SURFACE IMPREGNATED CONCRETE: A COMPARATIVE STUDY

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Abstract
This contribution reports the results of a comparative study on surface impregnations for concrete using three different commercial products: silane, siloxane and styren-butadien latex (SBR). On treated and untreated concrete specimens the following tests were conducted: porosity, chloride ion penetration, capillary water absorption, gas permeability, abrasion resistance, and depth of polymer impregnation.

All types of surface treatments resulted in significant improvements of most of the measured durability parameters. Amount of water soluble chloride ions in the concrete surface layer was reduced: 53 % for SBR, 63 % for siloxane, and 67 % for silane. Capillary water absorption coefficient was reduced even 34 times for silane, eight times for siloxane, while two times for SBR. Gas permeability reduction exhibited opposite trends: 30 % for SBR, and 15 % for silane and siloxane. Abrasion resistance was improved only by SBR treatment. It was concluded that the protection type should be chosen based on the concrete performance specification as well as their environmental impact (i.e. toxicity). The method of impregnating the concrete by SBR dispersion was used in repair of concrete bridge overlays and reinforced concrete structures exposed to chloride ion penetration and abrasion.

Keywords: impregnated concrete, durability, surface treatment, styren-butadien latex, silane, siloxane.

1. INTRODUCTION

The cover zone of concrete structures protects the embedded steel from aggressive actions from its surroundings [1-4]. Treatment of concrete surface by various impregnating products may result in an efficient and economical way to improve the durability of concrete structures [5-6]. Repairing concrete structures is up to ten times more expensive than preventive measures such as hydrophobic impregnation. However, it is not always correct to compare concrete repairing by a hydrophobic treatment with conventional repair (e.g. concrete replacement) because the hydrophobic treatment can be only made under certain boundary conditions (e.g. low chloride content). The life span of hydrophobic treatments is limited, too. Choosing of a right surface treatments requires knowledge on many properties of surface-treated concrete. The engineering aspects of the various surface treatments are reviewed by Basheer at al. [6]. The most widely used repellant is silane and its derivatives, e.g. silane-siloxane. According to EN 1504-2 the investigated surface protecting methods can be classified into two distinct groups: hydrophobic impregnation (e.g. silanes and siloxanes) and
impregnation (styren-butadien latex, SBR). Hydrophobic impregnation treats a concrete to obtain a water-repellent surface. It forms a semi-permeable membranes, a hydrophobic coat on the internal walls of pores and capillaries without filling them, that reflect big molecules or aggregation of ions on water molecules thus restricting the transport of liquid water, but allow the transport of water vapour. It does not form a film on the surface of the concrete so its appearance is unaltered or only slightly modified. Impregnation treats a concrete to reduce surface porosity and strengthen the surface, where the pores and capillaries are partially or completely filled. This treatment may form a thin, discontinuous film on the surface of concrete. Polymer-impregnated concrete (PIC) [1] is obtained by impregnating a hardened conventional concretes with a liquid monomer system (such as styrene and methyl methacrylate) that subsequently polymerises the monomer in situ, e.g. by heat treatment. For this applications, the slab is partially impregnated from the upper surface. The concept underlying PIC is that if voids are responsible for low strength as well as poor durability of concrete in severe environments, then eliminating them by filling with a polymer should improve the characteristics of the material. It is difficult for a liquid to penetrate porous material if the viscosity of the liquid is high and the voids in concrete are not empty (i.e. if they contain water and air). Therefore, for concrete surface treatments it is essential not only to select a low-viscosity liquid (e.g. polymer solution) for penetration but also to dry and evacuate the concrete before subjecting it to the penetration process. Upon impregnation, the resulting hardened material contains a continuous, interconnected matrix of coagulated polymer particles which fill up accessible pores in cement paste and aggregates and improve the bonding between aggregates and cement paste. As a result of this co-matrix formation, polymer impregnated cement based materials have low permeability, good freeze–thaw resistance, and a relatively higher flexural strength, which allow those materials to be advantageously employed for renovation works of damaged concrete, as well as improving the performance of a new structure. It is used for concrete buildings, concrete bridges, highway covering materials and waterproof materials [1,7].

This paper presents a comparative study on surface treatments for concretes prepared by using three commercial products: silane, siloxane and styren-butadien latex (SBR). The coagulation of a latex polymer dispersion (SBR latex) [7] that takes place by drying can be also associated to PIC category. According to American Concrete Institute recommendations [8] SBR is the preferred latex (a colloidal dispersion of polymer particles in water) for polymer modified concrete. Latex modified concrete is made by replacing part of mixing water with latex as an admixture in fresh concrete that significantly reduces the penetration of chlorides into the concrete and thus lowers the risk of rebar corrosion [7,8]. SBR latex modified concretes have been used on highway bridges in the US over the past 35 years, in Canada, Austria [9-11] and among others in Croatia [12,13] as well. In the last two decades, SBR latex-modified (PC) mortars have been widely used as repair materials for concrete and reinforced concrete structures because of their superior chemical as well as mechanical (e.g. frost attack, higher modulus of elasticity, higher tensile strength) resistance [7]. However, incorporating latex to form concrete-polymer composite with improved properties increases the expense by 3 – 5 times. Surface impregnations by SBR latex can be used to reduce this costs and still improve concrete properties. In this paper a water dispersion of SBR with 12 % solid polymer content was employed as a surface sealant in a way similar to the other more conventional sealants such as siloxanes and silanes.
2. EXPERIMENTAL

Old concrete and newly prepared concrete specimens were tested. The old concrete specimens were cylinder cores 10 cm in diameter and 5 cm in height that were drilled from a 25-year-old concrete (hydro-electric power plant’s pipeline, nominally w/c=0.55, d_{max}=32mm, cement blended with 20% pozzolans). Inner, i.e. unexposed sides were used for tests. Characteristic compressive strength of both specimens was 30 MPa. On treated and untreated concrete specimens the tests on porosity, chloride ion penetration, capillary water absorption, gas permeability, abrasion resistance, and depth of polymer impregnation were conducted. Newly prepared concrete specimens were used to test abrasion resistance only. A sequence of tests within the experimental plan on old concrete specimens was as follows. After drying at 105 °C until reaching a constant weight the specimens were weighed, then water saturated and again weighed. The open porosity was obtained from the measurements of the dry weight \( W_D \), the water saturated weight \( W_{Sat} \) and the specimen volume (by Archimedes method, \( W_{Arch} \)), according to the following equation:

\[
P_{OPEN} = \frac{W_{Sat} - W_D}{W_{Arch}}
\]

Gas permeability and capillary water absorption were measured on non-saturated specimens. Gas permeability was measured according to [14,15]. The water absorption coefficient due to capillary action of hardened mortar specimens was measured according to ASTM C1585 [16]. Broken sides of samples were immersed to a depth of 5–10 mm in water and the amount of absorbed water was determined with time (during 24 h). The sorptivity coefficient \( k \), was obtained by using the following expression [17]:

\[
A = k \sqrt{t}
\]

where \( A \) is the amount of water absorbed per cross section of specimen that was in contact with water (g m\(^{-2}\)); \( t \) is time (h), and \( k \) is the sorptivity coefficient of the specimen (g m\(^{-2}\) h\(^{-1/2}\)).

The specimens were sorted in categories according to the type of material used for impregnation and named as shown in Table 1. The specimens were dried again at 105 °C until reaching a constant weight and then impregnated by using different commercial products: silane, siloxane and styren-butadien latex (SBR). A water dispersion of SBR with 12 % solid polymer content was employed. Silane and siloxane impregnation products were applied on specimens following the recommendations of suppliers: the surface of the material is impregnated by brush-strokes until reaching the saturation, but before forming a layer of sealant on the concrete surface. Silane was used as a 40 % solution in isopropanol according to suppliers recommendations. Water dispersion of SBR was applied as 0.2 L/m\(^2\).

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Open porosity, %</th>
<th>Impregnation type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2, 3</td>
<td>14.1</td>
<td>Siloxane</td>
</tr>
<tr>
<td>4, 5, 6</td>
<td>14.3</td>
<td>SBR latex</td>
</tr>
<tr>
<td>9, 10, 11</td>
<td>14.8</td>
<td>Silane</td>
</tr>
</tbody>
</table>
The gas permeability and the capillary water absorption were measured again after the polymer solutions of the sealants have evaporated. Then, the specimens were saturated with water again, and the chloride ion penetration was tested by sealing the sides of the (cylindrical) specimens and immersing the bottom into a 5% solution of NaCl. After 3 months the concrete powder was obtained by drilling the bottom of the specimen until 2 cm depth. The powder was analysed for water soluble chlorides according to AFFREM test procedures [18].

The test of resistance of concrete specimens to grinding was performed following the Böhme procedure according to standard DIN 52108 [19,20]. The substrates used were five concrete panels with dimensions 10x10x50 cm, characteristic compressive strength 30 MPa, that were cured for 28 days at standard conditions. After 28 days the specimens were dried at laboratory conditions (<50% r.h.) and impregnated by the solutions (on the cast side). The quantity of the applied solutions for abrasion test is given in Table 2. Note that this amount corresponds to the saturation, i.e. when the specimen was not being able to absorb the impregnating liquid any more, but before forming a layer of sealant on the concrete surface. The specimens were fixed to the mounting holding it against a rotating grinding disk that provided a uniform grinding of its surface. The specimens were weighed before the test and then each time after a set of 4 cycles (one cycle consisted of 22 revolutions of the grinding disk) at 0.1 g accuracy. The prevailing deterioration process is abrasion through grinding; typically occurring in roads, walkable surfaces etc. The result of the test is the wear of concrete after 16 cycles, which is determined by the loss of volume of the specimen in cm³ in an area of 50 cm².

Table 2: The quantity of the applied solutions for abrasion test

<table>
<thead>
<tr>
<th>Impregnation type</th>
<th>L/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siloxan</td>
<td>1.65</td>
</tr>
<tr>
<td>SBR latex</td>
<td>1.05</td>
</tr>
<tr>
<td>Silane</td>
<td>3.34</td>
</tr>
</tbody>
</table>

3. RESULTS

Penetration depth of impregnation obtained by visual inspection of cross sections of (newly prepared) specimens resulted in 5-6 mm and 20-26 mm for SBR and silane treatments, respectively. The effect of protection type on the capillary water absorption is shown in Figure 1 and represents an arithmetic mean of at least three measurements. The sorption coefficient was calculated as the slope of the curves in Figure 1 from the intercept to the last reading (i.e. 24 h) and presented in Table 3. From these results it can be observed that all the specimens before the impregnation had a strong capillary water absorption with high values for sorption coefficients. After impregnations there was a significant decrease in capillary water absorption. Capillary water absorption coefficient was reduced even 34 times for silane, eight times for siloxane, while two times for SBR. Results on the effect of impregnation type on the gas permeability coefficient are shown in Table 4. Gas permeability reduction exhibited opposite trends to capillary water absorption results. There was a 30% reduction for SBR, and 15% for silane and siloxane.
Effect of impregnation type on chloride ion penetration is shown in Figure 2A. Amount of water soluble chloride ions content in the 2 cm concrete surface layer (after 3 months of immersion in 5 % NaCl) was reduced: 53 % for SBR, 63 % for siloxane, and 67 % for silane.

Table 3: Comparison of the sorption coefficient calculated from the capillary water absorption measurements after 24 h. Mean values ± standard deviation.

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Before treatment</th>
<th>After treatment</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$k_0$, g m$^{-2}$ min$^{-0.5}$</td>
<td>Impregnation type</td>
<td>$k_s$, g m$^{-2}$ min$^{-0.5}$</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>147 ± 37</td>
<td>Siloxane</td>
<td>18 ± 9</td>
</tr>
<tr>
<td>4, 5, 6</td>
<td>165 ± 24</td>
<td>SBR</td>
<td>76 ± 25</td>
</tr>
<tr>
<td>9, 10, 11</td>
<td>199 ± 40</td>
<td>Silane</td>
<td>5.8 ± 3</td>
</tr>
</tbody>
</table>

Table 4: Comparison of the gas permeability coefficient before ($\kappa_0$) and after treatment ($\kappa_s$)

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Before treatment</th>
<th>After treatment</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\kappa_0$, $10^{-16}$ m$^2$</td>
<td>Impregnation type</td>
<td>$\kappa_s$, $10^{-16}$ m$^2$</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>1.13 ± 0.69</td>
<td>Siloxane</td>
<td>0.96 ± 0.32</td>
</tr>
<tr>
<td>4, 5, 6</td>
<td>1.58 ± 0.24</td>
<td>SBR</td>
<td>1.1 ± 0.76</td>
</tr>
<tr>
<td>9, 10, 11</td>
<td>1.60 ± 1.4</td>
<td>Silane B</td>
<td>1.36 ± 1.0</td>
</tr>
</tbody>
</table>
Comparative results of the abrasion tests are shown in Figure 2B. These show that siloxane and silane treatment did not affect the abrasion wear. Only SBR treatment performs significantly (40 %) better than reference concrete. This increase in abrasion is explained by excellent abrasion resistance of rubber and a mechanical interlocking of coagulated SBR within the porous network of the concrete panel. This may be further enhanced by a chemical interaction of the surfactant located on polymer–concrete interphase. The surfactant used to disperse SBR particles could also act as a compatibilizer between organic (SBR) and inorganic (concrete) phase. Indeed, the use of latex-modified concrete and mortars as bonding agents for mortars to existing concrete substrates is a widespread practice [3,7]. Concrete pavements for roads have several advantages over bitumen pavements, such as long life, user and environmental friendliness, lower maintenance costs. The abrasion may lead to reduced concrete pavement life and thus increased pavement life cycle costs. Polymer -concrete composite provides better resistance to wear [7] that would reduce the life-cycle cost of bridge deck components. Skid resistance of concrete was not impaired was assured by

Summary comparison of impregnation types on concrete properties is given in Table 5. The drawback of silane products for application as concrete surface impregnations is their requirement for easily evaporable, but toxic solvents (in this paper a 40 % solution in isopropanol). For this reason, EU and USA environment protection legislations limit their application and give preference to surface treatment products that are based on water-based polymer dispersions (such as SBR latex and siloxane). Nowadays, solvent-free, aqueous and environmentally compatible silanes are also available on the market, however, this type was not investigated in this paper.
Table 5: Comparison summary of impregnation types on concrete properties.

Table legend: + good; ++ very good; 0 no effect; (% of change relative to non-treated concrete).

<table>
<thead>
<tr>
<th>Impregnation type</th>
<th>Water absorption</th>
<th>Gas permeability</th>
<th>Chloride ion penetration</th>
<th>Abrasion wear</th>
<th>Eco-Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siloxane</td>
<td>++ (200)</td>
<td>+ (15)</td>
<td>+ (63)</td>
<td>0</td>
<td>low</td>
</tr>
<tr>
<td>SBR latex</td>
<td>+ (800)</td>
<td>++ (30)</td>
<td>+ (53)</td>
<td>++ (43)</td>
<td>low</td>
</tr>
<tr>
<td>Silane <em>(with solvent)</em></td>
<td>++ (3400)</td>
<td>+ (15)</td>
<td>++ (67)</td>
<td>0</td>
<td>high'</td>
</tr>
</tbody>
</table>

The method of impregnating the concrete by SBR dispersion was used in repair of concrete bridge overlays and reinforced concrete structures exposed to chloride ion penetration and abrasion [12,13]. If compared to the “classical” solutions of pavement renewal by application of asphalt and waterproofing layers, the method employing high-performance composite for one-layer reinforced concrete bridge pavement structure reconstruction has following advantages [13]:
- 4 times faster renewal of the bridge;
- classic waterproofing system replaced by one-layer water-resistant concrete pavement with higher resistance to wear, freezing and de-icing salts;
- strengthening by maintaining the same mass of the bridge (asphalt dead load replaced by thickened reinforced concrete)
- the execution of widening the bridge by cantilever extension on old bridges is simple.

For this application SBR impregnation should not form a film on the surface of the concrete so that skid resistance is unaltered or only slightly modified.

4. CONCLUSIONS

All types of the investigated surface treatments resulted in significant improvements of most of the measured durability parameters. Capillary water absorption coefficient was reduced even 34 times for silane, eight times for siloxane, while two times for SBR. Gas permeability reduction exhibited opposite trends to capillary water absorption results. There was a 30 % reduction for SBR, and 15 % for silane and siloxane. Amount of water soluble chloride ions in the concrete surface layer was reduced: 53 % for SBR, 63 % for siloxane, and 67 % for silane. Abrasion resistance was improved only by SBR treatment (43 %). This increase in abrasion may be explained by a mechanical interlocking of coagulated SBR within the porous network of the concrete panel. Silane treatment exhibited significantly higher penetration depth. However, the drawback of silane products is their requirement for easily evaporable, but toxic solvents.

In conclusion, the concrete surface treatment type should be chosen based on the concrete performance specification as well as their environmental impact (i.e. toxicity). The method of impregnating the concrete by SBR dispersion could be advantageously used in repair of concrete bridge overlays and reinforced concrete structures exposed to chloride ion penetration and abrasion. Surface impregnations by SBR latex could be used to reduce materials costs for polymer-modified concrete composites while still significantly improving concrete properties.
ACKNOWLEDGEMENTS

Experimental results provided by prof. dr. sc. Velimir Ukrainczyk.

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