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Study of the performance of steel fiber reinforced concrete to water and salt freezing condition

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Properties of plain concrete and steel fiber reinforced concrete (SFRC) (with volume fraction of 0.5%, 1%, 1.5% and 2%) subjected to freeze–thaw cycles in water and in the 3.5% NaCl solution were investigated in this paper. Through the experiment, surface damage, weight loss and splitting tensile strength loss of SFRC were measured after different numbers of freeze–thaw circulations. The microstructure and the pore structure of SFRC were analyzed on the basis of scanning electron microscope (SEM) and mercury intrusion experiment. The test results show that the use of steel fiber could improve the pore structure and decelerate the damage of concrete during freeze–thaw cycles. However, the ability of steel fiber to reduce surface scaling of concrete is limited subjected to freeze–thaw cycles in the NaCl solution. Furthermore, the weight loss and the splitting tensile strength loss of concrete tested in the NaCl solution were larger than those in water. It is also shown that the steel fiber content has the great influence on the frost-resisting property of SFRC. When a relatively steel fiber content is introduced (1.5 vol.%), the deterioration process of concrete subjected to the frost damage is considerably reduced.

1. Introduction

In cold regions, the deterioration of concrete resulting from freezing–thaw damage has great impact on the durability and service life of concrete structures [1,2]. The decrease of concrete structural durability caused by freeze–thaw cycles ultimately leads to the formation and development of cracks in the concrete. Incorporation of steel fibers is the effective way to improve crack resistance behavior and consequently the ductility and fracture toughness of concrete, it can be explain that the steel fibers are able to transfer emerging loads by bridging the cracks [3–5]. For most structural and non-structural purposes, steel fiber is the most commonly used of all the fibers [6]. SFRC is a multiphase composite material which added disordered distribution of short steel fibers in plain concrete. With the development of economy and technology, SFRC has been applied widely in the engineering construction fields step by step.

Numerous works for evaluating mechanical properties of SFRC have been reported, it now has been well accepted that incorporation of steel fiber can significantly improve the mechanical behaviors of concrete. Düzgün et al. [7] investigated the effect of steel fibers on the mechanical properties of pumice aggregate concrete, declaring that the compressive strength, splitting tensile strength and flexural strength of concretes increased up to 21.1%, 61.2% and 120.2%, respectively. Song and Hwang [8] studied the mechanical properties of HSC, indicating that the compressive strength reached a maximum at 1.5 vol.% fraction, being a 15.3% improvement over the HSC. The splitting tensile strength improved with increasing the volume fraction, achieving 98.3% at 2 vol.% fraction. Amr and Dieb [9] investigated the compressive strength and splitting tensile strength of UHSC, indicating that improvement increases as the fiber volume fraction increases. According to Marar et al. [10], the compressive strength of HSFRC improved with the increase in fiber volume. And Daniel and Loukili [11] declared, the compressive strength of HSFRC held 15% advantage over the HSC. Incorporation of fibers into concrete is not only an effective way to improve concrete mechanical behaviors, but also durability. Pigeon et al. [12,13] obtained that the use of steel and particularly carbon microfibers improves the frost and deicer salt scaling resistance of mortars. Cantin and Pigeon [14] indicated that steel fibers have no significant influence on the deicer-scaling resistance of concrete. Yang and Zhu [15] reported that the deicer-scaling resistance of concrete is reduced by the addition of steel fibers at the same air content, especially for the air-entrained concrete. According to Sun et al. [16], steel fiber could retard the performance deterioration of the concrete and improve the resistance against multidamaging under severe conditions.

From the literatures, it is obvious that most research has focused on the mechanical properties and little information available

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Table 1
Mix proportions of concrete (kg/m^3).

Mix code	Cement	Sand	Coarse aggregate	Water	Steel fiber	Water reducer (%)
B1	367	765	1146	165	0	0.6
B2	367	735	1102	165	39	0.6
B3	367	733	1100	165	78	0.6
B4	367	718	1066	165	117	0.6
B5	367	702	1053	165	156	0.6

Table 2
Mechanical properties of concrete mixtures at 28 days.

Concrete	Cube compressive strength (MPa)	Splitting tensile strength (MPa)	Flexural strength (MPa)
B1	37.9	6.1	5.03
B2	38.3	8.1	5.34
B3	39.5	9.2	6.53
B4	40.7	11.0	7.16
B5	35.2	7.2	9.77

concerning the freeze and thaw durability of SFRC. Furthermore, microstructural features including the pore structure and the microcrack characteristics of SFRC under the action of freeze–thaw needs more investigate. In this paper, the volume fraction of steel fiber and number of freeze–thaw circulation were taken as variable parameter. Basic experimental research that the performance of SFRC to water and salt freezing condition was conducted on the basis of the macroscopic and microscopic test. Furthermore, the mechanism of SFRC such as reinforcement, damage and cracking resistance under the action of freeze–thaw was analyzed.

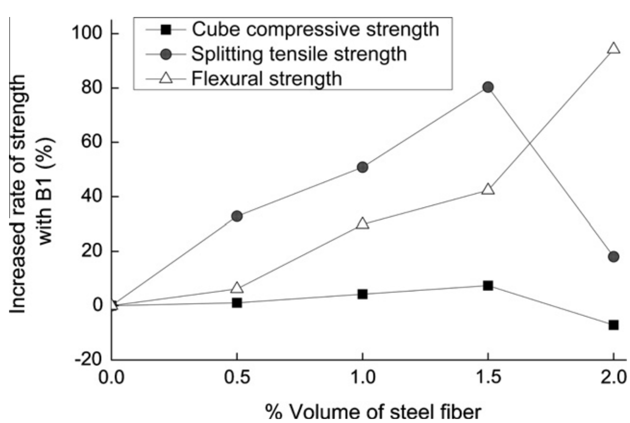

Fig. 1. Strength increased rate of SFRC.

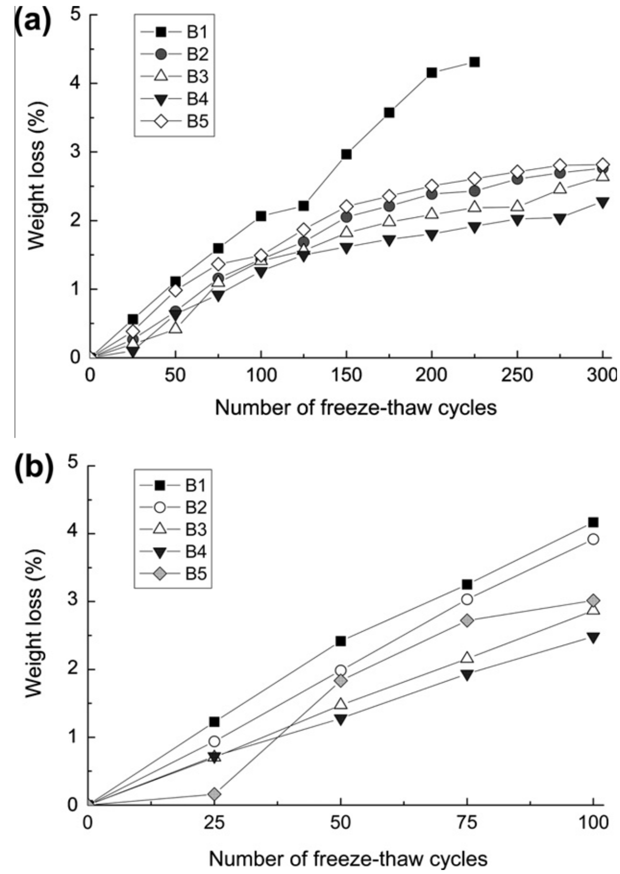

Fig. 3. Weight loss in concrete subjected to freeze–thaw cycles. (a) In water and (b) in the NaCl solution.

2. Experimental details

2.1. Materials and mix proportions

A Chinese standard Portland cement produced by Cement Factory of TongChuan was adopted, river sand with fineness modulus of 2.69, and coarse aggregate of crushed basalt stone with diameter of 5–16 mm were used in the test. A naphthalene-type superplasticizer was used, and the dosage was adjusted to keep the slump of fresh mixed plain concrete in the range of 50–120 mm. A steel fiber with a rectangular cross section, an aspect ratio of 60, and a length of 30 mm was adopted to prepare SFRC.

In this experiment, the water-binder ratio (W/B) was 0.45. A series of plain concrete (B1) and SFRC with additions of 0.5%, 1%, 1.5% and 2% steel fiber were prepared (denoted as B1, B2, B3, B4, B5 respectively). The proportions and basic characteristics of the various concrete mixes are given in Table 1.

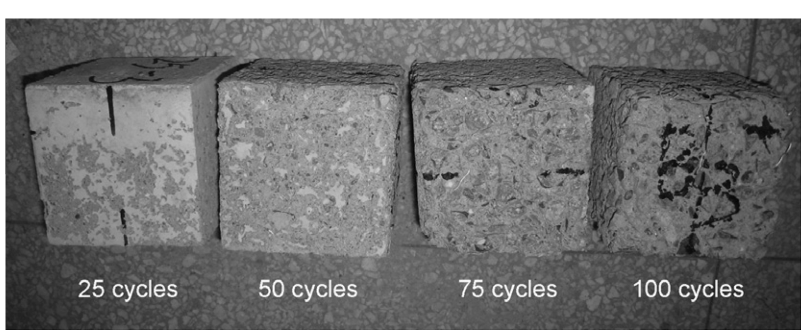

Fig. 2. Surface damage of B3 subjected to freeze–thaw cycles in the NaCl solution.