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Technical note

A novel electrochemical technique for enhancing silane penetration depth into mortar

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ABSTRACT

Concrete require a variety of additives and methods for improving their structure and performance, including the usage of silane. The conventional method of silane penetration has its disadvantages regarding the depth of penetration. A novel electrochemical technique for enhancing silane penetration depth into mortar was proposed. Mortar with different carbonation depths were prepared to simulate the mortars with different service durations. By a comparative experiment, the effectiveness of this method was evaluated by measurements of contact angle, capillary water absorption and penetration depth of silane into mortar. The results show that when compared to dipping method, this method enhances silane penetration depth into mortar effectively, especially for aging mortar (mortar with deeper carbonation depth). The produced silane layer exhibits a better hydrophobicity, of which surface contact angle is larger, and capillary water absorption coefficient is lower than those for the dipping method.

1. Introduction

Concrete has been widespread used as a major building material, owing to its performance and low cost. However, due to the porous structure of concrete, the aggressive medium in the environment such as water, O_2, CO_2, Cl^- and SO_4^{2-} has caused the deterioration of concrete, such that that its service-life is reduced [1]. The durability performance of concrete structures has been of great concern among researchers all over the world.

Nowadays, a variety of methods are applied to for upgrade the durability of concrete structure by reducing the permeability of concrete, such as structuring modifiers, plasticizing, additives and waterproof coating [2]. Among them, silane has been widely applied as waterproofing coating on concrete, penetrates into the concrete pores and thus forms an impervious film on the surface [3]. The impervious film is formed by the hydrolysis and condensation reactions of silane agents:

$$R - Si - OR' + H_2O \rightarrow R - Si - OH + R'OH \tag{1}$$

$$2R - Si - OH \rightarrow R - Si - O - Si - R + H_20 \tag{2}$$

$$2R - Si - OH + M - OH \rightarrow M - Si - O - R + H_20 \tag{3}$$

where R and R′ are functional group and methyl (or ethyl), respectively, and M stands for concrete. This protective action greatly improves the resistance to environmental attacks, such as chloride ions diffusion or water permeation [4]. However, the penetrating depth of silane is limited (about 1 to 4 mm) by the conventional method of dipping [5,6]. Once the impervious layer in concrete is denuded or abraded, aggressive substances in surrounding inevitably diffuse into concrete and compromise concrete durability. Therefore, the penetration depth of silane for concrete is important for its durability. However, to the best of my knowledge, the method that can be applied to enhance silane penetration depth into concrete is not yet available until now.

Nowadays, the electrochemical technique has been widely used for improving concrete structure durability [7–15]. For examples, the electrochemical chloride extraction is the technique that aims to move chloride ions away from the reinforcement so as to prevent the corrosion of reinforcement in chloride contaminated concrete structure [7,8]. Besides, during the electrochemical realkalisation treatment, the highly alkaline electrolyte is transported into the carbonated concrete for restoring the alkalinity of concrete, so that the corrosion of reinforcement in carbonated concrete stops [11,12]. In addition, the electrical injection of corrosion inhibitor can also mitigate the reinforcement corrosion [13,14], and the electrochemical penetration of lithium ions can suppress the concrete expansion induced by the alkali-silica reaction [15].

In this paper, a novel electrochemical technique for enhancing penetration depth of silane into mortar was proposed. In this

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method, two auxiliary electrodes positioned in the anodic and cathodic compartments were serviced as the anode and cathode, respectively. During this electrochemical method, due to the application of external electric field, silane is expected to be injected into mortar/concrete for enhancing the silane penetration depth. Mortar specimens with different carbonation depths were prepared to simulate the mortars with different service durations in real conditions. The constant voltage was applied between two auxiliary electrodes positioned in the anodic and cathodic compartments. By a comparative experiment, the effectiveness of this method was evaluated by measurements of contact angle, capillary water absorption and penetration depth.

1.1. Materials

The cement was No.42.5 ordinary Portland cement (OPC) made in China. Its oxide composition was listed in Table 1. The river sand with a fineness modulus of 2.1 was used as fine aggregate. Tap water and distilled water were adopted to prepare mortars and various electrolytic solutions, respectively.

The silane used in this work is iso-octyltriethoxy silane (liquid) supplied by SICONG chemical Co. Ltd. Technical parameters of iso-octyltriethoxy silane are shown in Table 2.

1.2. Electrochemical treatment

The mortar samples with the size of 4 cm × 4 cm × 16 cm were fabricated by using the water/cement ratios of 0.45 and cement-sand ratio of 0.4. After 24 h of casting, the mortar samples were removed from the molded then cured in a 95% humidity chamber at 20 ± 2 °C for twenty-seven days. After the curing, in order to simulate the mortar with different service duration in real conditions, the mortar samples were also previously carbonated after 0 d, 3 d and 28 d in a chamber with an atmosphere at T = 20 ± 5 °C, HR = 70 ± 5% and 20 ± 2% of CO_2 concentration. The mean carbonation depth for mortar samples carbonated 0 d, 3 d and 28 d was 0 mm, 6.3 mm and 14.3 mm, respectively.

After carbonation, the mortar sample was installed in the middle of electrolytic tank made from organic glass. Titanium meshes were served as the anode and cathode. Silane mixed solution and saturated calcium hydroxide were added into anodic and cathodic compartments, respectively. The silane mixed solution contains 50vol.% silane dissolved in 75/25 ethanol/water mixed solvent (pH 10 adjusted by ammonium hydroxide). The detailed experimental configuration of experimental arrangement for the electrochemical treatment was indicated in Fig. 1. The sealing treatment was applied to prevent the solutions in the compartments from carbonation and evaporation. The applied voltage and conduction time were 12 V and 3 d, respectively. The temperature was controlled at 20 ± 2 °C in the water bath.

The mortar samples treated by dipping method were prepared for a comparison. The details of dipping method are as follows: the lateral face of mortar sample was dipped with the silane amount of 300 ml/m^2. Subsequent to this, the mortar sample was placed in atmosphere for 12 h. After this, the dipping was repeated. Then, the mortar samples were stored for 7 days at 20°Cand 65% HR before carrying out the tests [16]. For all tests, three samples were used in each case studied.

1.3. Methods

The contact angle was determined by static contact angle measurement at room temperature using a goni-ometer, with an accuracy of ±0.2°. A single droplet of 2–4 μl was dispensed at a time on the surface of concrete substrate using a motorized syringe. The average contact angles were recorded immediately after the droplets touched the substrate and at least five measurements were conducted for each test. Capillary water absorption test was conducted in accordance to standard ISO 15148 [17]. All the sides of mortar specimens except the face with silane film were sealed with epoxy resin, and the mortar face with silane film was remained to be exposed to water. The weight of specimens was monitored in a period of time (0–4 h) along the contact with the water. The silane penetration depth test was the following: after drying at 40 °C for 24 h, the mortar sample was splitted and moistened at the broken surface by red ink. The depth of penetration was shown in the hydrophobic zone (which is red), and ruler was also used to measure silane penetration depth.

2. Results and discussion

The contact angle results have been shown in Fig. 2. Both the dipping method and this electrochemical method can make the mortar surface contact angle more than 120°, indicating an extremely good hydrophobicity. It has been found that there are a marginal growth in surface contact angle for mortar samples after the application of electrochemical method, when compared to the dipping method. About 5° to 15° increment of surface contact angle can be obtained. The improvement of surface contact angel through this electrochemical treatment may be due to the fact that electrochemical method improves the migration of silane on the mortar surface, so that the silane film on mortar surface get thicker.

The results of capillary water absorption of mortar with different service duration are shown in Fig. 3. The statistical water absorption amount of this electrochemical treatment is appreciably larger than that of the dipping method. This indicates the better hydrophobicity on mortar surface after this electrochemical treatment, which is correspond to the result obtained by the contact angle. Furthermore, the amounts of capillary water absorption were used to calculate the water absorption coefficient from the following formula:

$$K \times \sqrt{t} = Q/a \tag{4}$$

where K is the water absorption coefficient (kg/m^2/h$^{1/2}$); t is the time of exposure (h); Q/a is the amount of absorbed water per unit surface (kg/m^2). Besides, when compared to the dipping method, the reduction of water absorption coefficient for mortar treated with this electrochemical treatment is obvious, and about 25–50% reduction in the water absorption coefficient can be attained. Moreover, with the increase of carbonation depth, the water absorption coefficient for as-obtained mortar samples decline obviously. This is confirmed that this electrochemical method is more efficient on aging mortar.

The penetration depths of silane for mortar samples with different service duration after this electrochemical method and the dipping method are shown in Fig. 4. The silane penetration depth of the dipping method for young mortar (without carbonation) is

Table 1
Oxide composition of cement (% w/w).

Oxide	SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	SO_3	Ignition loss
% w/w	22.97	9.28	59.68	3.10	1.03	1.73	1.23	0.98