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EFFECT OF SURFACE-PENETRANTS FOR CONCRETE UNDER FREEZE-THAW CYCLES

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Reinforced concrete (RC) structures are generally deteriorated by penetration of water and gases that induce corrosion of reinforcements. Surface-penetrants, which increase gas-penetration resistance of concrete, can improve the long-term durability of RC members. A kind of surface-treatment, such as silane penetrants, gives a high water-repellant effect to concrete. It is well known that concrete in cold regions is occasionally damaged by freezing and thawing (F-T) cycles. In a microscopic viewpoint, water-pressure in pore structures of concrete increases due to freezing. The increase of internal water pressure may be a cause of the F-T damage of concrete. It is possibly hard to ease the water-pressure in saturated concrete incorporating the water-repellant penetrant. That is, the surface-treated concrete under the F-T cycles may deteriorate seriously. To examine the effect of surface-treatment, the study conducted the F-T test (JIS A 1148) by using concrete that was painted with surface-penetrants. The foci of this investigation are to examine the F-T durability of surface-treated concretes and to compare the effect of the surface-penetrants. This paper reports the effects of the water-repellant penetrant on the F-T durability.

Keywords: Lithium, Siloxane, Silane, Relative dynamic modulus of elasticity.

1 INTRODUCTION

Most of the civil infrastructures, such as concrete bridges and other road structures, are generally exposed to temperature variations due to daily/monthly climate changes. Such concrete structures in cold regions are often damaged by extreme cold temperature. Even in mild weather regions, the concrete structures are occasionally subjected to severe cold temperature environments during the service life. The temperature variation around freezing temperature of water, which is always included in the pore structures of concrete, is a serious concern for the deterioration of infrastructures. It is well known as the freeze-thaw (F-T) effect on concrete. When concrete is exposed to freezing temperature or lower, the water in the microstructures is possibly frozen. In such a case, water-pressure in the pore structures of the concrete increases as freezing water. The cyclic F-T effect occasionally damages microscopic pore walls. Concrete structures without adequate entrained-air are damaged by the cyclic F-T temperature variations.

Surface-penetrants can improve the surface quality of the concrete and are often used to prevent the ingress of water and/or chloride ion (Tran *et al*. 2018, Bader *et al*. 2019). The surface-treated concrete indicates excellent durability because it has higher resistance to the ingress than the conventional concrete (Pan *et al*. 2017). Hence, various penetrants for concrete have been developed and used in the world. Note that some surface-penetrants contribute to increase the water-repellant effect on concrete. When the surface-penetrant, having the water-repellant effect, is used in saturated concrete under F-T temperature cycles, the water-pressure must be significantly higher than the concrete without the water-repellant penetrant. That is, such a surface-penetrant may decrease the F-T deterioration resistance of concrete rather than the durability improvement effect.

The foci of this investigation are to examine the F-T durability of surface-treated concretes and to compare the effect of the surface-penetrants. The standard F-T tests were conducted by using concrete beam specimens coated with surface-penetrant, which has a water-repellant effect. The present paper reports the fundamental experiment of F-T degradation and discusses the effect of the surface-penetrant on the concrete durability.

2 TEST MATERIALS AND SPECIMENS

2.1 Concrete Specimens

Materials used for the concrete are given in Table 1. In addition, the mixture proportion of concrete is shown in Table 2. Three concrete specimens (100 × 100 × 400mm) for each parameter were tested. All concrete specimens were made in a laboratory and cured in a water-tank for 28 days. The F-T tests described in the next section were conducted after the concrete age of 91 days or longer, hence, the effect of un-hydrated cement on the F-T durability can be ignored in the study.

Table 1. Materials for concrete.

	Materials	**Density**
Water ***W***	Tap water	1.0 g/cm^3
Cement ***C***	Ordinary Portland cement	3.16 g/cm^3
Fine aggregate ***S***	Sea sand	2.60 g/cm^3
Coarse aggregate G_1	Crushed sandstone (20–15 mm)	2.72 g/cm^3
Coarse aggregate G_2	Crushed sandstone (15–5 mm)	2.70 g/cm^3
Admixture ***WRA***	Air entraining and water reducing agent	1.0 g/cm^3

Table 2. Mixture proportion of concrete.

w/cm	***W***	***C***	***S***	G_1	G_2	***WRA***	***Air***
0.54	172 kg/m^3	319 kg/m^3	880 kg/m^3	464 kg/m^3	464 kg/m^3	29 g/m^3	4.5 %

2.2 Surface-Penetrants

Figure 1 shows the preparation condition of test specimens coated with the surface-penetrant (sealer). Table 3 summarizes the test parameters in this study. Concretes of Type-N were control specimens without surface-penetrant. Table 3 presents primary chemical compositions of the surface-penetrants tested. The surface-penetrant Type-D is of the same material as of Type-C, though the usage volume (per unit-area of concrete surface) was almost double to the volume of Type-C. The water absorptions for 100 days were 1.29% (A), 1.05% (B), 0.60% (C), and 0.53% (D), respectively. The surface-treated concrete with Type-C and Type-D indicated significantly lower water-absorption than the other concretes.

a) Sealer coating b) Coated specimens

Figure 1. Surface-treated concretes.

Table 3. Test parameters.

Type	Chemical compositions of surface-penetrant	Usage volume	Water absorption	F-T test (wet-wet)	F-T test (dry-wet)
A	Lithium silicate	1 / 7 (liter / m^2)	1.29 %	3	3
B	Lithium silicate + siloxane	1 / 7 (liter / m^2)	1.05 %	3	3
C	Lithium silicate + silane	1 / 7 (liter / m^2)	0.60 %	3	3
D	Lithium silicate + silane	2 / 7 (liter / m^2)	0.53 %	3	3
N	---	---	1.15 %	3	3

a) Procedure-A b) Procedure-B

Figure 2. Concrete specimens for F-T tests.

3 FREEZE-THAW TESTS

The Japanese Industrial Standard (JIS-A-1148 2010) standardize two kinds of F-T tests: [Procedure-A], freezing and thawing under water, and [Procedure-B], freezing under dry and thawing under water. Each F-T test are described below.

a) Dynamic modulus b) Mass-loss measurement

Figure 3. Dynamic modulus and mass-loss tests.

3.1 Procedure-A (Wet-Wet Cycles)

The test is often conducted for determining F-T durability of concrete. The freezing and thawing processes were performed in a specialized water-tank for the F-T test. Hence, the test provides more severe conditions than in Procedure-B. All concrete specimens were covered with a rubber jacket to protect the direct damage from icing by water-brine (Figure 2). The temperature range was -18 °C – 5 °C. The relative dynamic modulus (Figure 3) and mass-loss were determined at every 30 F-T cycle (up to 300 F-T cycles). When the saturated concrete specimens are covered with water-repellant sealer, the water pressure in the microscopic pores of the concrete may be higher than the other concrete without the material. Hence, the surface-treated concrete under the F-T cycles may deteriorate significantly.

3.2 Procedure-B (Dry-Wet Cycles)

In this test, concrete specimens are subjected to F-T cycles, freezing under dry and thawing under wet conditions. The concrete specimens are dried under the freezing process, so the internal water, which is a cause of F-T deterioration, is possibly decreased. When the concrete surface is water-repellant layered (surface-coated), it can be assumed that the F-T damages of each coated material is not different. Like in Procedure-A, the temperature range was -18 °C – 5 °C. The relative dynamic modulus (Figure 3) and mass-loss were determined at every 30 F-T cycles (up to 300 F-T cycles).

4 TEST RESULTS AND DISCUSSION

4.1 F-T Test for Saturated Concrete (Procedure-A)

The F-T test of Procedure-A was conducted by using saturated concrete specimens (B, C, and D). According to this preliminary test, the relative dynamic modulus ratios at 300 F-T cycles were 74% (Type-B), 47% (Type-C), and 35% (Type-N). Note that the Type-C concrete has a higher water-repellant effect than the Type-B concrete. The F-T durability of the saturated concrete of Type-C is significantly lower than the durability of Type-B while it was slightly higher than the control concrete (Type-N). The observation implies that the saturated concrete with higher water-repellant sealer might be deteriorated by the increase of internal water pressure during the freezing.

4.2 F-T Test for Saturated Concrete (Procedure-B)

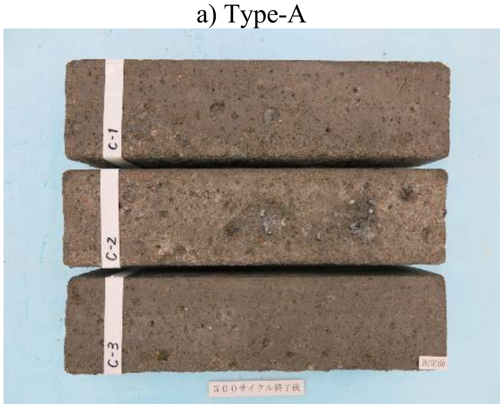
To confirm the properties of the surface-treated concrete under F-T cycles, an F-T test of Procedure-B was conducted by using saturated concrete specimens (A, B, C, and D). The relative dynamic modulus ratios of all the concretes were in the range of 99% – 100%, and mass-loss was also negligible. Compared to the F-T test results in Procedure-A, the deterioration was hardly observed in the test of Procedure-B. The difference in both results must be due to the different test conditions (wet-wet and dry-wet cycles).

4.3 F-T Test for Surface-Dried Concrete (Procedure-A)

To examine the effect of internal water on the F-T deterioration, the F-T test of Procedure-A was reconducted by using partially dried concrete specimens (A, B, C, and D). To prepare the surface-dried concrete, all test specimens were stored in a drying room for a week after the standard water curing of 91 days. The dried concrete specimens were coated with the sealers (A, B, C, and D).

a) Type-A

b) Type-B



c) Type-A

d) Type-B

Figure 4. Surface conditions after 300 F-T cycles.

Figure 4(a) through Figure 4(d) show the surface deteriorated conditions of concrete after 300 F-T cycles. Local damages in these concretes were observed; however, remarkable F-T deterioration was not found. Figure 5 presents the relative dynamic modulus of surface-treated concretes (A, B, C, and D). The results confirmed that the relative dynamic moduli of all tested concretes decreased in accordance with F-T cycles, while the ratios were hardly decreased in the test of Procedure-B. It is noteworthy that the decreases were significantly lower than the result of the saturated concrete tested in Procedure-A. The comparative result in the tests of Procedure-A confirms that the internal water restrained by the sealer layer in the concrete is an influencing factor on the F-T durability of the surface-treated concrete. Further researches should be done to reveal the deterioration mechanism of the surface-penetrant concrete exposed to F-T cycles.

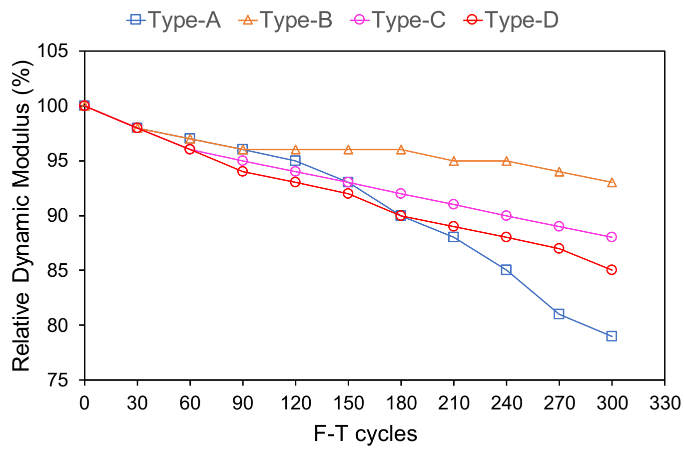


Figure 5. Relative dynamic modulus (Procedure-A: surface-dried concrete).

5 SUMMARY

The study conducted the F-T tests by using concrete painted with surface-penetrants and examined the effect of the surface-penetrants. The F-T test of Procedure-A, using saturated concrete, indicated remarkable deterioration of the surface-treated concrete, though, F-T damage was not observed in the F-T test of Procedure-B. Comparative results of saturated and partially dried concrete with water-repellant sealer revealed the different F-T deterioration. The different deterioration processes were possibly due to the volume of water restrained by the sealer layer. To evaluate the F-T durability of the surface-treated concrete, further researches should be performed in the future.

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