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Surface skin protection of concrete with silicate-based impregnations: Influence of the substrate roughness and moisture

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HIGHLIGHTS

- Silicate-based impregnations for concrete superficial protection.
- Influence of the substrate roughness and moisture on impregnation performance.
- Concrete substrate condition influences performance of silicate impregnation.
- The above mentioned influence is dependent on the property at stake.

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ABSTRACT

Silicate-based impregnations are often used to protect concrete against aggressive external actions. However, the understanding of several aspects concerning this type of impregnations is still rather limited, including the influence of the concrete substrate on their performance. This paper presents results of an experimental study about (i) the efficacy of silicate-based impregnations to protect concrete elements, and (ii) the influence of the concrete substrate's characteristics on the performance of such superficial protection. Concrete specimens with two different water/cement ratios (0.40 and 0.70) were produced and, prior to the application of the impregnation, were prepared following different procedures that created (i) three different surface roughnesses (no surface preparation, 160 bar water jet and needle scalers) and (ii) three different moisture contents (3.0%, 4.5% and 6.0%). The performance of unprotected and protected concrete specimens was assessed by means of the following procedures, indicated in EN 1504-2 standard: (i) product penetration depth; (ii) water absorption by immersion; (iii) abrasion resistance; (iv) impact resistance; and (v) bond strength. Results obtained show that the silicate-based impregnation was effective in improving the resistance to water penetration and abrasion resistance, but did not improve the resistance to impact. The surface roughness and the moisture content at the instant of the application of the surface protection proved to influence the performance of the impregnation product, however such influence was dependent on the property at stake.

1. Introduction

In the last few decades, the deterioration of reinforced concrete (RC) structures has become a major problem in most countries. This concern is attested by the increasing number of RC structures presenting premature deterioration, which is leading to a substantial growth of financial costs associated to their rehabilitation [1]. Environmental agents can produce different types of physical, chemical and mechanical damage in RC structures [2]. The causes of deterioration and the degradation mechanisms of RC structures are presently reasonably well understood and have been described in more or less detail in the technical literature (e.g. [3]).

In order to extend the durability of both new and existing concrete structures, several kinds of surface treatments can be adopted. In general, the surface treatments are classified into three groups, illustrated in Fig. 1: (i) hydrophobic impregnations that produce a water repellent surface generally with no pore filling effect; (ii) impregnations, which reduce the surface porosity by filling totally or partially the concrete pores; and (iii) coatings that produce a continuous protective layer along the concrete surface [4,5]. Some of these surface treatments can penetrate inside the concrete pores and react with the hydration products of concrete, reducing the surface porosity and increasing the superficial

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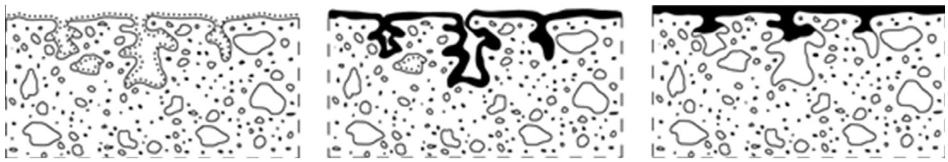

Fig. 1. Surface treatments classification: (a) hydrophobic impregnations, (b) impregnations, (c) coatings (adapted from [5]).

strength. In some cases, they have a pore lining effect or form a continuous layer at the concrete surface, thus acting as a barrier between the environmental agents and concrete, preventing and/or delaying the penetration of aggressive agents, such as moisture, chloride ions, carbon dioxide and sulphates.

Several factors must be considered when selecting a commercial surface treatment product, namely the substrate condition, the moisture content, the required durability for the protection system, requirements concerning the application process and budgetary aspects [6–8]. However, the surface treatments available for concrete protection can provide different levels of protection, even those that exhibit similar generic chemical composition [6,9,10].

In recent years, two types of surface impregnation treatments have been used more frequently in civil engineering applications: (i) silane- and siloxane-based (water repellents), and (ii) silicate-based (pore blockers, also known as "waterglass"). In the first type of impregnations, the active ingredient product produces a thin hydrophobic layer on the pores, while in the second type, the reaction product can block the pores, strengthening the concrete surface [11,12]. Although silicate-based impregnations are relatively often applied, a review of the technical literature (presented in the next section) shows that the knowledge about their performance and behaviour is still rather limited, particularly when compared with silane-based impregnations.

The present paper aims at improving the understanding about the protection of concrete substrates with silicate-based impregnations. In particular, this work aims at evaluating the influence of the concrete substrate in their performance, particularly in what concerns the type of concrete and the roughness [13] and moisture content [14] of the substrate prior to the application of the impregnation.

2. Literature review

One of the first studies addressing the performance of silicate sealers on concrete is the one by Thompson et al. [11]. The authors evaluated the performance of two different aqueous sodium silicates in protecting (i) commercial paving blocks and (ii) concrete produced in the laboratory with a water/cement (w/c) ratio of 0.48. Results obtained from water absorption, abrasion resistance and chloride penetration tests showed that the tested sodium silicate products were only moderately effective.

Ibrahim et al. [15,16] compared the performance of different types of surface treatments (sodium silicate, silicon resin solution, silane/siloxane, alkyl alkoxy silane, silane/siloxane with acrylic top coating and two-component acrylic coating) in preventing the deterioration of concrete with a w/c ratio of 0.45 due to sulphate attack, carbonation and chloride penetration. The best performance was obtained by the silane/siloxane protection with acrylic top coating, with the sodium silicate impregnation providing the less effective protection. The sodium silicate impregnation reduced the concrete's carbonation depth after five weeks by approximately 50% compared with unprotected concrete, however the same effectiveness was not obtained in reducing chloride diffusion coefficient as well as in maintaining compressive strength of concrete immersed in a sulphate solution (330 days) [16].

Dai et al. [10] evaluated the influence of surface treatments in protecting reinforced concrete structures located in humid subtropical marine environments. Two families of products were analysed: (i) four types of silane-based water repellent agents and (ii) two types of sodium silicate-based pore blockers. In this study, concrete specimens with a w/c ratio of 0.68 were exposed for 1 year to cyclic sea water shower under an outdoor environment of accelerated dry/wet cycles. The results obtained revealed that sodium silicate-based impregnations were not efficient in preventing water absorption and chloride penetration into the concrete, in contrast with the silane-based products.

Mirza et al. [17] compared the performance of several surface treatments, namely 28 silanes, 13 siloxanes, 12 cement-based sealers, 2 epoxies resins, 2 acrylic resins and 1 silicate, in protecting concrete structures with w/c ratios of 0.55 and 0.70 at low temperature. In that study, in which the surface protections were applied and cured for 14 days at a temperature of only 4 °C, the best performance was provided by silane and siloxane family impregnations; as in the preceding studies, silicates presented a poor performance in terms of water absorption and water vapour transmission capacity.

Recently, Pigino et al. [18] studied the characteristics and performance of ethyl silicate for the surface treatment of concrete with w/c ratios of 0.45 and 0.65. After the treatment, both concretes showed a significant decrease in capillary suction, chloride diffusion coefficient and carbonation depth, indicating an interesting potential of this specific type of silicate. In this study, the changes in colour and brightness presented by the concrete over time were also analysed, an aspect that may be relevant in some outdoor applications due to aesthetical reasons.

As aforementioned, only a relatively limited number of studies were performed to characterise the performance and mechanisms of action of silicate-based impregnation products in protecting concrete elements, especially focusing their potential efficacy in changing the concrete surface skin. The literature review shows that the efficacy of this kind of impregnations in protecting concrete against the ingress of water, chloride and carbonation is much lower compared to other products, namely the hydrophobic impregnations. However, other physical principles of action of those products were still not properly addressed. In addition, there are still several aspects concerning this type of concrete surface protection whose understanding is still insufficient. Among those aspects, according to the best of the authors' knowledge, the influence of the concrete substrate, namely the type of concrete, as well as the substrate condition, in terms of surface roughness and moisture content, is still not documented in the literature.

3. Materials and methods

3.1. Experimental programme

The experimental programme comprised the production of two different types of concrete specimens, with w/c ratios of 0.40 and 0.70, a part of which was protected with a commercial silicate-based impregnation product. These types of concrete comprise low and high w/c ratios, thus allowing to assess the influence of the concrete compactness on the efficacy of the impregnation.