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Determining the effective service life of silane treatments in concrete bridge decks

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HIGHLIGHTS

- The effectiveness of silane is investigated in 60 bridge decks with service life of 6–20 years.
- The silane layer starts to decrease after 12 years of service.
- The average silane thickness is reduced by 75% in 17–20 year old bridges.
- Abrasion was not a significant silane deterioration mechanism in investigated structures.
- Silane deterioration starts in the bulk of the concrete and progresses towards the surface.

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ABSTRACT

Silane is a commonly used surface treatment to reduce water entry into concrete. Only limited work has been done to show the effective lifespan of silane treatments. This work uses 360 cores taken from 60 bridge decks treated with silane that have been in-service between 6 and 20 years. Optical staining techniques showed that the average silane thickness started decreasing after 12 years of service. The deterioration primarily occurs from the bulk of the concrete towards the surface. This suggests that deterioration from the alkali pore solution of the concrete may be important.

1. Introduction

When external liquids penetrate into concrete then corrosion, alkali silica reaction, sulfate attack, bulk freezing and thawing damage, and scaling can occur [1,2]. One cost effective method to extend the service life of concrete is to use protective coatings that decrease the penetration of these fluids. This is done by either lining the concrete pores with a hydrophobic surface, filling the pores, or a combination of these [3–6].

Organosilanes or silanes are monomeric silicon-containing chemicals that contain at least one carbon-silicon bond. The organic groups of the silane are bound to the silicon atoms by hydrolytically-stable carbon-silicon bonds and they coat the surface of the pores with a non-polar, low surface energy, and hydrophobic lining [7–10]. This coating inhibits water intrusion, but allows vapor in or out of the concrete [11]. Silanes are usually dissolved in a carrier, such as water or alcohol, to ensure deeper and more equal distribution into the concrete. The performance of silanes is a balance between the amount of active ingredients and the ability of the carrier to penetrate into the concrete [8,11,12–14].

Although silanes have been proven to be effective at reducing the ingress of brine solutions [15–17], little work has been done to show the effective lifespan of these pore lining materials and their long-term performance [18]. The effectiveness of silanes has been suggested to decrease from ultraviolet light, physical abrasion, weathering, and alkaline attack of the hydrophobic molecules [19–22]. The latter deterioration mechanism could be caused by a breakdown of silicon bonding by the alkalinity of pore solution [22,23]. Tosun et al. [23] have observed the loss of Si-O and Si-O-Si bonds of silane hydrophobic layer in high alkaline environments by using Fourier transform infrared spectroscopy (FT-IR) analysis on concrete samples.

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One method for evaluating the long-term performance of silanes is to conduct a field assessment of in-service structures [12]. Currently, there is little guidance in the literature about the expected lifespan of silanes from field structures. According to Christodoulou et al. [18], silane treatments on eight bridges in the United Kingdom maintained a hydrophobic lining after 20 years of service. Schueremans et al. [24] showed that a silane treated sea wall maintained a reduced rate of chloride penetration after 12 years of exposure in an aggressive marine environment in Belgium. According to Weyers et al. [25], the estimated service life of silane is 9–10 years based on the estimated rate of abrasion for two highly traveled bridges in the United States. This limited number of studies shows that only a small collection of information exists for the field performance of silane treatments.

The objective of this study was to evaluate the performance of silane treatments for 60 bridges that were in-service between 6 and 20 years in the state of Oklahoma, in the United States. The bridges were in a hot and humid climate with moderate deicer usage during the winters. The samples were investigated with techniques that stain non-hydrophobic portions of the concrete [26,27]. These findings will be helpful to practitioners to determine the long-term performance of silane treatments.

2. Experimental methods

2.1. Sample acquisition

Cores that were approximately 18 mm in diameter by 25 mm in height were taken from the driving lane and shoulder of 60 bridge decks. Six cores were taken from each bridge for a total of 360 cores. Three cores were taken from the shoulder and three from the travel lane. These cores were taken at parallel locations so that the amount surface wear could be compared. Cores were taken from areas that were clear of debris, cracks, oil, and salt scaling damage. These cores were also inspected to be sure that they did not contain a large aggregate near their surface as this would interfere with the measurement of the silane penetration. If this occurred then another core was taken. These cores were collected with a cordless drill without using water to cool the bit. This technique allowed two researchers to sample each bridge in about 1 h. This minimized the requirement for traffic control and allowed more samples to be collected in a day. Since the cores were small, this minimized damage and patching to the bridges. These bridges had an age range of 6–20 years. Details about the sampled bridges can be found in another publication [28]. The investigated bridges had an average annual daily traffic (AADT) between 3,800 and 18,000 [29]. Typical weather conditions in Oklahoma are shown in Fig. 1.

Although the concrete mixture designs and silanes varied, all of them were constructed to known specifications [30]. The concrete mixture had a maximum water to binder ratio of 0.42, a minimum cement content of 335 kg/m^3 and class C fly ash was allowed to be used at 20% replacement. All approved silanes are alcohol based with a recommended coverage rate of 3.7–6.1 m^2/L and used between 40% and 50% active ingredient and were treated within a year of construction. The specified depth of silane was 3.2 mm (1/8″) or greater and was verified by using a dye and visual inspection with an optical microscope from extracted cores at the time of construction by the Oklahoma Department of Transportation.

2.2. Sample preparation and testing

A cross section of each core was exposed by polishing with 120 grit sandpaper for 5 min. Next, the polished surface was cleaned with ethanol to remove any dirt and residue. A new piece of sand paper was used for each sample. Each sample was inspected with two techniques to determine the presence of the silane.

First, the core is ponded in blue clothes dye for 30 min. The dye stains the concrete that is not treated with the silane. An example can be seen in Fig. 2b. Past publications used X-ray fluorescent microscopy to image silane sealed concrete before and after treatment with the dye to verify the accuracy [26,27]. Next, the depth of the silane was measured at six different points by using a caliper and an optical microscope and an average was reported for each core.

Next, the core was polished to remove the dye from the exposed surface and then ponded in mineral based cutting oil for 60 s. The oil will wet the surface of the concrete that does not contain the silane. The depth is then measured as described previously with the optical microscope and calipers. Typical results are shown in Fig. 2c. Both methods had good agreement with one another and allowed a verification of the measurement. While it common practice to use water to highlight the silane layer, this method was not successful with any of the samples that had been in the field for more than six years.

2.3. Statistical analysis methods

The results were statistically analyzed with an analysis of variance (ANOVA) together with a Duncan's multiple range pairwise comparison. ANOVA is an appropriate procedure for testing the equality of several means. Duncan's multiple range pairwise comparison is useful for pairwise comparison of group means. This is useful to establish the population means of two groups are statistically different from one another [32–34]. In the ANOVA, the dependent variable was the mean of the silane depth, and the independent variable was the age of bridge decks. The statistical analysis was undertaken to compare the average silane depths from different bridges with various ages and to evaluate the significance of difference between the averages. In addition, two-way ANOVA was used to determine the significance of difference between results of travel lane and shoulder.

3. Results and discussion

3.1. Silane penetration depth

Figs. 3 and 4 show the average and standard deviation of the silane depth from the three cores in the travel lane and shoulder for each bridge. A horizontal line at 3.2 mm is shown in the graphs, as this is the minimum value required by specification and verified at construction. Based on results, all of the bridges that are less than 12 years old showed a silane depth higher than 3.2 mm. After 15 years of service, 67% of the bridges (8/12) had a silane depth

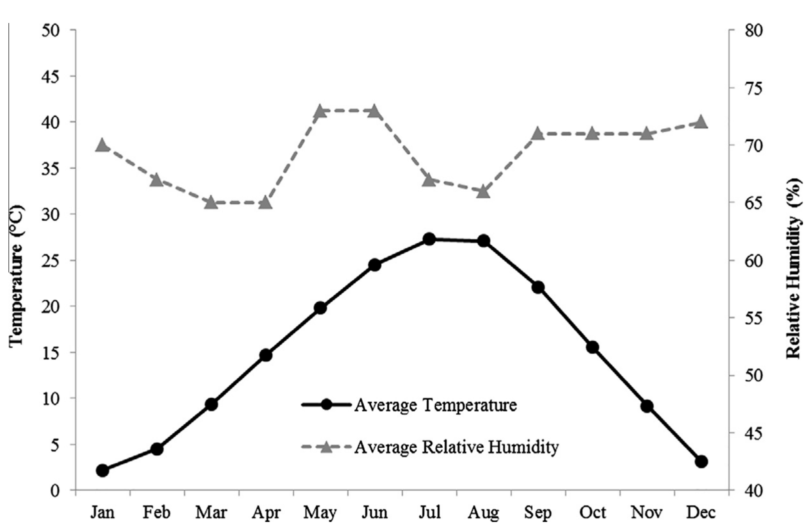

Fig. 1. Variations in mean ambient temperature and relative humidity of Stillwater, Oklahoma [31].