SURFACE PROTECTION OF CONCRETE. INFLUENCE OF THE SUBTRACT PREPARATION IN THE PERFORMANCE OF IMPREGNATION PRODUCTS

Beatriz Simões Guerreiro Monteiro Lopes

ABSTRACT: The durability of concrete structural members can be defined as the ability of such elements to maintain a minimum performance during a certain period of time under the influence of aggressive agents. Reinforced concrete structures have a good durability; however, the interaction with natural agents causes their degradation which may lead to a reduction of structural, aesthetic and functional performances. This work focuses on the surface protection of concrete structures, more specifically, making use of impregnation products. The research aimed at investigating in further depth the applicability and performance of impregnation products for concrete protection, in accordance with EN 1504 standard - particular attention was given to the effect of surface preparation on the performance of those products. Two types of concrete were produced with water/cement (w/c) ratios of 0,40 and 0,70, and their surface was prepared with water jet and a needle scaler in order to obtain different surfaces roughnesses. Three types of surface protection products (silicates, water based resin and solvent based resin) were applied and their performance in protecting the different types of concrete with the different surface roughnesses was evaluated regarding the following aspects: capillary absorption, abrasion resistance, impact resistance, adhesion of the product to the substrate (pull-off test) and depth of product penetration into the substrate. Results obtained in this study show that the application of the impregnation products improved the performance of concrete in terms of capillary water absorption and abrasion resistance. For the remaining tests (impact resistance and pull-off test), the application of the impregnation products did not introduce significant changes when compared to the concrete without treatment –this result may stem from the fact that the penetration of the products was very limited. On the other hand, it was also possible to conclude that the roughness of the substrate influences the behavior of impregnation products, but differently according to the parameter under study. As expected, the concrete with the lowest w/c ratio presented a superior performance for all parameters studied.

KEY-WORDS: Concrete; Impregnation Products; Durability; Substrate roughness.
1. INTRODUCTION

The protection of concrete structures against aggressive agents is one of the possible intervention strategies for both new and existing constructions in order to prevent the appearance of defects, which then lead to the degradation of concrete structures. However, the protection of reinforced concrete structures is a very wide field, as presently there are many types of systems commercially available. For this purpose, EN 1504 standard "Products and Systems for Protection and Repair of Concrete Structures" [1] was recently published and provides procedures and requirements for such type of intervention.

In what concerns surface protection of concrete, one of the possibilities is the use of impregnating products, also known as pore blockers, which basically can have two main origins: either they are compounds based on silicates (sodium silicate or fluorosilicates), of which the most commonly used is sodium silicate; or they are based in synthetic resins (epoxy or acrylic), which harden by chemical reaction inside the pores and capillaries, creating a blocking effect. The literature review shows that only a few investigations have been conducted about impregnating products (silicates or resins), making it difficult to reliably establish their performance in terms of both mechanical and durability properties.

Nair et al. studied the performance of acrylic (PMMA) impregnation in mortar [2]. Results of this study can be extrapolated, with a certain degree of approximation, to the performance of such product in concrete protection. In this investigation the parameters under study were resistance to bending and compression, ultrasound velocity and several durability properties, including water absorption, resistance to hydrochloric acid, exposure to marine environments and freeze / thaw cycles. The results of all tests showed improvements by comparison with samples without surface treatment, so the concrete tests should lead to similar effects, especially the durability tests, resistance to aggressive agents and the development of defects.

Thompson et al. [3] also conducted a study focusing on the characterization of the performance of silicates acting as sealants in the concrete. Two types of samples, blocks of concrete commercial pavement and concrete produced in the laboratory, were protected with the application of sodium silicate products with different concentrations. The test programme included water absorption, abrasion resistance and chloride permeability tests, as well as the characterization of surface morphology of treated and untreated samples. Regarding water absorption, this study allowed concluding that the treated samples have an absorption rate lower than the untreated samples. On the other hand, in what concerns the silicate concentration, results showed that the higher the concentration, the lower the absorption. In terms of abrasion resistance, it was observed that the coefficient of abrasion is lower in treated samples when compared with non-treated samples. The permeability to chloride ions test showed that the application of the products improves this feature for the different concretes and concentrations of silicates. Finally, through the observation of the surface of the specimens, the authors concluded that treated specimens have a smooth and soft surface, while untreated samples have a rough surface [3].
The present work aims at contributing to a deeper understanding on the protection of concrete surfaces by impregnating products, used in order to improve the durability of concrete structures and extend their service life. The main goals of this work consisted of assessing the performance of surface protection products and studying the influence of the substrate in their performance, particularly, the effect of the type of concrete and the roughness of the support in the performance of those products. In order to study the performance of these products, an experimental program was carried out, in which two types of concrete were produced with different water/cement (w/c) ratios (MC0,40 and C0,70), and their surface was mechanically prepared in order to obtain different surfaces roughnesses - the surface modification processes chosen were water jet with 160 bar and needle scaler. Then, three types of surface protection products of different natures were selected for further evaluation of their performance, namely silicates and two different types of epoxy resins. These products were applied in the two types of concrete with different surface roughnesses. According to EN 1504-2, the following parameters were accessed: capillary absorption [4], abrasion resistance [5], impact resistance [6], adhesion of the product to the substrate (pull-off test) [7] and depth of product penetration into the substrate [1]. The main goal of the present study was to assess the performance of the different products, when exposed to different actions, and to evaluate the influence of the treatment of the substrate on their performance.

2. EXPERIMENTAL PROGRAM

2.1. MATERIALS

Concrete slabs with 30 x 30 x 4 cm were produced with two different water/cement (w/c) ratios: concrete type B1, with a w/c ratio of 0.40, and concrete type B2, with a w/c ratio of 0.70. The slabs were then cut with a diamond blade in different dimensions according to the test to be performed (cf. section 2.5)

The following three impregnation products were used in the experimental program: (i) a solvent based epoxy (P1); (ii) a water based epoxy (P2); and (iii) a surface hardener additive (P3). According to the manufacturers technical specifications, product P1 is an epoxy impregnation, which is a colorless product based on epoxy resins and a Mannich hardener containing solvents. Product P2 is a ligand based liquid epoxy resin and a solvent free and water based hardener. Product P3 is a surface hardener additive for concrete and mortar that penetrates by impregnation and acts according to the two following modes of action: (i) strengthening of the crystal structure, by formation of mineral compounds with high hardness, after the reaction with the basic elements of the free support; and (ii) increased sealing, by penetration of a polymer resin in the pores of the support.

In order to consistently and reliably assess the performance of concrete as well as the effect of the impregnating products during the experimental program, it was important to stabilize the moisture content of the specimens before applying the impregnation products. Therefore, a moisture content of about 5% was set for all samples prior to the application of the impregnation products.

The quantities of products applied to the specimens were in agreement with the manufacturers specifications and are listed in Table 1.
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<table>
<thead>
<tr>
<th>P1</th>
<th>P2</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 to 250 cc/m²</td>
<td>approx. 250 gr/m²</td>
<td>5 to 10 l/m²</td>
</tr>
</tbody>
</table>

Table 1 – Quantities of products applied to the surface of the specimens.

2.2. SURFACE TREATMENTS

The surface of the concrete specimens was treated with different mechanical processes with the purpose of studying the effect of the concrete roughness on the performance of the different impregnation products. The following three roughness conditions were defined (Figure 1): (i) concrete surface without any treatment, i.e., regular roughness - R0; (ii) concrete surface subjected to a surface treatment using a water jet with 160 bar - R1; and (iii) concrete surface subjected to a surface treatment, using a needle scaler - R2.

![Figure 1 – Surface treatment with water jet (left) and needle scaler (right).](image)

2.3. CHARACTERIZATION OF CONCRETE AND IMPREGNATION PRODUCTS

Concrete was tested at the age of 28 days in order to determine its compressive strength (according to EN 12390-3 [8]) and splitting tensile strength (EN 12390-6 [8]). Tests were performed on cubic (150 mm) and cylindrical (150 x 300 mm) specimens, respectively.

The impregnation products were characterized in terms of density (ISO 2811-1 [9]), volatile matter content (EN ISO 3251 [10]) and molecular identification by means of Fourier transform infrared spectrophotometry (FTIR). This technique consists in using a device that uses a beam of energy containing the entire infrared spectrum to identify the constituents of the products. The beam is split into two, half in a mirror moving at high speed by modifying the optical path of the beam, while the other half is reflected in a fixed mirror. Subsequently, the beams are recombined, with the aim of creating constructive and destructive interference, from which one obtains a spectrum of interference. Finally, the Fourier transform is applied to the variation of the interference spectrum in time, obtaining the final absorbance spectrum as a function of the wave number [11].

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2.4. CHARACTERIZATION OF SURFACE ROUGHNESS
The surface roughness was evaluated using the two alternative techniques: (i) surface texture determination, according to the profile method defined in ISO 4287 [12]; and (ii) roughness index determination, according to the technique defined in EN 1766 [13]. To accomplish the first test a technique based in plasticine casts was used and the surface was impressed in the plasticine to be studied according to the ISO 4287 [11].

2.5. TESTS FOR THE ASSESSMENT OF THE PERFORMANCE OF THE PRODUCTS

2.5.1. CAPILLARY ABSORPTION TEST
The test to evaluate the water permeability of the three impregnation products was conducted according to the EN 1062-3 standard [4]. The specimens used had the following geometry: 7 cm long, 5 cm wide and 4 cm thick. The test consisted in the immersion of the samples in water. The procedure began with weighing the samples and placing them in a recipient, containing water up to 1 cm above the top surface of the specimen. The temperature of the water was in the range (23 ± 2) °C, according to the standard. The samples were removed from the water and the surface was dried with absorbent paper and the samples were weighed after 1h, 2h, 3h, 6h, 24h, 30h, 48h and then every 2 days until attaining saturation.

Using the values of the weights measured it was possible to plot the curve of the speed of transmission of liquid water per square root of time (h). The transmission of water was calculated by the increase of the mass (in kg) divided by the area the sample surface (in m²).

2.5.2. ABRASION RESISTANCE TEST
In order to evaluate and compare the abrasion resistance of concrete with and without application of surface protection products, this test was conducted using the Taber abrader, according to EN ISO 5470-1 standard [5]. The dimensions of the specimens used in this test were as follows: 11 cm wide, 11 cm long and 1 cm high. The corners of the specimens were cropped to allow their placement on the Taber abrader. Then, according to EN 1504-2 standard [1], H22 abrasive wheels were used and a load of 1000 g was attached to the device. According to the standard referred, 1000 cycles should be executed for each specimen, but after concluding 100 cycles, it was observed that the product had completely disappeared in most specimens. Thus, it was decided to perform only 300 cycles, since the remaining 700 cycles would correspond to values of abrasion resistance of the concrete, with no interest for the study, which focused on the performance of the impregnation products.

The test consisted in the initial weighing of the specimens to the nearest 0.001 g and in the execution of 100 cycles in the Taber abrader, followed by reweighing. This process was repeated three times totaling 300 cycles. Finally, the calculations were made to obtain the percentage of mass loss during the cycles in order to analyze and compare different types of specimens. According to EN 1504-2 standard [1], the mass loss by abrasion of concrete should improve approximately 30% due to the application of the impregnation product.
2.5.3. IMPACT RESISTANCE TEST

In order to evaluate the impact resistance before and after the application of the products under study, the test presented in EN ISO 6272-1 standard [6] was performed. In this case, the number and dimensions of the specimens are not specified in the standard, so three trials for each specimen were performed and the following specimen dimensions were chosen: 10 cm long, 7 cm wide and 4 cm high. According to the standard [6] a device was used to drop a mass and the corresponding primary and secondary masses, for a total of 1973.36 g, with a sphere of 20 mm in diameter. The test was performed with a load corresponding to class 2 (10 Nm) according to EN 1504-2 [1], because tests for classes 1 and 3 were ran and the latter class (class 3) caused the fracture of the concrete samples. Thus, the height of fall of the mass was determined using equation 1.

\[ U = m \times g \times h \]  

(1)

where,

- \( U \) – potential energy (Nm);
- \( m \) – mass;
- \( g \) – gravity;
- \( h \) – altitude;

For a mass of 1973.36 g, the drop height of the masses (primary and secondary) should be 51.7 cm. Finally, after the fall of the masses was completed, the impact sites were examined, making use of a magnifying glass and the diameters of the cavities were measured with a metallic scale. Thus, it was possible to quantitatively analyze and compare the behavior of concrete with and without surface protection product.

2.5.4. MEASUREMENT OF BOND STRENGTH BY PULL-OFF

The pull-off test consisted in assessing the strength of the adhesion between the substrate and the protective layer applied and was performed according to EN 1542 standard [7]. The dimensions of the specimens and the number of discs used for the quantification of this parameter are presented in Table 2.

<table>
<thead>
<tr>
<th></th>
<th>29 cm (R1 e R2) e 14,5 cm (R0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td></td>
</tr>
<tr>
<td>Width</td>
<td>14,5 cm</td>
</tr>
<tr>
<td>Height</td>
<td>4 cm</td>
</tr>
</tbody>
</table>

**Table 2 – Dimensions of pull-off samples.**
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The test began with the execution of drills on the concrete surface with a depth of 10 mm and a diameter of 50 mm, using a core drilling machine. Then the metallic discs with 50 mm of diameter were glued in the surface of the core, which was then attached to the pull-off equipment. Finally, the tensile test was performed and consisted in connecting the disc to the pull-off equipment with a screw. Then the handle of the equipment was rolled applying an increasing tensile force until failure, i.e. the debonding of the disc and the surface. Finally, the tensile force required to separate the disc was registered, the type of failure was classified according to EN 1542 standard [7] and the following equation was used to compute the bond strength:

$$\sigma = \frac{F_{\text{max}}}{A_{\text{disc}}}$$  \hspace{1cm} (2)

where,

- $\sigma$ – stress;
- $F_{\text{max}}$ – maximum normal load;
- $A_{\text{disc}}$ – metallic dolly surface area.

2.5.5. PRODUCT PENETRATION TEST

This test was carried out according to EN1504-2 standard [1], since there is no specific standard for this purpose. To determine the depth of penetration of the product in concrete the EN 1504 standard [1] suggests the use of cubes of 100 mm edge, and the measurement of the depth of penetration by breaking the cubes and spraying the fracture surface with water. In this study, the specimens for the pull-off test were used instead. Thus, to perform the penetration test, it was necessary to create a fracture (the sample is split into two parts) in the concrete substrate in the surface where the impregnation product was applied. Next, the fractured surface was sprayed with water, similarly to the depth of carbonation test which uses phenolphthalein. Finally, the depth of penetration of the product corresponded to the dry zone of the fractured surface and it was measured using a crack comparator. According to the 1504-2 standard [1], the depth of penetration of the product should be higher than 5 mm.
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3. RESULTS AND DISCUSSION

3.1. CHARACTERIZATION OF CONCRETE AND IMPREGNATION PRODUCTS

The results of compressive and tensile strength test, for both type of concrete, are presented in Table 3.

<table>
<thead>
<tr>
<th>Product ID</th>
<th>Compressive Strength [MPa]</th>
<th>Tensile Strength [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>B1</td>
<td>56,25</td>
<td>1,31</td>
</tr>
<tr>
<td>B2</td>
<td>33,08</td>
<td>1,59</td>
</tr>
</tbody>
</table>

Table 3 – Compressive and tensile strength test.

The test results of compressive and tensile strength are superior to the concrete with lower a w/c ratio, presented in Table 3. These results were expected, since the cement is the component that gives mechanical strength to the concrete, and the presence of water leads to the emergence of voids by evaporation, leading to a lower mechanical resistance.

The results of the tests to determine the density, the non-volatile content and the infrared absorption spectrum are presented in the Table 4.

<table>
<thead>
<tr>
<th>Product ID</th>
<th>Components</th>
<th>Density (g/ml)</th>
<th>Non-Volatile Matter Content (%)</th>
<th>Molecular Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>A</td>
<td>1,07</td>
<td>62,42</td>
<td>Aromatic amine</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>A</td>
<td>1,01</td>
<td>51,99</td>
<td>Epoxy polymer (bisphenol A and epichlorohydrin)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td>A</td>
<td>1,07</td>
<td>35,04</td>
<td>Acrylic polymer and silicates</td>
</tr>
</tbody>
</table>

Table 4 – Results of density, non volatile matter content and molecular identification.

The results in Table 4 were expected for the three tests.

3.2. CHARACTERIZATION OF SURFACE ROUGHNESS

The results of the tests to determine the surface roughness are summarized in Table 5.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Plasticine Casts</th>
<th>Sand Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>B1.R0</td>
<td>0,014</td>
<td>0,003</td>
</tr>
<tr>
<td>B1.R1</td>
<td>0,020</td>
<td>0,008</td>
</tr>
<tr>
<td>B1.R2</td>
<td>0,022</td>
<td>0,003</td>
</tr>
<tr>
<td>B2.R0</td>
<td>0,017</td>
<td>0,006</td>
</tr>
<tr>
<td>B2.R1</td>
<td>0,024</td>
<td>0,013</td>
</tr>
<tr>
<td>B2.R2</td>
<td>0,027</td>
<td>0,005</td>
</tr>
</tbody>
</table>

Table 5 – Results of the two methods of assessing surface roughness.

The concrete with higher roughness index is the concrete type B2, since it has a higher w/c ratio, so it has a higher porosity due to the number of voids that occur after the evaporation of the water during
the hardening of the concrete. On the other hand, the roughness is more pronounced in roughness type R2, obtained using the needle scaler, when compared to R0 (reference concrete) and R1 (water jet). This result can be explained due to the power of the needle scaler that is superior to the water jet. Therefore, the surface treated with this method has a more pronounced roughness. The two methods of assessing surface roughness follow the same trend, with some differences caused by the nature of the tests.

3.3. PERFORMANCE OF IMPREGNATION PRODUCTS

3.3.1. CAPILLARY ABSORPTION TEST
The water transmissibility measured in the two types of concrete, with different surface roughnesses and impregnation products is illustrated in Figures 2 to 7.
The product that revealed the most ineffective performance in protecting the concrete against the ingress of water was product P3, as confirmed in all the graphics. The slope of the curves of product P3 is higher when compared to the other products and not too different when compared to untreated specimens. This conclusion can be explained by the fact that the product P3 is a silicate-based product, i.e., it reacts with the surface of the concrete by creating crystals in the concrete pores. On the other hand, both the product P1 and the product P2 form a film on the concrete surface, and have more favorable features for the protection against the ingress of water when applied on the concrete surface, so the behavior of both is very similar. The best performance of product P1 can be explained by its better ability to create a waterproof film – it is worth reminding that unlike product P2, which is a water based product and probably is more affected by the presence of water, product P1 is a solvent based product.

The results illustrated in the graphics above also show that the speed of transmission of liquid water decreases with the increase of the roughness, when compared with samples which did not have any type of product. This test also showed that concrete B1 (MC0, 40) had the best performance – such results could be expected a priori, owing to the lower w/c ratio of such composition, and thus its lower porosity.

3.3.2. ABRASION RESISTANCE TEST

Figure 8 and 9 show the results obtained in the abrasion resistance test for specimens of types B1 and B2, respectively, after being subject to 300 cycles in the Taber abrader. As already mentioned, after 300 cycles the product layer had completely disappeared.
The results demonstrate that products P1 and P2 had the best performance, with product P2 having a slightly better performance, and that product P3 presents by far the worst performance. This result can be explained by the nature of the products, i.e., product P1 is a solvent-based epoxy resin and product P2 is a water-based epoxy resin. Both products operate on the concrete surface forming a film layer, which explains the superior results when compared to product P3, since the surface layer is more efficient in the protection against abrasion. The product P3 is a mono-component product, based on acrylic and silicates and acts in the concrete surface by forming crystals in its pores. Thus, it does not form a film on the concrete surface, so there is a larger area without protection when compared with products P1 and P2. It is also important to highlight that product P3, unlike products P1 and P2, did not confer an improvement of 30% of mass loss, as required by the standard [5].

For the three roughnesses studied, the analysis of results obtained allows concluding that the roughness R0 presents better results for all products, followed by roughness R1 and, finally, by roughness R2 (R0>R1>R2). These results are due to the presence of concrete slurry laitance at the surface of R0 roughness specimens - in the cases of P1 and P2 products, such presence led to the formation of a film with greater continuity and thickness, when compared with the surfaces with greater roughness (R1 and R2).

It is also noteworthy that the values obtained for the B2 concrete samples are lower than those obtained for B1 samples due to their different composition, namely the different w/c ratios. Results obtained are in agreement with those differences - concrete type B1 has a w/c ratio lower than that of concrete type B2, so the former is less porous and presents higher mechanical resistance, by comparison with concrete type B2.

3.3.3. IMPACT RESISTANCE TEST
The impact resistance test results for the B1 and B2 concrete types are shown in figures 10 and 11, respectively.
In what regards impact resistance, no significant improvements were achieved by comparing the diameter of the impact zone for the samples with and without treatment. In the case of samples without any product (SP), those who resisted better to the impact were the R0 type (no surface treatment), since they still have the slurry laitance of the concrete, and therefore are more resistant to shock. For roughnesses R1 and R2 (with surface preparation), the difference is not statistically significant, although the average diameter of the impact zones of specimens with roughness R1 is higher than that of specimens with roughness R2. On the other hand, concerning the effect of the surface protection products (P1, P2 e P3), in the first case (P1), no significant differences between the various types of roughness were observed, which leads to the conclusion that product P1 does not give a performance improvement in the impact resistance. The second and third products (P2 and P3), in general, slightly decreased the diameter of impact when compared to P1 and SP specimens, so it can be concluded that both products have improved, albeit very slightly, the impact resistance for surfaces with roughnesses R1 and R2.

Finally, comparing the two types of concrete, the concrete with the higher w/c ratio (B2) showed a lower performance, as demonstrated by the size of the diameter of the impact zone of the sphere, i.e. the diameter of the impact zones of concrete B2 in average were 2 mm higher when compared to those of concrete B1.

3.3.4. MEASUREMENT OF BOND STRENGTH BY PULL-OFF
Figures 12 and 13 present the results of bond strength measurements, comparing the results of the different types of products and surface roughnesses for concrete types B1 and B2, respectively. Results plotted in those figures correspond only to “valid” failure modes – specimens in which bonding problems were encountered were excluded from the analysis, in particular in the calculation of the average and standard deviation of bond strength.
The values of bond strength tests showed that the adhesion between the different products and the concrete substrate with untreated surface (R0) is weaker, since the values of the stress are lower than those of samples which have no product. The roughness that showed a superior performance in the adhesion between the substrate and the product was roughness R1 (water jet). For this roughness the values of tensile strength are higher for all products, when compared with specimens without product applied. The roughness that results from the treatment with needle scaler (R2) shows a slightly higher performance, when compared with the results of specimens without product applied, but presents lower performance than that corresponding to roughness R1.

In what concerns the comparison of the different products, the product with best performance, i.e., the product that bonded better to the support for all types of roughnesses, was product P1 (solvent-based resin), followed by product P2 (water-based resin) and, finally, by product P3 (silicate-based product).

Finally, the performance of the two types of concrete (B1 and B2) was different – pull-off strength was higher for specimens of concrete type B1, compared to specimens of concrete type B2. Such result stems from the fact that concrete type B1 has a lower w/c ratio, which provides a higher mechanical strength and compactness.

3.3.5. PRODUCT PENETRATION TEST

The penetration test was performed according to the suggestion of EN 1504-2 standard [1]. The visual analysis of the samples sprayed with water showed that the products P1 and P2 did not penetrate the substrate, forming only a surface film, for both types of concrete (B1 and B2) and for the three types of roughness (R0, R1 and R2). For product P3, although it did not form a film, the penetration in the concrete was not measurable, for the three types of roughnesses.

According to the EN 1504-2 standard [1] product penetration should have been higher than 5 mm. The standard suggests that the products should be applied as suggested by the manufacturer, which was the case in the present study. The inability to achieve the penetration required by the standard is related to the characteristics of the products studied: two of them (P1 and P2) form a film on the concrete surface,
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not penetrating deep enough, and the third (P3) probably has a viscosity that prevents a higher penetration and/or the amount of product applied (although fulfilling the manufacturers recommendations) was not enough.

4. CONCLUSIONS

Based on the results obtained in the experimental investigations, concerning the performance of different types of surface impregnation products and the effects of different surface preparation techniques, the following main conclusions are drawn:

1. For the capillary absorption of water, it can be concluded that for higher roughnesses the speed of transmission of liquid water is lower in comparison with specimens in which impregnation products were not applied. On the other hand, the products with the best performance are the resins (P1 and P2), while the worst performance was obtained with the silicate-based product (P3). Finally, it is important to note that the concrete type B1 (w/c ration of 0.40) presented better results regarding the speed of transmission of liquid water, when compared with the concrete type B2 (w/c ratio of 0.70), as expected.

2. Regarding the abrasion resistance test, the resins (P1 and P2) showed the best performance, while the silicate-based product (P3) revealed a much lower performance. For the different roughnesses, it appears that the roughness R0 leads to a superior performance for all products.

3. In terms of impact resistance, it was concluded that the application of the impregnation products studied does not change significantly the performance of concrete.

4. For the test of adhesion between the substrate and the impregnation product, the roughnesses that provided better results for both types of concrete (B1 and B2) were R1 and R2. In addition, the products with better performance were the resins (P1 and P2).

5. The product penetration depth of all products tested did not meet the requirement defined in EN 1504-2 standard [1] (5 mm penetration). This result seems to be due to the nature of the three products: products P1 and P2 being resins form a film on the concrete surface, not penetrating any deeper, while silicate-based product P3 has a viscosity that prevents its penetration or the amount of product applied was not enough to be detected in depth.

6. Regarding the influence of the substrate on the performance of the products, two important conclusions were obtained. Firstly, there is some influence of the roughness in the performance of the products, but such influence acts differently, depending on the performance parameter under study. In the case of capillary absorption of water, the more pronounced roughness (R2) allowed for a more effective performance of the products, while in the case of abrasion it was roughness R0 that provided the best results. Therefore, it is not possible to draw general conclusions about the most effective type of roughness. Secondly, the two types of concrete B1 and B2 showed different results, with the best overall performance corresponding to the
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Concrete type B1. This composition, having a lower w/c ratio (0.40), presents higher strength and compactness, leading to superior performance in all tests.

7. Finally, regarding the three types of products studied, the performance of the resins (P1 and P2) was better for all parameters studied, except for tests where the application of the products did not introduce significant differences: resistance to impact and penetration depth of the product.

5. REFERENCES


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