

## Performance of Concrete in Aggressive Environment

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**Abstract:** Surface treatments act as a barrier between the environment and the concrete, preventing or retarding the entry of harmful substances and cutting off the transportation path into concrete. The effectiveness of a surface protection preventing the permeation depends on how close and strongly connected are the resin molecules. This work intends to contribute to a better understanding of the performance of protected concrete in chemically aggressive environments, by presenting results of ion diffusion and resistance to aggressive solutions of several hydrophobic agents and coatings used to protect concrete. Three different types of surface protections were tested: silicone hydrophobic agent, acrylic and epoxy coatings. The obtained results indicate that the overall performance of epoxy resin was better than the other selected types of protections.

**Keywords:** silicone hydrophobic agent, acrylic coating, epoxy coating, protected concrete, chemical attack.

### 1. Introduction

Reinforced concrete structures can be highly durable 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 and early failure of reinforced concrete structures may even occur.<sup>1</sup> 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. 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.<sup>2</sup>

It is now accepted that the durability of reinforced concrete depends essentially on the composition and properties of the concrete surface layer.<sup>3</sup> This layer, sometimes with a thickness closer to the cover of the reinforcement, is most of the times the only responsible for the corrosion protection of the steel 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.<sup>4</sup> Surface coatings with appropriate "barrier" characteristics can cut off the transportation path into concrete. The European standard EN 1504-2,<sup>5</sup> establishes as a minimum requirement for the coated concrete ingress that the capillary absorption and the water permeability coefficient should not

exceed  $0.1 \text{ kg/m}^2 \text{ h}^{0.5}$  and the  $\text{CO}_2$  permeability should at least correspond to a  $S_D$  value of 50 m.

Swamy and Tanikawa<sup>6</sup> 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. However, with a wide range of coatings available in the market, it becomes extremely difficult to choose the right type of hydrophobic agent or coating, since similar generic types are known to possess considerably different diffusion characteristics.<sup>7</sup>

The performance of the available generic types under different service conditions needs to be studied. There is also a need to develop performance criteria for evaluation of concrete protection materials and guidelines for the selection of hydrophobic agents and coatings suitable for various exposure conditions.<sup>8</sup>

### 2. Experimental method

#### 2.1 Materials

To evaluate the influence of cement, two types were used: portland type I 42.5R and type IV/A (V) 32.5R made with 35% of fly ash. Crushed granite with a density of  $2,566 \text{ kg/m}^3$ , water absorption of 2.1%, fineness modulus of 5.89 and a maximum size of 9.53 mm was used as coarse aggregate, while crushed sand with a density of  $2,477 \text{ kg/m}^3$ , water absorption of 1.36 %, fineness modulus of 3.16 and a maximum size of 4.76 mm was used as fine aggregate in the preparation of concrete specimens.

Three types of concretes were used. The concretes I-A and IV made with the two types of cement, with a water-cement ratio of 0.60 and a cement content of  $320 \text{ kg/m}^3$ ; the concrete I-B made with portland cement type I 42.5R, water-cement ratio of 0.40 and a cement content of  $500 \text{ kg/m}^3$ . The slump test achieved values of about 60 mm for concretes I-A and IV. The concrete I-B presented a slump of 180 mm. The average compressive strength of concrete I-A attained 27.5 MPa at 28 days of age, the concrete I-B

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55.6 MPa and the concrete IV 20.8 MPa. The experimental program was designed in order to test uncoated and coated specimens.

Concrete coatings were selected to represent the commercially available and most used generic types:

- i. Silicone agents (S);
- ii. Acrylic coatings (A);
- iii. Epoxy coatings (E).

This study started with each generic type represented by two products from different producers. The selection was made as presented in a previous paper.<sup>9</sup> Table 1 shows the properties of the selected concrete coatings. All coatings were applied on the concrete substrate by brush following the recommendations of the suppliers and after a good drying of the specimen.

### 2.2 Penetration of chlorides

The characterization of the resistance to chlorides penetration was made by tests based on a non-steady state procedure known as CTH Rapid Method developed by Luping.<sup>10</sup> After the production of the concretes, cylinders with Ø110 × 230 mm were moulded. These cylinders were cuted in order to obtain smaller cylinders with Ø110 × 50 mm, to be used as specimens for the tests. The paintings were only applied in one face of the cylinders. The instructions of the supplier of the paintings were followed during all the process. The tests occurred 7 days after paintings were applied on concrete specimens. Fig. 1 shows one test in development.

After the time needed for the conclusion of the test, the specimens were removed from the equipment and broken in two halves by splitting-tensile strength test. The solution of silver nitrate was then applied on the concrete surface and the colorimetric test was made in order to measure the depth of chlorides penetration (Fig. 2). Five specimens of each product and composition were tested.

### 2.3 Sulphate attack

The tests were made following an ASTM standard<sup>11</sup> with some adaptations. The procedure of the tests consists on cycles of immersion in the prepared solution of sodium sulphate for not less



Fig. 1 Test of penetration of chlorides.

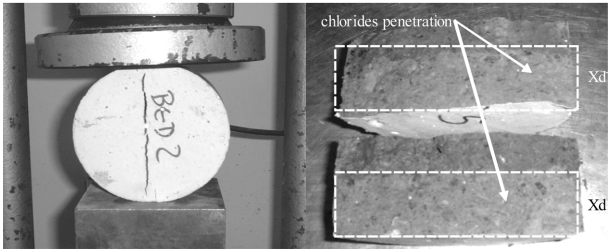


Fig. 2 Colorimetric test of one specimen.

than 16 h nor more than 18 h. After, the specimens were removed from the solution, permitted to drain for 15 ± 5 min, and placed in the drying oven. According the mentioned standard the temperature of the oven shall have been brought previously to 110 ± 5°C. The test of specimens with hydrophobic agents and coatings did not recommend the use of a temperature such high. So, the temperature of the oven in our tests was changed to the maximum of 50 ± 5°C. The specimens were dried at this temperature until constant weight. After, the specimens were immersed again in the prepared solution of sodium sulphate.

After the production of the concretes, cubes with 100 × 100 × 100 mm<sup>3</sup> were moulded. The hydrophobic agent or the coatings were applied when the concrete had 28 days. Before applying coatings the concrete specimens stayed 7 days outside water, in order to guarantee that the surfaces were not in wet conditions. The instructions of the supplier of the hydrophobic agents and coatings were followed during all the process. The tests occurred 7 days after products were applied on concrete specimens. A total of eight cycles was made. Analyze of sulphates attack was made by the weight variation along the cycles. Each value presented is the average of the weight variation of five specimens.

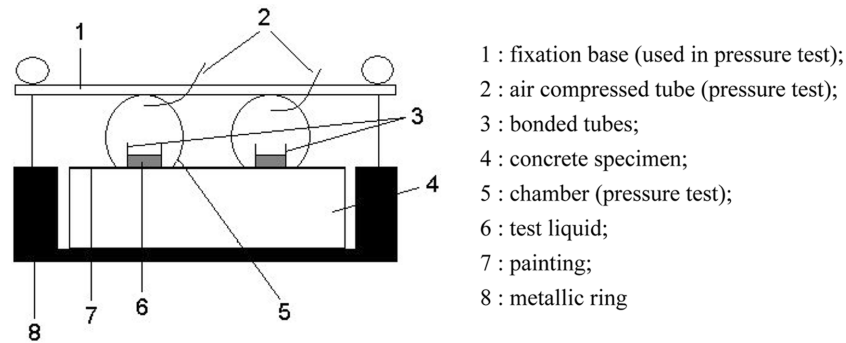
### 2.4 Acids and bases attack

The resistance of paintings to severe chemical attack was measured by exposition of one face to the test liquid following an European standard.<sup>12</sup> The specimens used on the test had the dimensions of 750 × 400 × 50 mm<sup>3</sup> made as mentioned in another European standard.<sup>13</sup> The paintings were applied when the concrete had 28 days. Before applying coatings the concrete specimens stay 7 days outside water, in order to guarantee that the surfaces were not in wet conditions. The instructions of the supplier of the paintings were followed during all the process. The tests occurred 7 days after paintings were applied on concrete specimens.

The schema of the test consisted on putting eight PVC tubes Ø110 × 30 mm, on the specimen surface, when concrete was still fresh (Fig. 3). Inside the tubes the solutions to be tested (acids and bases) were putted above the coated concretes, till a height of 10 mm. Two concretes were tested, I-A and I-B, in order to verify how paintings can perform on different concretes and analyze the performance of the concretes themselves. The test liquids used

Table 1 Description of the selected coating.

Coating type	Generic type	Coverage rate (m <sup>2</sup> /dm <sup>3</sup> )	Density at 20 °C (kg/dm <sup>3</sup> )
Silicone	Siloxane resin in solvent base	2.8	0.83
Acrylic	Aqueous based acrylic resin	3.5	1.40
Epoxy	Two-component epoxy resin	4.0	1.30



**Fig. 3** Schema of acids and bases attack test.

were the following:  $H_2SO_4$  (pH: -0.19) and  $NH_4OH$  (pH: 11.87), with a concentration of 20% by volume. During the test the tubes were covered by a plastic film, in order to avoid the evaporation of the test liquids.

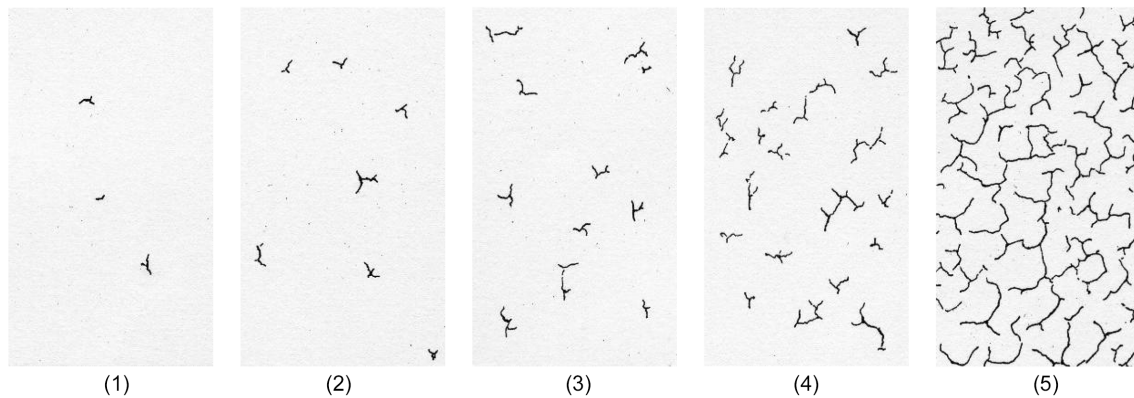
The duration of the test was 28 days in accordance with [Reference 5]. Once a week the degradation of the specimens was analyzed comparing with non tested specimens and, if necessary the level of the test liquid was reposed. The results of blistering, cracking, flaking and chalking will be presented following ISO

standards<sup>14-17</sup> that give methods for evaluation the degrees of degradation of coatings (Fig. 4). At the end of the exposition to the test liquids, adhesion tests were made following an ASTM standard<sup>18</sup> by pull-off method.

### 3. Experimental results

#### 3.1 Penetration of chlorides

Table 2 and Fig. 5 present the results of penetration of chlorides



**Fig. 4** Photos to assessment the degree of cracking, no preferential direction (1, 2, 3, 4 and 5).

**Table 2** Diffusion coefficients for different types of paintings and concretes.

References	C (kg/m <sup>3</sup> )	A/C	D × 10 <sup>-12</sup> (m <sup>2</sup> /s)
I-A	320	0.60	14.40
IV	320	0.60	9.87
I-B	500	0.40	6.90
SIL I-A	320	0.60	4.68
SIL I-B	500	0.40	2.04
ACR I-A	320	0.60	6.53
ACR I-B	500	0.40	3.86
EP I-A	320	0.60	0.00
EP I-B	500	0.40	0.00

where:

I-A: concrete with CEM I 42.5 R;

IV: concrete with CEM IV 32.5 R;

I-B: concrete with CEM I 42.5 R;

SIL I-A: concrete with CEM I 42.5 R, painted with silicone varnish;

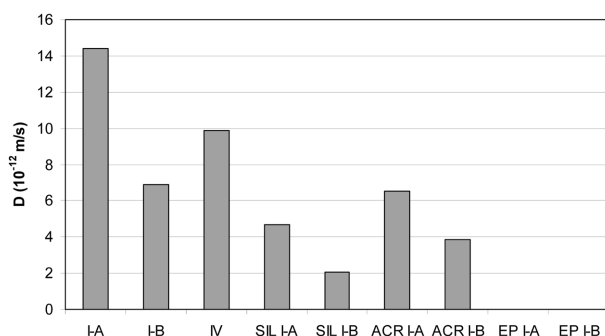
SIL I-B: concrete with CEM I 42.5R, painted with silicone varnish;

ACR I-A: concrete with CEM I 42.5 R, painted with acrylic resin;

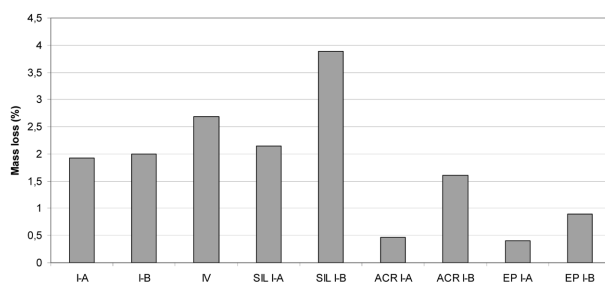
ACR I-B: concrete with CEM I 42.5 R, painted with acrylic resin;

EP I-A: concrete with CEM I 42.5 R, painted with epoxy resin;

EP I-B: concrete with CEM I 42.5 R, painted with epoxy resin.



**Fig. 5** Coefficients of diffusion in a non-steady regime for different concretes and different paintings.



**Fig. 6** Mass losses for different concretes and different paintings.

in a non-steady regime. As it can be observed the use of paintings decreases the penetration of chlorides. In the case of the epoxy resin the diffusion coefficient was null, revealing the inadequacy of this test, but demonstrating the high resistance to chloride penetration of this type of coating. For concretes with similar composition, the penetration of chlorides depends on the porosity of the surface. Higher is the porosity less will be the current that pass through the concrete surface. The porosity depends on the solids volume, on the thickness and type of the painting used. Epoxy resins with a solvent base have shown good resistance to chlorides penetration because they become strong and with low porosity.<sup>19</sup>

The concrete hydrophobic agent and coatings decreases significantly the diffusion coefficient of the tested concretes. All unprotected concretes presented higher diffusion coefficients than the protected concretes. The concrete I-B, with high cement content and a low water-cement ratio, presented without any protection a good resistance to chlorides penetration. The concrete ACR I-A presented only a diffusion coefficient 5.4% lower than the concrete I-B, with a comparable performance.

The silicone agent presented the best performance after the

epoxy resin. The silicone has a reaction with the cement matrix that forms a hydrophobic layer at the pores walls. This protects the concrete from the ingress of the chlorides. The concrete IV presented a diffusion coefficient 31.5% lower than the diffusion coefficient of concrete I-A, with the same water-cement ratio and the same cement content 320 kg/m<sup>3</sup>. This can only be explaining by the additions of the cement IV that ameliorate the behaviour of the concrete in presence of chlorides.

### 3.2 Sulphate attack

Fig. 6 presents the mass losses at the end of the sulphates attack tests. The used silicone hydrophobic agent did not increase the protection against sulphate attack. The mass losses of the concretes with silicone hydrophobic agent (SIL I-A and SIL I-B) were higher than the mass losses of the unprotected concretes. The sulphate solution penetrated and as the cement is a non sulphate resistant the attack occurred. The used acrylic and epoxy coats (ACR I-A, ACR I-B, EP I-A and EP I-B) increased the protection against sulphate attack. The best performance was achieved with the epoxy coating concretes (EP I-A and EP I-B).

The concretes without protection (I-A, I-B and IV) presented similar mass losses. The use of higher cement content and lower water-cement ratio (concrete I-B compared with concrete I-A) did not contribute to increase the performance against sulphate attack. Less porosity is also less space to accommodate expansions caused by reactions between sulphates and cement constituents.

### 3.3 Acids and bases attack

Tables 3 and 4 present the results of the acids and bases attack tests and of the visual inspections made. The concretes coated with epoxy resin (EP I-A and EP I-B) presented better behaviour than concretes coated with acrylic resin (ACR I-A and ACR I-B),

**Table 4** Results of loss in adhesion strength after acid and base attack.

References		Loss in adhesion strength (%)
Test liquid	Concrete	
H <sub>2</sub> SO <sub>4</sub>	ACR I-A	100
H <sub>2</sub> SO <sub>4</sub>	ACR I-B	100
H <sub>2</sub> SO <sub>4</sub>	EP I-A	8
H <sub>2</sub> SO <sub>4</sub>	EP I-B	10
NH <sub>4</sub> OH	ACR I-A	0
NH <sub>4</sub> OH	ACR I-B	5
NH <sub>4</sub> OH	EP I-A	0
NH <sub>4</sub> OH	EP I-B	1

**Table 3** Results of acid and base attack.

References		Blistering		Cracking		Flaking	Chalking
Test liquid	Concrete	Dimension (degree)	Surface (degree)	Dimension (degree)	Surface (degree)	Degree	Degree
H <sub>2</sub> SO <sub>4</sub>	ACR I-A	5	5	0	0	0	1
H <sub>2</sub> SO <sub>4</sub>	ACR I-B	5	5	0	0	0	*
H <sub>2</sub> SO <sub>4</sub>	EP I-A	3	3	4	2	0	2
H <sub>2</sub> SO <sub>4</sub>	EP I-B	5	2	5	4	0	4
NH <sub>4</sub> OH	ACR I-A	1	1	0	0	0	2
NH <sub>4</sub> OH	ACR I-B	0	0	0	0	0	0
NH <sub>4</sub> OH	EP I-A	0	0	2	1	0	1
NH <sub>4</sub> OH	EP I-B	0	0	2	1	0	2

\*The test was not possible due to 100% of blistering.

excepted for cracking and chalking parameters. The difference between acrylic and epoxy is important in adhesion after acid attack, with a bad behaviour for acrylic painting. The acid caused more degradation than the base. About acid attack there was a worst behaviour of coated concrete I-B (ACR I-B and EP I-B). This is due to the expansive reactions that occur between sulphuric acid and components of concrete. The low porosity of concrete I-B leave less space to accommodate these expansions and the degradations appear.

#### 4. Conclusions

The performance of the used protected concretes against chemically aggressive environments was generally better than the performance of the unprotected concretes. The used epoxy coated concrete achieved the best results in all the chemical environments that include chlorides, sulphates, one acid and one base. The composition of the concretes is an important factor talking about performance against chemically aggressive environments. The unprotected and the protected concrete with higher cement content and lower water-cement ratio performed better than the others concretes, against penetration of chlorides, due to the less porosity. Related to sulphates and sulphuric acid attacks, unprotected and protected concretes that performed best, were made with the lower cement content and the higher water-cement ratio. The high porosity is good to accommodate expansions caused by reactions that occur during these attacks.

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