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Systems for superficial protection of concretes

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ABSTRACT

Nowadays, it is consensual that the biggest degradation of concrete happens from outside to inside actions, due to the penetration of moisture, active gases and aggressive ions, by mechanical, physical and chemical causes that frequently act together. A low porosity, permeability and concrete penetration to moisture and gases are the first lines of defence against several deterioration mechanisms. The durability of concrete depends largely on how hard or easy fluids (water, carbon dioxide, oxygen) in liquid or gas form can migrate through the concrete hardened mass. When selecting the paint coating for concrete protection, importance is given to the properties of diffusion and permeability resistance, besides the properties of durability and chemical resistance. The paint coatings must stop the penetration of water and delay the influence of aggressive agents (CO_2, SO_2, Cl^- ions), allowing the structure to breathe by a water vapour diffusion mechanism. Through tests of capillarity absorption, immersion absorption, porosity, water and oxygen permeability, a comparison was made between painted and non painted concrete specimens. Three different coating types were tested: silicon varnish; acrylic and epoxy paints. The results showed that, in general, all coatings reduce the porosity and the permeability. The epoxy paints proved to be the best ones.

1. INTRODUCTION

Concrete can be a highly durable construction material as long as care and quality control are enforced at all stages of the design, production and construction processes. However, experience has demonstrated that its potential long-term durability is not always achieved, leading to early failure of reinforced concrete structures (Rodrigues, 2000). It should be recognized that concrete is intrinsically a porous material, despite the improvements on its formulation and quality control to the best possible extent, it is not possible to prevent completely the ingress of potentially harmful agents into it. Micro-cracks and macro-pores will always exist on the concrete surface, providing a path for the transportation of aggressive ions into the interior of concrete (Swamy, 1998).

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It is now accepted that the durability of the reinforced concrete depends mainly on the composition and properties of the concrete surface layer (Kreijger, 1984). This layer, sometimes with a thickness close to the cover of the reinforcement, is most of the times the only responsible for the corrosion protection of the reinforcement. Surface treatments act as a barrier between the environment and the concrete. They prevent or retard the entry of harmful substances such as water, chlorides, etc. (Pfeifer, 1981). Surface coatings with appropriate "barrier" characteristics can cut off the transportation path into concrete. The standard EN 1504-2, establishes as a minimum requirement for the coated concrete ingress that the water permeability coefficient should not exceed 0.1 $kgm^{-2}h^{-0.5}$ and the CO_2 permeability should exceed 50 m.

Swamy and Tanikawa (1990) evaluated the effect of concrete coatings to preserve concrete durability and concluded that the application of an impervious surface coating to concrete is a very attractive solution to protect new and existing concrete structures.

Water is the most critical agent because it lies on the root of many important degradation processes: it is related to freeze-thaw durability, it provides the transport path for chloride ions and establishes electrolytic continuity inside concrete. Besides, in order that the carbonation reaction can take place, the presence of a certain amount of water is required (Duval, 1992).

This work intends to contribute to a better understanding of this issue, by presenting data of water and gas permeability of several coatings used to protect concrete. The effect of organic coatings on water and chloride transport in reinforced concrete was studied by Fluckiger *et al* (1990). They concluded that the concrete coatings strongly reduced the water and chloride uptake in concrete.

Concrete coatings have the unique advantage that they can be applied to protect either the existing or the new structures. However, with a wide range of coatings available in the market, it becomes extremely difficult to choose the right type of coating, since coatings of similar generic types are known to possess considerably different diffusion characteristics (Hawkins, 1985).

The performance of the available generic types under varying service conditions needs to be studied. There is also a need to develop performance criteria for evaluation of concrete coatings guidelines for the selection of coatings appropriate for various exposure conditions (Almusallam, 2002).

2. EXPERIMENTAL PROGRAM

2.1. Materials

To evaluate the influence of cement, two types of cement were used: Portland Type I 42.5R and Type IV/A (V) 32.5R. Crushed granite with a density of 2566 kg/m^3, water absorption of 2.1% and a maximum size of 9.53 mm was used as a coarse aggregate, while crushed sand with a density of 2477 kg/m^3 and water absorption of 1.36 % was used as a fine aggregate in the preparation of concrete specimens.

Concrete coatings were selected to represent the following three generic types:

i. Silicone varnish (S);
ii. Acrylic coatings (A);
iii. Epoxy resin coatings (E).

Each generic type was represented by two coatings from different manufacturers. Table 1 shows the properties of the selected concrete coatings. All coatings were applied on the substrate by brush following the recommendations of the manufacturers and after a good drying of the specimen.

2.2. Preparation of specimens

Cylinder concrete specimens 110 mm in diameter and 230 mm in eight (ø110 x 230) were cast to evaluate the absorption by capillarity of the selected concrete coatings. Cubic concrete specimens 100x100x100 mm^3 were cast to evaluate the absorption by immersion of the selected concrete coatings. Disk concrete specimens 50 mm in diameter and 40 mm in thickness (ø50 x 40) were cast to evaluate the permeability to oxygen, the permeability to water and the porosity of the selected concrete coatings.

The concrete specimens were proportioned for an effective water-to-cementitious materials ratio of 0.60 and a cement content of 320 kg/m^3.

Table 1 – Description of the selected coating

Coating type	Generic type	Coverage rate m^2/dm^3	Specific weight Kg/dm^3
Silicone, SA	Siloxane resin-based water repellent	2.8	0.83
Silicone, SB	Siloxane resin-based water repellent	4.0	0.80
Acrylic, AA	Water-based acrylic resin	3.5	1.40
Acrylic, AB	Water-based acrylic resin	5.0	1.30
Epoxy, EA	Two-component epoxy resin	2.2	1.30
Epoxy, EB	Two-component epoxy resin	4.0	1.60

2.3. Test procedures for evaluation of concrete coatings

The selected concrete coatings were applied to concrete. The coverage rate is shown in Table 1. The purpose of the tests performed in laboratory was the evaluation of the "barrier" properties of the coatings against water and gases, by determining their absorption by capillarity and immersion, porosity and permeability to water and oxygen.

2.3.1. Absorption by capillarity

The selected concrete coatings were applied on one face of the cylindrical concrete specimens measuring ø110 x 230 after drying. A rapid set epoxy resin coating with 20 mm was painted in the curved surfaces of the concrete specimens to ensure the absorption by capillarity. One week later, the specimens were then placed in a tank with 5±1mm height of water and weighted in time intervals outlined in LNEC E393 (1993), which is based on the RILEM CPC11.2 (1974) draft recommendation. Dividing the increase of mass by the area in contact with the water, we can obtain the absorption of water by capillarity, in each interval.

$$Kc_M = \frac{(M_i - M_0)}{A} \tag{1}$$

Kc_M – absorption of water by capillarity (g/mm^2);
M_i – specimen mass in time t_i (g);
M_0 – specimen initial mass (g);
A – specimen inferior surface area (mm^2).

2.3.2. Absorption by immersion

After painting all the faces of the concrete specimens measuring 100x100x100 mm^3 with the selected concrete coatings, they were placed in a tank filled with water in a room with a controlled environment. Before the beginning of the test at least one week should pass to ensure a good cure of the coatings. When the specimens mass becomes stable, following the procedure outlined in LNEC E394 (1993), they were weighted. Then the specimens were placed in an oven at a temperature of 105±5 ºC, until the mass becomes constant, after that they were weighted again. The absorption of water by immersion at atmospheric pressure was calculated using the following equation:

$$Ai_M = \frac{m_1 - m_3}{m_1 - m_2} \times 100 \tag{2}$$

Ai_M – absorption of water by immersion (%);
m_1 – saturated specimen mass (g);
m_2 – specimen hydrostatic mass after saturation (g);
m_3 – dry specimen mass (g).

2.3.3. Porosity

After painting all the faces of the concrete cylindrical specimens ø50x40 with the selected concrete coatings, they were placed in an excicator, respecting the cure time. After keeping the specimens in vacuum state during 3 hours, the specimens were immersed in distilled water and kept in vacuum state for another 3 hours, following LNEC E395 (1993).

The porosity was calculated using the following equation:

$$P_{AM} = \frac{m_1 - m_2}{m_1 - m_3} \times 100 \tag{3}$$

P_{AM} – porosity (%);
m_1 – specimen saturated mass (g);
m_2 – specimen dry mass (g);
m_3 – specimen immerse mass (g).

2.3.4. Permeability to oxygen

After porosity test, the cylindrical specimens ø50x40 were subjected to permeability to oxygen test using the apparatus developed at Leeds University (Cabrera, 1999). This device (Figure 1) ensures that the specimen is subjected to a steady state flow of the fluid that passes through the sample under a given pressure during a certain period of time. The specimens were inserted under pressure in a rubber ring and then inside the test cell, which was closed with a torque wrench. Then all the valves were closed and the oxygen-holder was open. The test pressure was selected in a way that time of the soap-bubble route for a distance of 10 cm would be greater than 45 seconds after 30 minutes of test. The permeability to oxygen was calculated using the following equation:

$$K_{GM} = \frac{4{,}04 \times v \times L \times 10^{-16}}{A \times (P_1^2 - 1)} \tag{4}$$

K_{GM} – permeability to oxygen (1E-16 m^2);
v – determinated flow, pipette reading (cm^3/s);
A – cross-sectional area of the specimen (m^2);
L – specimen height (m);
P_1 – test pressure (bar).

Figure 1 – Permeability device

2.3.5. Permeability to water

The same specimens used in the porosity test were afterwards subjected to oxygen permeability and then to water permeability test. The apparatus developed at Leeds University were also used. The test procedure is similar to the described oxygen permeability test except that after the closing of the test cell, an alcohol, water and fenolftalein solution was introduced in the valve of the cell. Then, all the valves were closed and the oxygen-holder was open. The test pressure was selected and after 3 hours the test was finished. The specimen was then broken in half and the penetration of the solution was measured. The permeability to water was calculated using the following equation:

$$K_{WM} = \frac{d_p^2 \times \delta}{2 \times h \times t} \times 1.3 \times 10^{-7} \quad (5)$$

K_{WM} – permeability to water (1E-16m^2);
d_p – penetration depth (m);
δ – specimen porosity;
t – time to reach d_p depth (s);
h – height of water (H_2Om); 1 bar = 10.207 H_2Om.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Water absorption by capillarity

In Figure 2 one can observe the obtained capillary water absorption tests results. This figure shows that the use of the selected coatings decreases the absorption by capillarity, specially the silicone varnish and the epoxy resin. In the case of the silicone varnish the results were surprisingly good, reducing the absorption in 99.2% to the uncoated conventional cement specimens and 99.6% to the uncoated specimens with Type IV cement, which had the worst result of all, due to a bigger porosity. The two products seem to be very similar and to have the same behaviour.

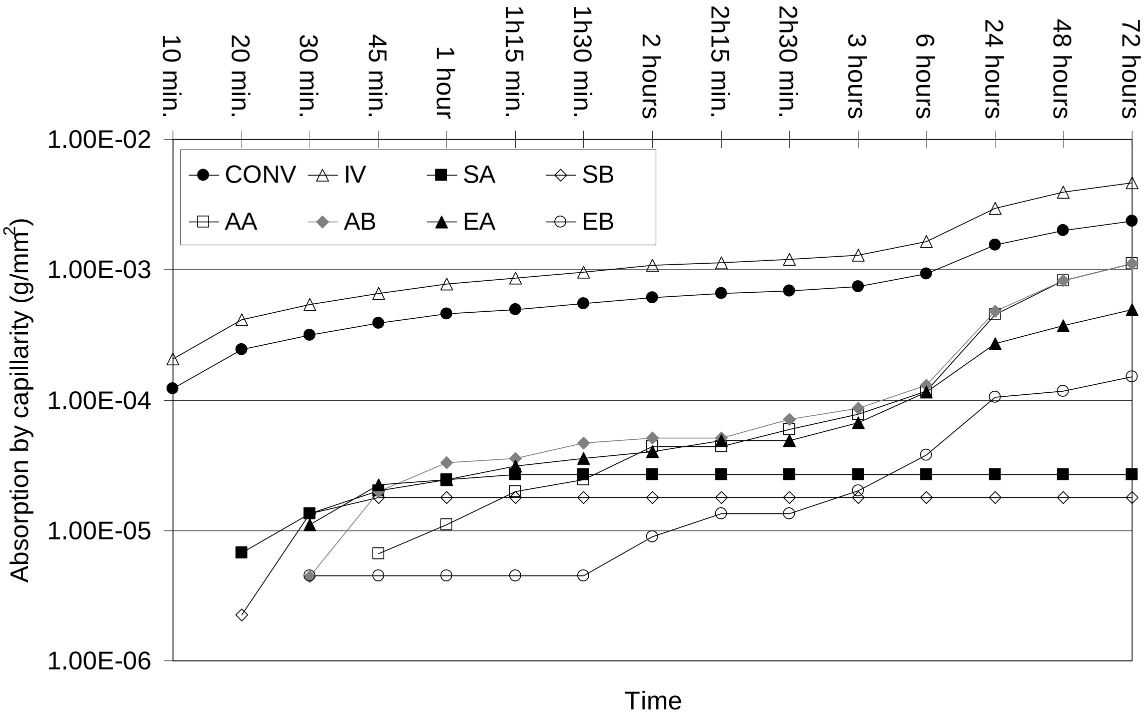

Figure 2 – Water absorption by capillarity in the coated and uncoated specimens

Concerning the acrylic paints, they had the worst performance of all the selected coatings. They had a good start, absorbing even less than the silicone varnish in the first 30 minutes, but then they never stop to increase. Nevertheless, the best product reduced the absorption in 53.0% to the uncoated conventional cement specimens and 76.0% to the uncoated Type IV cement specimens. The two products seem to be very similar, having product B a bigger absorption in the first two hours.

The epoxy paints had the best results next to the silicones varnishes, although the two products had the same behaviour. In the 24 hour interval measures, the two products had the same behaviour, but with less intensity than before and always with bigger absorption of the product A. The use of the best epoxy paint allowed a reduction in the absorption by capillarity of 93.6% to the uncoated conventional cement specimens and 96.7% to the uncoated Type IV cement specimens.

3.2. Water absorption by immersion

Figure 3 shows that the use of the selected coatings diminishes the absorption by immersion, specially the epoxy resins. The best epoxy resin reduced the absorption of water by immersion in 80.3% to the uncoated conventional cement specimens and 80.1% to the uncoated Type IV cement. Product B proved to be better than product A.

The acrylic resins had a similar behaviour, with a slight advantage of product B, reducing the absorption by immersion in 29.7% to the uncoated conventional cement specimens and in 28.9% to the uncoated Type IV cement specimens.

The varnishes of silicone didn't improve significantly the specimen's behaviour. The best product only reduces 6.8%, showing that this coating isn't appropriate to protect concrete against this type of water absorption.

Between the uncoated specimens with conventional cement and Type IV cement, one couldn't see significant differences, showing that the Type IV cement is not an improved choice to reduce the water absorption by immersion in concrete.

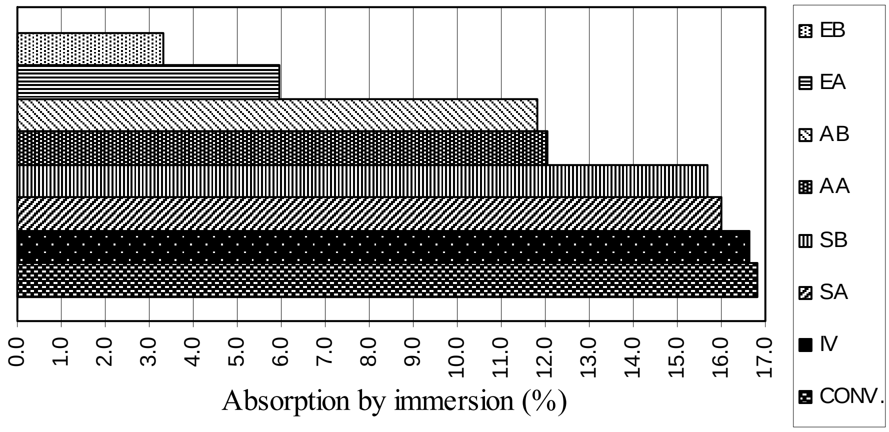

Figure 3 – Water absorption by capillarity in the coated and uncoated specimens

3.3. Porosity

By observing Figure 4, we can conclude that the use of the selected coatings decreases the porosity, specially the epoxy resins. The specimens painted with the best epoxy resin (product B) had 96.6% less porosity than the uncoated specimens with conventional cement and 96.8% less than the uncoated specimens with Type IV cement.

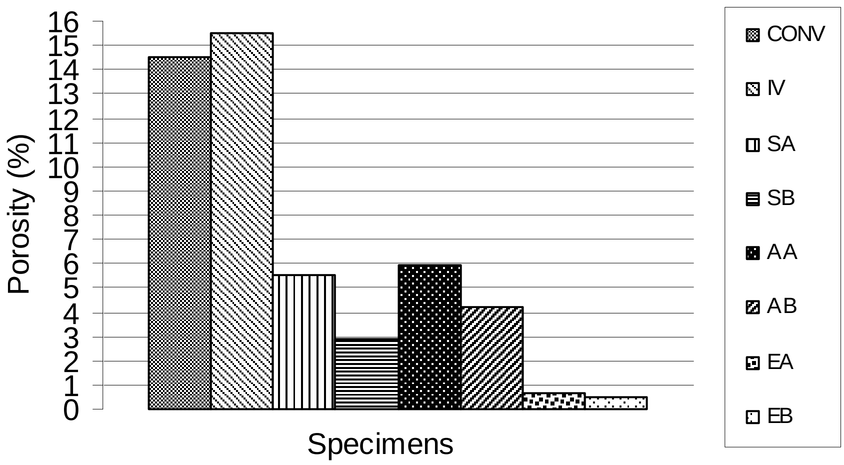

Figure 4 – Porosity in the coated and uncoated specimens

The acrylic resins and the silicone varnishes had a very similar performance. The silicone varnish B behaved even better than the two acrylic resins and the silicone varnish A was better than the acrylic resin A, which was a surprise. This excellent behaviour of the silicone varnishes can be explained by its hydrophobic impregnation responsible by the pores and capillaries internal coating.

The acrylic resin B allowed a reduction of the porosity in 71.1% to the uncoated specimens with conventional cement and 73.1% to the uncoated specimens with Type IV cement.

The specimens coated with varnish silicone B had less 80.0% porosity then the uncoated specimens with conventional cement and less 81.4% than the uncoated specimens with Type IV cement. The uncoated specimens with Type IV cement had 6.8% more porosity than the uncoated specimens with conventional cement, although they had the same cement content and the same water-to-cementitious materials ratio and addictions.

3.4. Oxygen permeability

From Figure 5 we can conclude that the use of the selected coatings decreases the permeability to the oxygen, specially the epoxy and acrylic resins.

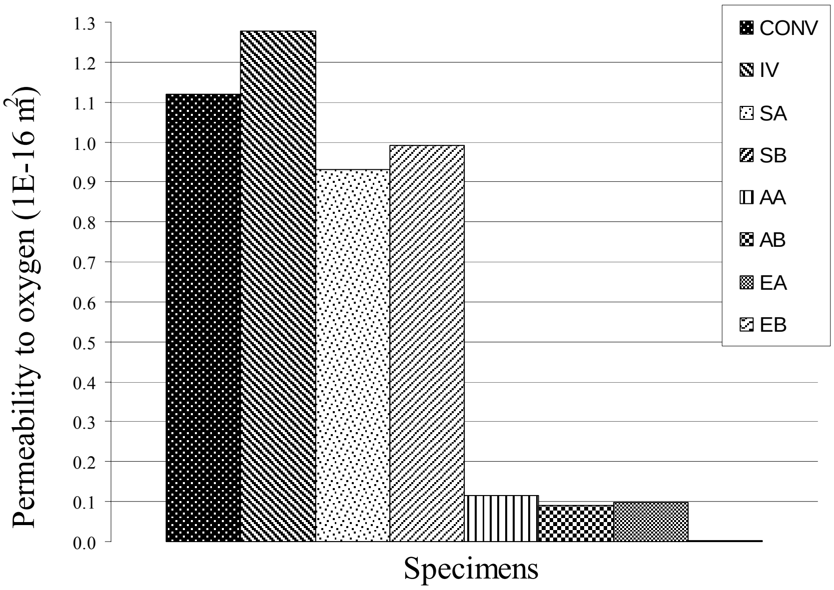

Figure 5 – Oxygen permeability in the coated and uncoated specimens

In the epoxy resins product B had by far the best performance, reducing the permeability to oxygen in 99.7% to the uncoated specimens with conventional cement and 99.8% to the uncoated specimens with Type IV cement. Surprisingly product A had a bigger permeability than the one of the acrylic resins. In the test were used pressures of 9.5 bar for product B and 6.3 to 9.3 bar for product A, using pipettes with 2,9 mm of diameter, due to the low permeability of these products, specially of product B.

The acrylic resins had the best results next to the epoxy resins, in the case of the acrylic resin B the behaviour was even better than the epoxy resin A. Product B allows a reduction of the permeability in 91.2% to the uncoated specimens with conventional cement and 92.2% to the uncoated specimens with Type IV cement. In the test were used pressures of 5.8 to 6.8 bar for product B and 5.7 to 7.1 bar for product A using pipettes with 2.9 mm and 4.8 mm of diameter. The reduction in the diameter was made to allow the measuring of the soap-bubble with more precision and speed.

The varnishes of silicone had the worst behaviour, the best product (A) was only able to reduce the permeability in 17.0% to the uncoated specimens with conventional cement and 27.2% to the uncoated with Type IV cement, which indicates that this product is not the most indicated to decrease the permeability of concrete to oxygen.

The uncoated specimens with Type IV cement had a permeability 12.3% bigger than the uncoated specimens with conventional cement, due to its bigger porosity, despite having the same cement content, the same water-to-cementitious materials ratio and addictions.

3.5. Water permeability

Figure 6 show that the use of the selected coatings decreases the permeability to water, specially the epoxy and acrylic resins.

Product B of epoxy resins proved to be completely impermeable to the penetration of water. Product A had a very good performance reducing the permeability to water in 99.5% to the uncoated specimens with conventional cement and 99.7% to the uncoated specimens with Type IV cement. In the test were used pressures of 5.5 to 5.8 bar in product B and 5.3 to 5.6 bar in product A.

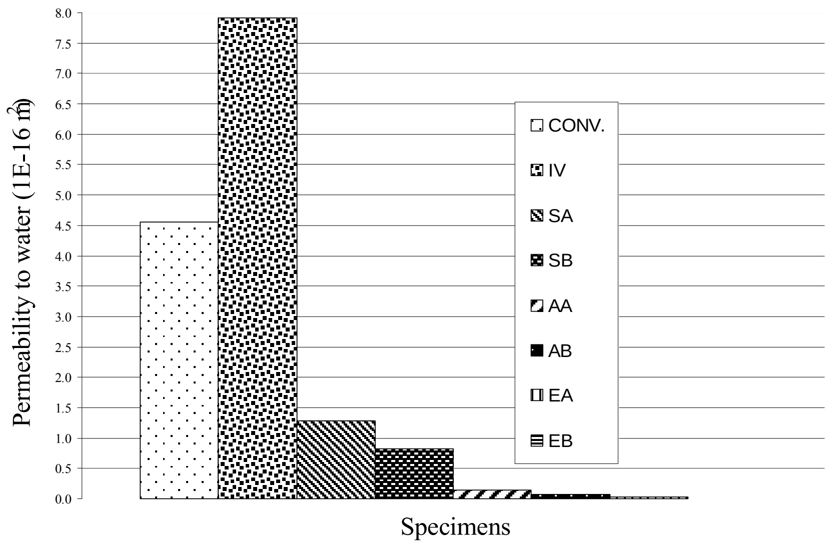

Figure 6 – Water permeability in the coated and uncoated specimens

The acrylic resins had the best performance next to the epoxy resins reducing, in the case of product B, the permeability in 98.5% to the uncoated specimens with conventional cement and 99.2% to the uncoated specimens with Type IV cement. In the test were used pressures of 5.2 to 5.98 bar in product B and 4.6 to 5.4 bar in product A.

The varnishes of silicone had the worst results reducing (for product B) the permeability in 81.9% to the uncoated specimens with conventional cement and 89.5% to the uncoated specimens with Type IV cement, which indicates that this material is still effective protecting the concrete from water.

The uncoated specimens with Type IV cement had a permeability 42.4% bigger than the uncoated specimens with conventional cement, due to its bigger porosity, despite having the same cement content, the same water-to-cementitious materials ratio and addictions.

4. PERFORMANCE RANKING OF CONCRETE COATINGS

The performance of the selected concrete coatings under the test regimes evaluated in this research work is summarized in Table 2. First, it was given a degree of importance to each test, based on the element tested, gas or water. Since the water is the main agent of degradation in concrete, (Li, 2000) a bigger weight (1.5) was given to the tests that study the behaviour of this element in concrete: absorption by immersion, capillarity and permeability to water. A lower weight (1.0) was given to the other tests. Afterwards it was attributed a classification for every test and for each selected coating based on their performance.

Based on the results obtained in this study the overall ranking of the performance of the selected coatings in the descending order of importance is as shown below:

EB → EA → AB → SB → AA ,SA → CONV → IV

The results obtained in this study have also indicated that there is a variation in the performance of coatings of similar generic types. That was shown with silicone varnishes and with the acrylic resins. It is, therefore, recommended that whenever a coating is selected for use in aggressive environments, it should be tested under conditions similar to those it will be exposed to during its service life.

Table 2 – Performance ranking of selected coatings

Specimen	Absorption by capillarity	Absorption by immersion	Porosity	Permeability to oxygen	Permeability to water	**Total**
CONV	1X1.5	2X1.5	2X1.0	2X1.0	2X1.5	**11.5**
IV	2X1.5	1X1.5	1X1.0	1X1.0	1X1.5	**8.0**
SA	3X1.5	7X1.5	4X1.0	4X1.0	3X1.5	**27.5**
SB	4X1.5	8X1.5	6X1.0	3X1.0	4X1.5	**33**
AA	5X1.5	3X1.5	3X1.0	5X1.0	5X1.5	**27.5**
AB	6X1.5	4X1.5	5X1.0	7X1.0	6X1.5	**36**
EA	7X1.5	5X1.5	7X.10	6X1.0	7X1.5	**41.5**
EB	8X1.5	6X1.5	8X1.0	8X1.0	8X1.5	**49**

5. CONCLUSIONS

The selected coatings proved to be effective protecting the concrete against the action of water and gas (oxygen). The silicone varnishes exhibited the lowest absorption by capillarity, followed by epoxy and acrylic resins. The acrylic resins were not effective in protecting the concrete against absorption of water by capillarity and should not be used in situations where this is the basic requirement. The ability of the epoxy resins to prevent the absorption by immersion was better than that of acrylic resins and silicone varnishes. The silicone varnishes were not effective reducing the absorption of water by immersion.

The epoxy resins were highly effective in reducing the porosity of concrete, which was almost negligible. The epoxy resins were followed by the silicone varnish and the acrylic resin B. The silicone varnish and the acrylic resin A were the most porous of the selected coatings. Nevertheless, they reduced significantly the porosity of concrete.

The permeability to oxygen of the epoxy resin B was negligible. It was followed by the acrylic resin from the same fabricant and the epoxy and acrylic resins A, all with identical permeability. Both silicone varnishes were ineffective in controlling the permeability of concrete to oxygen and should not be used in situations where this is the basic requirement.

The permeability to water of the epoxy resins was negligible, especially product B which was impermeable. They were followed by the acrylic resin B whose permeability to water was also negligible and by the acrylic resin A with a very low permeability. Both silicone varnishes were less effective in controlling the permeability of concrete to water, despite controlling very well the permeability of the concrete to water.

As an overall evaluation, the performance of epoxy resins was much better than that of other concrete coatings studied in this research work. The acrylic resin A followed by the silicone varnish A proved to be very similar quality products, although with a much smaller performance than the epoxy resins.

The acrylic resin and the silicone varnish B had the worst results of the selected coatings with the same place in the ranking. This means that the quality of the acrylic resin A seems to be inadequate and the quality of the silicone A is much worst than the one of product B.

From the ranking we can conclude that the economic comparison between some products should be done. For example, between the acrylic A and the silicone varnish A with the same ranking and between the acrylic B and the silicone varnish B with a very close ranking.

The results obtained in this study indicate that the performance of coatings varies with the exposure conditions. While the performance of a certain coating is better under certain exposure conditions, it does not perform better than others in another environment. Therefore, the selection of the coatings should be case specific.

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Contents

Preface

The use of polymers and concrete can be considered a good combination. In some cases polymers are the best solution to increase some specific property of concrete and to guarantee a secure and durable repair of this material. The use of small quantities of polymers enhances the durability of concrete. This aspect is especially relevant to the development of the world and to contribute to the sustainability of construction materials.

Polymers in Concrete cover a vast field of knowledge and technology so it was decided to limit the scope of the Conference and to on a few aspects such as innovations in concrete polymer composites (CPC), the applications of FRP for reinforcements and CPC as coatings. Also considered were topics that covered: testing methods, industrial applications, ecological aspects, durability of repair works, repair of repair, polymer based industrial floor systems, research and case studies. It is hoped that the papers included in the Proceedings will in some way contribute to objectives of this Symposium.

All the papers included in the Proceedings have been reviewed by two specialists of the field of the paper concerned. I am very much grateful to all members of the International Scientific Committee who gave much of their time and effort in reviewing the papers. In some cases external experts were also included in the peer review of papers and I want to express my thanks to all of them. I would also to acknowledge the support given by all the sponsors of the Symposium. Organization of an International Symposium requires support from many people. I thank all those who have helped us, but my particular thanks go to Daniel Pinheiro, Lídia Gonçalves and Daniela Silva whose enthusiasm and help was a key element in the success of the Symposium. I would also like to than all the authors for their relevant contributions. Important contribution was also received from the students of the Civil Engineering Course.

If the work and ideas expressed in these papers have contributed in some way to further development of polymers in concrete, and consequently to sustainable construction, then our efforts have not been in vain.

José Barroso de Aguiar
Guimarães, April 2006

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RILEM – International Union of Laboratories and Experts in Construction Materials, Systems and Structures

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