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Effect of hydrophobic surface treatment on freeze-thaw durability of concrete

Zhichao Liu*, Will Hansen

Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI 48109, USA

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ABSTRACT

The effect of surface treatment using silanes on the frost durability is investigated on both laboratory and field specimens in an accelerated laboratory test. Measurements include moisture uptake during the pre-saturation and F-T stages, cumulative mass loss and internal bulk cracking under frost salt/water exposure. It is found silane treatment substantially reduces surface scaling, but cannot prevent bulk moisture uptake or the occurrence of the internal frost damage when concrete is insufficiently air entrained. Salt scaling is dominated by the capillary suction process in the thin surface region under freezing which can be curtailed by the pore lining effect from silanes creating a hydrophobic barrier to the ingress of external liquid. This in turn suppresses ice growth in the surface region, evidenced by the complete elimination of sub-freezing dilation in a length-change measurement of small-scale concrete specimens with surface treatment. However, internal frost damage is controlled by the universal degree of pore saturation which in turn is dependent on the bulk moisture uptake.

1. Introduction

Hydrophobic surface treatment has been proven to be an effective technique to minimize moisture transport into concrete and its effect on durability improvement and service life extension is well-documented [1–7]. Silanes are one of the common surface treatment agents for concrete structures. They fall into the category of pore liners and can easily penetrate capillary pores due to the small molecular size (1–2 nm) [3], which substantially reduces capillary suction. Their working mechanism is explained as follows.

Capillary suction is an unsaturated transport process by means of capillary forces, which is a function of surface tension σ of the wetting liquid and its contact angle θ with a pore of a radius r.

$$\Delta P = \frac{2\sigma \cos\theta}{r} \tag{1}$$

It is thermodynamically a spontaneous process when $\theta<90^\circ$, in which case there is a molecular attraction between the liquid and substrate, accompanied by a capillary rise and a concave meniscus (Fig. 1(a)). Silanes are able to increase the contact angle above 90° by forming a water repellent lining on the pore walls [2,3,8], such that the pressure difference is reversed and extra work is needed for moisture to penetrate the pores [1], as seen in Fig. 1(b).

Freeze-thaw (F-T) damage is a common materials-related distress in concrete structures and it is substantially intensified in the presence of deicers used for pavement or bridge maintenance in winter, which is known as salt frost deterioration [9]. This degradation manifests itself in two aspects [10]: (1) internal frost damage leading to bulk cracking and loss of integrity, (2) superficial scaling typically involving progressive swelling and flaking of the mortar component. A number of studies have found that salt scaling was significantly reduced by the hydrophobic surface treatment using silane [2,7,11–13], which is generally attributed to the reduction in salt solution penetration [11–13]. However, there is a scarcity of data regarding the concurrent evaluation of surface scaling, internal frost cracking and the associated bulk moisture absorption. Moreover, laboratory tests for the impedance to moisture ingress into concrete are normally carried out at atmospheric pressure and room temperature, with no consideration for F-T exposure [7,14,15].

In this paper, the effect of hydrophobic surface treatment by silanes on F-T durability is evaluated on concrete specimens prepared in the laboratory and obtained from the field and its working mechanism is proposed by the simultaneous measurements of mass loss, moisture absorption and internal damage in a salt scaling

* Corresponding author. Department of Civil and Environmental Engineering, 2350 Hayward, 2330 GG Brown, Ann Arbor, MI 48109-2125, USA.
E-mail address: lzc@umich.edu (Z. Liu).

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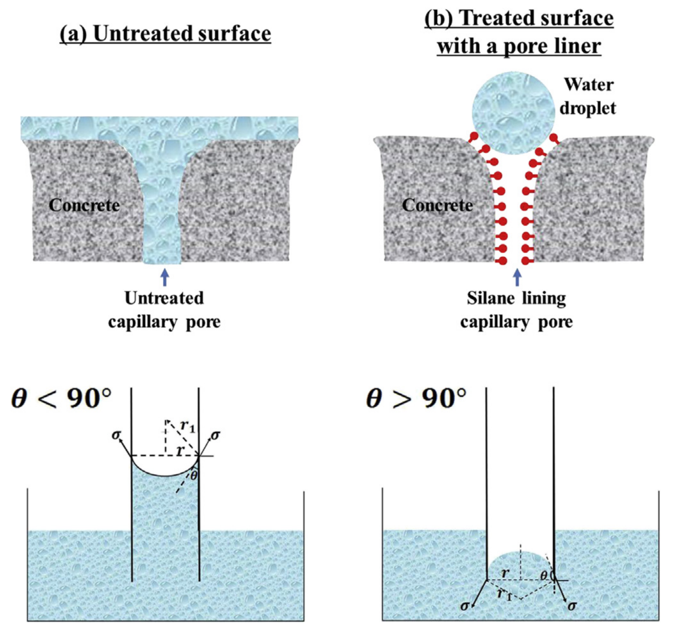

Fig. 1. Illustration of silane pore lining effect.

test, along with the continuous monitoring of sub-freezing length change on small-scale concrete specimens.

2. Experimental

2.1. Materials

Cement used was commercially available Type I portland cement. Aggregates included silica sand as the fine aggregate with a fineness modulus of 2.43 and lime stone as the coarse aggregate with a 25 mm nominal maximum size. Two commercially available silane-based water repellent agents from the same manufacturer but of two different concentrations (40% and 100%) were used for surface treatment of concrete specimens. They have a specific gravity of 0.947–0.957 and their application will not alter the appearance of concrete surface (Fig. 2). A polycarboxylate-based superplasticizer and a synthetic air-entraining agent were used for workability and air content regulation, respectively. Both concrete admixtures are of aqueous solutions and commercially available.

2.2. Mix characteristics and specimen preparation

A 0.45 w/c ratio concrete mix was prepared in the laboratory according to ASTM C 192 [16] and the mix design is shown in Table 1. 150 mm × 300 mm cylindrical specimens were cast and left in the mould for 1 day before curing started. Specimens for F-T test was moist cured for 27 days while specimens for pore structure measurement underwent additional air curing for >1 year. Additional field samples of the same size were obtained by drilling cores

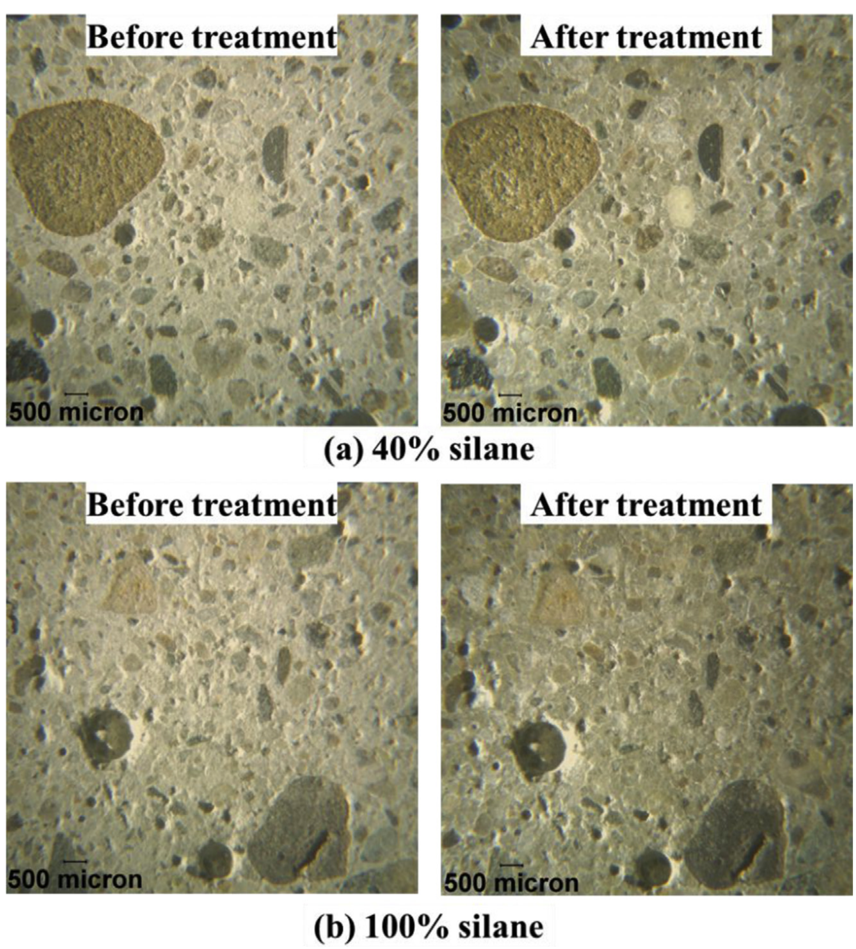

Fig. 2. Surface profile before and after silane treatment.