Application of silane to improve durability of concretes with different age and moisture content

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This paper presents the improvement effects of silane impregnation treatment on durability of concretes with different strength grades (C30 and C50) and air content. The influence of age and initial moisture content of concrete were considered and the water adsorption and freeze-thaw resistance of concretes were measured. The age of concrete was simulated by exposing specimens to different cycles of freeze-thaw before silane treatment, and three different drying processes were selected to prepare different moisture contents in specimens. The results show that both water adsorption and freeze-thaw resistance of concretes are significantly improved by the silane impregnation treatment. The lower initial moisture content leads to the more improvement of freeze-thaw resistance of silane treated concretes. Therefore, the freeze-thaw resistance of both new and old concretes can be improved by the silane treatment, and the earlier treatment leads to the better improvement of concrete durability.

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Keywords: Concrete, Freeze-thaw resistance, Silane impregnation, Age, Moisture content

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1. Introduction

It is well-known that cement concrete is an extensively used structural material because of its low cost, ease of construction and good durability. However, durability of concrete is of great concern in recent years, because more and more existing structures occurred premature deterioration when exposed to severe environments [1, 2]. Concrete is typically one porous and brittle material, water-saturated concrete is easily damaged by the repetition of freeze-thaw cycles in cold regions if no protection methods are adopted [3, 4]. For many years, air entrainment has been suggested as one of the most efficient methods to improve the frost resistance of concretes that are subjected to freezing and thawing [5, 6]. Current building codes require varying amounts of entrained air depending on the severity of the exposure condition. Entrained air voids provide small air pockets where water can expand when freezing and where water pressure can be relieved as freezing occurs. There may be as many as 300 billion entrained air voids in a cubic yard of concrete with a total air content of 4–6% by volume. The voids generally have a diameter of about 0.05 mm and are uniformly distributed throughout the concrete, and entrained air voids are typically spaced within 0.2 mm of each other [7]. An air content between 4% and 8% is generally considered adequate to provide resistance to the freezing and thawing action [8]. However, air entrainment may have some negative influences on the concrete strength [7], and this method is not capable of improving the frost resistance of old concrete structures which has no enough air content.

According to the freeze-thaw degradation mechanism of concrete, the reduced amount of pore water in concrete induces the lower internal expansion pressure and slighter frost damage induced by ice formation [9]. A newly-developed protective surface treatment can effectively prevent water from penetrating into concrete material, in which the material surface is impregnated with some silane-based hydrophobic agents [10]. Its validity in decreasing the moisture content and significantly suppressing the capillary water absorption has been well studied [11]. This study aims to find the improvement effects of silane impregnation treatment on the water adsorption and freeze-thaw resistance of concretes, in which both the initial moisture content and treatment age (before and after a certain cycles of freeze-thaw) of concrete specimens are considered. The experimental results suggest that the potential application of silane impregnation to improve the durability of both new and old concrete structures in cold regions.

2. Experimental details

2.1 Raw materials and concrete mixtures

The cement used is ordinary Portland cement with strength grade of 42.5 according to Chinese standard GB 175-2007. A Class Ⅱ fly ash was used with a water requirement ratio of 97% according to Chinese Standard GB1596-2005. The chemical compositions of cement and fly ash is presented in Table 1. Crushed granite gravel was used as coarse aggregate, which had a maximum particle diameter of 25-mm and crushed index of 4.8%. River sand was used as fine aggregate with a fineness modulus of 2.82. A commercially available, polycarboxylate-based, high-range water-reducing agent (SP) was used to improve the workability of fresh concrete. One type of air-entraining agent (AIR), with a recommended dosage of 0.005~0.015% of binder by mass, was used to produce different contents of air in concrete. One silane-based water repellent agent was selected after many experiments, which had a recommended impregnation dosage of 0.2-0.25 kg per m^2 of concrete surface. Four concrete mixes were designed to represent two strength grades (C30 and C50) as shown in Table 2. Both air-entrained and non air-entrained mixes were prepared for each strength grade.

Table 1. Chemical composition of cement and fly ash.

Name	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	SO_3	LOI
Cement	62.28	21.08	5.47	3.96	1.73	0.71	0.24	2.63	1.61
Fly ash	3.05	66.57	18.95	4.44	1.22	1.44	0.64	0.31	3.1

Table 2. Mixing proportion and basic properties of concrete.

No.	Mixing Proportion (kg/m^3)							Air Content (%)	Slump (mm)	f_{28d} (MPa)
	C	FA	W	S	G	SP	AIR			
C30	285	95	155	721	1082	4.2	0	1.5	215	45.7
C30-A	285	95	155	721	1082	4.3	0.04	4.3	220	39.6
C50	408	72	150	706	1060	6.0	0	1.8	210	66.9
C50-A	408	72	150	706	1060	5.5	0.04	4.2	220	65.8

C: Cement; FA: Fly ash; W: Water; S: sand; G: Gravel; SP: high-range water-reducing agent; AIR: air-entraining agent; f_{28d}: Compressive strength at 28 days.

2.2 Measurement methods

100 mm×100 mm×100 mm cubes and 100 mm×100 mm×400 mm prisms were prepared for every concrete mixture. All the specimens were demoulded after 24 hours and cured for another 27 days in a standard curing chamber (20±2℃ and RH 95%). Then the specimens were removed from the curing room, cleaned to eliminate the dust in pores and the oil-polluted surface and dried in three different conditions: RH 75% for 7 days, RH 55% for 7 days and vacuum drying oven (60 ℃) for 3 days. Therefore, three different moisture content specimens were prepared for every mixture before silane treatment. On the other hand, in order to compare the improving effects of silane treatment on new and old concrete structures, some selected prisms underwent a certain number of freeze-thaw cycles prior to the above cleaning and drying treatment. These cleaned and dried specimens were divided into two groups: one group was for the silane impregnation treatment, another was the blank sample. The surface treatment was carried out by evenly spraying the silane agent, with an average dosage of 0.25 kg/m^2, on one selected surface of cube specimen and all surfaces of prism specimen. The silane treated specimens were cured for at least 7 days in air before further tests.

The water adsorption measurement was performed on the cubic specimens by monitoring the weight change of concrete specimen with only the treated surface immersed into water. The water depth during the test was kept constant and 2 mm above the surface of the specimen in contact with water. The mass of water penetrating into per unit of surface was used to express the water adsorption property and three specimens were tested for each mix. The freeze-thaw resistance was carried out on the prism specimens by using the method for rapid freezing and thawing in accordance to Chinese Standard GB/T 50082-2009. The relative dynamic modulus of elasticity and weight variation of specimen were monitored every 25 freeze-thaw cycles, and the results were compared with those of the control specimens.

3. Results and discussion

3.1 Improved water adsorption capacity

Water adsorption is one important property for concretes exposed to freeze-thaw cycles, as the frost damage partly depends on the water saturation degree of concrete [12]. The time-dependent water adsorption of untreated concrete specimen is shown in Fig. 1. In general, the water adsorption increased steadily with the immersion time for every sample and the larger water absorption occurred for the lower strength concrete, being attributable to the higher porosity and coarser pore structure [13]. For concretes with the same strength grade, the air entrainment decreased the water adsorption by 15.4% for C30 concrete and 33.1% for C50 concrete. This result can be explained by the reduced crack propagation in air entrained concrete. When the specimen surface was impregnated by the silane, the water adsorption of specimen developed very quickly during the first one hour and then tended to a stable value, as shown in Fig. 2. The final water adsorption was decreased by 92.3%, 92.0%, 91.5% and 90.0% for C30, C30-A, C50 and C50-A concrete respectively when compared with the untreated specimens. This is because sliane agent penetrates concrete pores and reacts with cement hydration products, leading to the formation of a hydrophobic lining on the pore walls [14]. The remarkably improved water adsorption of silane treated concretes is expectedly favorable to all kinds of durability performances related to water penetration.

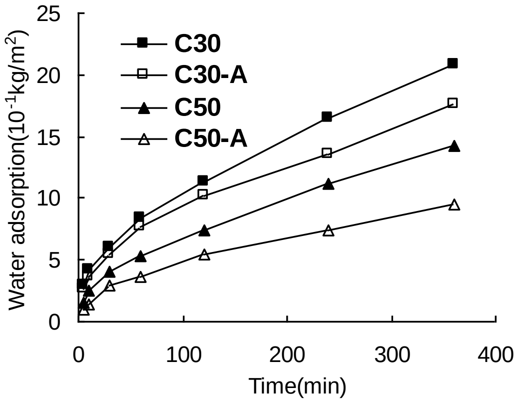


Fig. 1. Water adsorption of untreated specimens.

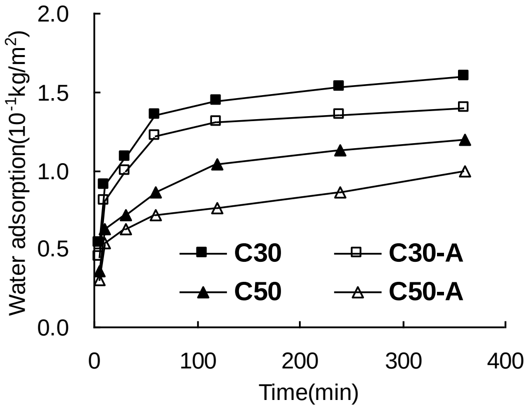
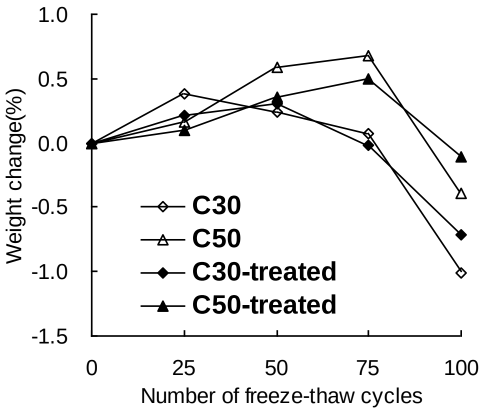


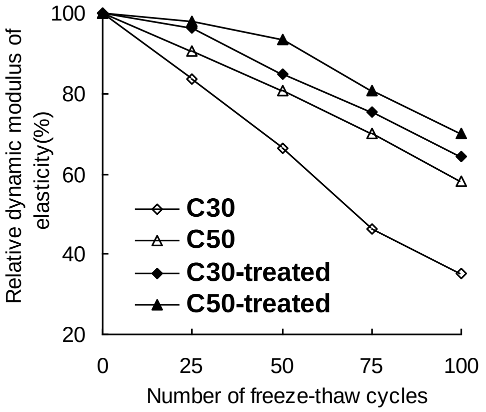
Fig. 2. Water adsorption of silane treated specimens.

3.2 Freeze-thaw resistance of difference mixture concretes

Freeze-thaw resistances of all concretes prior to and after silane treatment were presented in Fig. 3 and Fig. 4. In this part, each concrete specimen underwent an oven drying for 3 days before the silane impregnation treatment. It can be found that all the specimens experienced a weight increase during the first 50 freeze-thaw cycles, being attributable to the further hydration of cement and more water ingress through micro-cracks and capillaries, and then showed a weight loss with the further increasing cycles of freeze-thaw. The silane treatment somewhat decreased the amount of weight variation during the test due to the hydrophobic property of surface concrete. For the plain specimens of C30 and C50 mixtures, the relative dynamic modulus of elasticity remarkably decreased with the increase of freeze-thaw cycles. After 100 cycles of freeze-thaw, plain specimens of C30 and C50 mixtures showed a relative dynamic modulus of elasticity of 35% and 58% respectively, representing a very low resistance to freeze-thaw; the silane treated specimens of C30 and C50 mixtures showed a relative dynamic modulus of elasticity of 64% and 70% respectively.



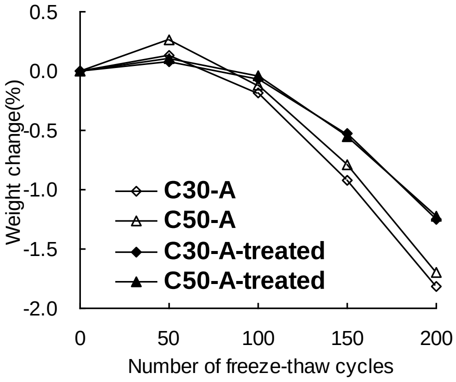
(a) Weight loss



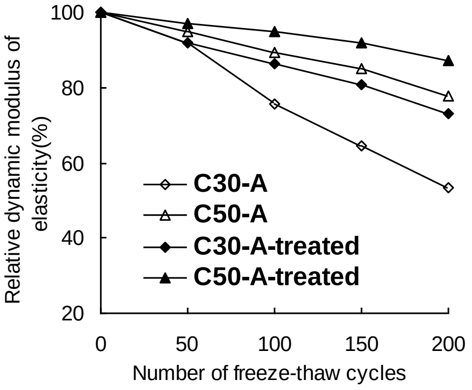
(b) Relative dynamic modulus of elasticity

Fig. 3. Freeze-thaw resistance of concretes without air entrainment.

As expected, the air entrained mixtures showed a better freeze-thaw resistance than the non-air entrained mixture as shown in Fig. 4. After 200 cycles of freeze-thaw, the untreated specimens of C30-A and C50-A mixtures showed a relative dynamic modulus of elasticity of 53% and 78% respectively; the silane treated specimens of these two mixtures showed a relative dynamic modulus of elasticity of 73% and 87% respectively, representing a wonderful resistance to freeze-thaw. Therefore, the silane treatment can significantly improve the freeze-thaw resistance of concretes, and it is more effective for the lower strength and non-air entrained mixture.



(a) Weight loss



(b) Relative dynamic modulus of elasticity

Fig. 4. Freeze-thaw resistance of concretes with air entrainment.

3.3 Influences of initial moisture content on freeze-thaw resistance

The initial moisture content was reported as one of the most important factors on the silane penetration depth in concrete [15]. The variations of penetration depth will influence the long-term properties of concrete structure. Three drying conditions were selected to prepare different initial moisture contents of concrete samples: oven drying, RH 55% and RH 75%. In this part, only non-air entrained concrete mixtures are presented in Fig. 5 and Fig. 6. All three silane treated specimens showed a higher relative dynamic modulus of elasticity than the untreated specimen for each mixture. For mixture C30, the oven drying, RH 55% and RH 75% samples showed a relative dynamic modulus of elasticity of 64%, 59% and 53% respectively, much higher than 35% for the untreated sample; for mixture C50, the oven drying, RH 55% and RH 75% samples showed a relative dynamic modulus of elasticity of 70%, 66% and 65% respectively, a little higher than 58% for the untreated sample. The severer drying condition led to the better improvement of freeze-thaw resistance, which being explained by a more amount of silane impregnated into concrete with a lower moisture content [16]. On the other hand, such difference due to initial moisture content seems less obvious for higher strength concrete which has a less silane impregnation [17].

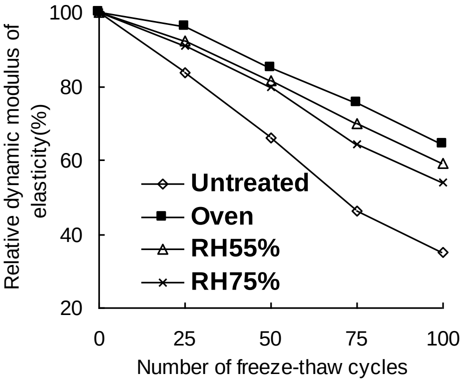


Fig. 5. Freeze-thaw resistance of concretes treated after different drying conditions (C30).

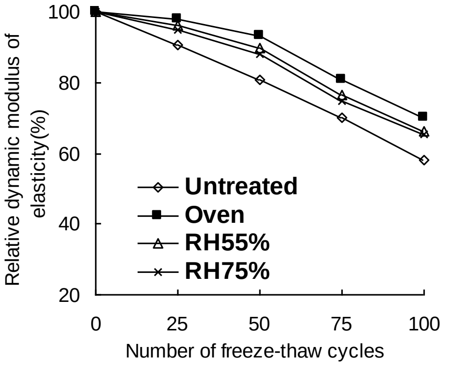


Fig. 6. Freeze-thaw resistance of concretes treated after different drying conditions (C50).

3.4 Influences of treatment age on freeze-thaw resistance

The silane surface treatment can be applied to both new and old structures [18, 19], but the possible protection on old structures of this technology are still questionable. Concrete specimens were divided into several groups, each group underwent a certain cycles of freeze-thaw and the influences of silane treatment on the further resistance to freeze-thaw on them were compared. The experimental results are presented in Fig. 7 and Fig. 8. For C30-A concretes, when comparing with the untreated sample, the final relative dynamic modulus of elasticity in this test was increased by 37.0%, 33.8% and 21.7% for silane treated specimens which underwent no freeze-thaw, 50 and 100 cycles of freeze-thaw respectively. For C50-A concrete, the final relative dynamic modulus of elasticity was increased by 18.3%, 12.1% and 9.1% for silane treated specimens that underwent no freeze-thaw, 50 and 100 cycles of freeze-thaw respectively. Therefore, the silane treatment can be applied to increase the freeze-thaw resistance of both new and old concretes, the earlier treatment leads to the better improvement of concrete durability.

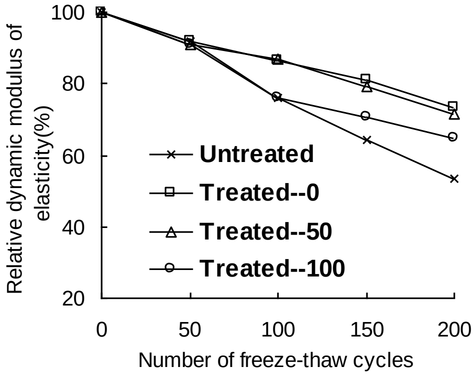


Fig. 7. Freeze-thaw resistance of concretes with different treatment ages (C30-A).

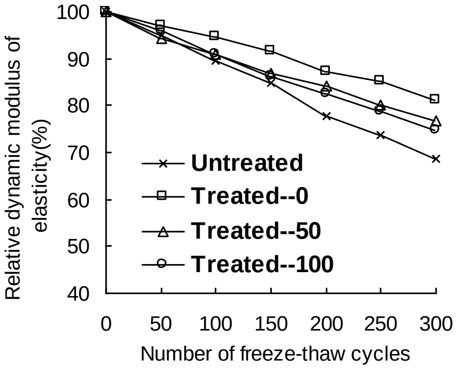


Fig. 8. Freeze-thaw resistance of concretes with different treatment ages (C50-A).

4. Conclusions

Based on the above experimental results, the following conclusions can be drawn:

1) Both water absorption and freeze-thaw resistance of concretes are significantly improved by the silane impregnation treatment. And such an improvement on freeze-thaw resistance is more effective for the lower strength and non-air entrained concretes.

2) The low initial moisture content is favorable to the silane impregnation and the induced improvement of freeze-thaw resistance. However, such difference due to initial moisture content seems less obvious for high strength concretes.

3) The resistance to freeze-thaw of both new and old concretes can be improved by the silane treatment, but the earlier treatment leads to the better improvement of concrete durability.

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