

Long-term performance of surface impregnation of reinforced concrete structures with silane



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HIGHLIGHTS

- Long-term performance of silane coatings on reinforced concrete.
- Hydrophobic effects of silanes following 10 years of service.
- Capillary absorption testing.

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ABSTRACT

Silanes can act as hydrophobic pore liners for reinforced concrete (RC) structures. They can significantly reduce the depth of chloride penetration, a major cause of steel reinforcement corrosion. However, there is little published information on their long-term performance. Thirty-two concrete cores were extracted from eight full-scale RC bridge supporting cross-beams that were treated with silane 20 years ago. Their water absorption by capillarity was measured and compared with sixteen control cores extracted from four non-silane treated RC cross-beams constructed at the same time. Results show that silanes may provide a residual protective effect against water even after 20 years of service.

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1. Introduction

Concrete is a naturally porous material. The size and distribution of pores in concrete varies and depends on the constituent materials, quality of compaction, the materials used in the mix design, the water-to-cement ratio, the degree of hydration, and curing [1]. Some of these pores will be interconnected to form a network of pore space that can be penetrated by water, gas or ions.

The relevant transport mechanisms for the ingress of water, gases and ions are [2]:

- diffusion of free molecules or ions due to a concentration difference;
- permeation of gases or liquids through water saturated specimens due to hydraulic pressure difference; and

- capillary suction of liquids due to surface tension acting in capillaries.

Whilst, these mechanisms act together under natural environmental exposure conditions for atmospherically exposed concrete, capillary suction tends to be the dominant mechanism [1–3]. Ions such as chlorides are transported into the concrete pore system by being dissolved into water, which subsequently cause corrosion of the steel reinforcement and ultimately spalling of the surrounding concrete cover.

Hydrophobic impregnation have therefore been used in various forms in the construction industry to help prevent water and chloride ingress and their benefits are well documented [4–9]. They can be divided into three categories: coatings, pore blockers and pore liners (Fig. 1).

Silanes belong to the pore liner category and are a group of silicones containing one silicon atom [11]. Alkoxy and alkyl silanes are routinely used for surface impregnations. The basic composition of an alkyl alkoxy silane is shown by Fig. 2. The alkoxy groups

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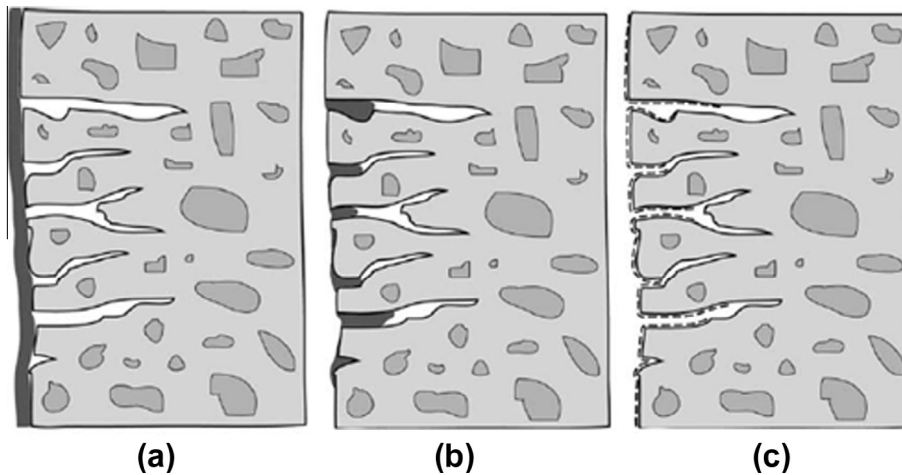


Fig. 1. Categories of surface impregnations : (a) coatings, (b) pore blockers and (c) pore liners [10].

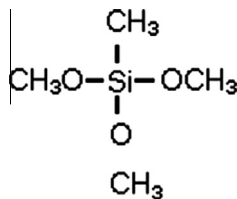


Fig. 2. Typical alkyl alkoxy silane molecular structure.

(CH₃O) linked to the silicate atom (S_i) contain silicon–oxygen bonds that will bond to silicates present in the concrete. The organic alkylic (CH₃) group remaining will protrude from the pore structure and are responsible for the hydrophobic characteristics [5,6].

Evidence from numerous studies demonstrate that the application of silanes significantly reduces water uptake, which as a result reduces the ingress of chlorides and hence also reduces the corrosion risk to the reinforcement [6,9,12–18]. However, their performance is affected by surface imperfections, cyclic wetting and drying, skill of the applicator, surface preparation, application rates and local environmental conditions at the time of application.

Polder and de Vries [19] demonstrated that silane treated specimens still had a residual protective effect even after 5 years of outdoor exposure in the Netherlands, by measuring the water absorption and chloride content. In a similar study, Schueremans et al. [20] demonstrated the protective effects of silanes after 12 years of exposure in an aggressive marine environment on a RC quay-wall in a port in Belgium by measuring their chloride content.

Work by the Transport Research Laboratory [21,22] in the UK indicated that silanes were reasonably effective in reducing chloride ingress into concrete structures based upon a review of principal inspection reports, various Managing Area Contractors, laboratory testing, and testing of cores extracted from full-scale motorway RC structures. The performance of the silanes was tested primarily by means of water absorption and sorptivity, but the age of silane at time of testing was limited to 5 years.

From all of the above it is apparent that very little is known regarding the durability of silane impregnations and their long-term residual protection (i.e. following at least 10 years of service). Very commonly their performance is assessed by measuring chloride contamination at various depths over time. However, this is only an indirect method and does not provide information on the

residual hydrophobic effect against water uptake. Extracting cores for laboratory testing from full-scale structures is neither desirable nor always feasible.

The objective of this study was to address this gap in knowledge, improve our understanding of the efficacy and long-term service life of silane impregnations by undertaking testing of full-scale RC structures. The findings will help contribute towards the development of new improved corrosion management strategies and assist in a more accurate whole life cost assessment of silane impregnations. The findings also provide additional information regarding the maintenance requirements of RC structures with an existing silane impregnation. Early results of this work have also been reported [23].

2. Methodology

This section presents the basic theory, selection strategy for the cross-beams, the properties of the concrete investigated, and the test methods applied including their selection criteria.

2.1. Capillary theory

The transport of chlorides into concrete is governed by a mixed mode of capillary absorption of water and diffusion. *Capillarity absorption* can be defined as the transport of liquids in porous and non-saturated solids due to surface tension acting in capillaries and without appreciable external pressure [2]. For short-term contact between the liquid and the porous solid surface, a non-steady-state transport mechanism exists. This resembles conditions encountered on site by atmospherically exposed full-scale RC structures. It can be measured as the increase in mass due to capillary water absorption as a function of the square root of time and it is usually termed as *rate of absorption*. It can be also expressed as the increase in volume as a function of the square root of time which, termed *sorptivity*.

Diffusion can be defined as the transfer of mass by random motion of free molecules or ions in a pore solution resulting in a net flow from regions of higher concentration to regions of lower concentration [2,24].

Concrete in contact with a salt solution will become contaminated with chlorides primarily due to capillary absorption rather than diffusion alone. Absorbed chlorides can continue to penetrate by diffusion but at a significantly lower movement rate. Thus, measuring the rate of absorption (or sorptivity) can provide useful information on the condition of silane impregnations.

The rate of water absorption can be expressed by Eq. (1) [2]. Sorptivity is the uni-axial one-dimensional capillary absorption and can be expressed by following equation [2]:

$$\text{Rate of water absorption} = \frac{W_w}{(A_c \sqrt{t})} \quad \text{kg/m}^2/\text{h}^{0.5} \quad (1)$$

$$\text{Sorptivity} = \frac{V_w}{(A_c \sqrt{t})} \quad \text{m/h}^{0.5} \quad (2)$$

where W_w (g) is the weight gained by the specimen, A_c (mm²) the surface area of the specimen in contact with the water, t (s) the time of exposure and V_w (mm³) the volume of water absorbed.

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