) and thermogravimetric analysis.

2. Materials and experiments

2.1. Raw materials

In this study, the chemical composition of used Huaxin 42.5 ordinary Portland cement and fly ash were determined using X-ray fluorescence spectrometer, as shown in Table 1. In the meantime, according to Chinese GB/T 1346-2011, the basic properties (fineness, setting time and compressive strength) of cement were illustrated in Table 2.

Water used in this study was de-ionized and de-aired. The fineness modulus of sand was approximately 2.3. The size of crushed fine and coarse aggregates used ranged from 5 to 20 mm and 20 to 40 mm. Superplasticizer (PCA-I type), air-entraining agent (PYQ-3 type) and shrinkage reducing agent (SBT-SRH I type) in this study were manufactured by Sobute New Materials Co., Ltd.

2.2. Mix proportion

In this study, the three dimensional accelerated alternative freeze-thaw and carbonation test aimed at the cubic concrete samples, while one dimensional test was referred to as single side freeze-thaw and one dimensional carbonation for prismatic concrete samples. In order to comprehensively compare differences between two cases above, two mix proportions were designed as in this study: the experimental procedure of mix A for the freeze-thaw and carbonation test for cubic samples was according to prEn12390-9 while the one of mix B followed Chinese GB/T 50082-2009 for the single side freeze-thaw and one dimensional carbonation test. When the influence of water to cement ratio and air-entraining agent was taken into consideration, Batch A1-5 were designed and shown in Table 3. The size of mix A cubic sample was $100 \times 100 \times 100\ \text{mm}^3$. All the faces of concrete samples of mix A were suffered from freeze-thaw and carbonation alternative attacks.

While mix B shown in Table 4 was the practical mix of face slab in Gongbo Gorge hydropower station. As the maximal aggregate size was approximately 40 mm in mix B, the size of mix B prismatic sample was set as $150 \times 150 \times 75\ \text{mm}^3$. Both mix A and B were cured under $20 \pm 3\ ^{\circ}\text{C}$ and RH $\geqslant 95\%$ for 60 days prior to most of experimental tests (compressive strength, freeze-thaw, carbonation and pore structure analysis).

2.3. Experimental protocol

With respect to mix A, Batch A1, A4 and A5 were selected to compare the influence of water to cement ratio (0.46, 0.5 and 0.6). A1-3 was utilized to analyze the role of air-entraining agent in concrete samples. The notations, "FC", "CF", "F" and"C" shown in Table 5 and undermentioned Figs. 2–5 and 7–21, represented different alternative and single attack modes, i.e., alternative freeze-thaw and carbonation, alternative carbonation and freeze-thaw, single freeze-thaw and single carbonation. The test sequence and protocol of alternative freeze-thaw and carbonation group, namely FC group, were set as:1) water immersion for 1 day prior to 8 freeze-thaw cycles for approximately 4 days; 2) carbonation exposure for 4 days after samples were oven-dried at 105 °C for 1 day. That was to say, the successive 10 days were taken as an alternative cycle. While the test sequence of CF group was reverse, compared with the one of FC group. F or C group only reserved single freeze-thaw or carbonation test and the subsequent ambient environment curing was implemented for the remaining 5 days. 4 alternative cycles were in total applied on all the groups of mix A.

For the case of mix B, with the purpose of simplicity, the single side freeze thaw and one dimensional carbonation tests were performed for FC and F groups. One of typical alternative cycle of FC group for mix B was presented as: water immersion (1 day) + 2 freeze-thaw cycles (1 day) + oven dry (1 day) + carbonation (1 day). While the alternative cycle of F group was relatively simple, only including the water immersion for 1 day, 2 freeze-thaw cycles for 1 day and ambient environment curing for 2 days. In order to assess the cumulative equivalent effect with mix A as possibly, the concrete samples of mix B were suffered from 14 successive alternative cycles mentioned above.

2.4. Experimental methods

2.4.1. Compressive strength

The compressive strength tests were undertaken with a loading rate 4 kN/s for mix A concrete sample. Three cubes for each kind of concrete samples were tested for the calculation of average value of compressive strength.

Table 1
Chemical composition of cement and fly ash.

Materials (%)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	Fe_2O_3
Cement	0.0934	1.33	4.945	18.56	0.128	3.1	1.08	58.14	3.302
Fly ash	0.24	1.12	23.67	50.21	0.612	0.507	1.37	3.31	8.788

Table 2
Properties of cement.

Fineness (%)*	Initial set (min)	Final set (min)	Compressive strength, 7 days (MPa)	Compressive strength, 28 days (MPa)	Flexural strength, 7 days (MPa)	Flexural strength, 28 days (MPa)
8.46	100	240	26.6	49	6.95	9.03

* Residue for 80 μm square mesh sieve.