Durability of Concrete Protected by an Acrylic Painting

José B. Aguiar, Amparo C. Ramos and Helena I. Soares

ABSTRACT: The fast degradation of concrete is a problem that occurs in some structures. In order to have less degradation, the use of protection systems could be recommended. Acrylic paintings have properties that make possible its use as a protection material of concrete. In our study, one concrete that could be classified as a C33/43, was protected with two coats of an acrylic painting. The durability of the protected concrete was studied. Tests made were: capillarity absorption, oxygen permeability, sulphates attack and freeze-thaw.
The results show in general, that the degradation of the protected concrete is lower than the degradation of non protected concrete. For the absorption of water by capillarity the non protected specimens absorbed about three times more water than the protected specimens. The oxygen permeability of the protected specimens was about half of that of the non protected specimens. The results of the tests did not show any increase on the resistance of the concrete to the sulphate attack by the use of an acrylic painting. The non protected specimens presented degradation on the freeze-thaw tests after the cycle number 220. The protected systems only presented degradation on the same tests after the cycle number 270.

Keywords: Acrylic painting, Durability, Concrete, Capillarity absorption, Oxygen permeability, Sulphates attack, Freeze-thaw.

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INTRODUCTION

The fast degradation of concrete is a problem that appears in the entire world, in some structures [1]. Today the durability of the concrete is considered not very high, with reference to environmental exposure. The concrete needs to be designed for durability. Of course mechanical resistance is important, but at the same time the concrete designer can not forget durability. During the production of concrete, preoccupations with durability need to be present.

In order to increase durability, the use of an adequate surface protection system is recommended [2]. Inside the surface protection systems, the acrylic paintings are one of the most used. It is important to know the increase of durability obtained with this kind of protection. Durability studies are complex. It is necessary the execution a high quantity of tests to study all possible exposure conditions. In European standard [3] durability is considered by exposure classes. There are several exposure classes taking account of mechanisms of degradation considered for concrete. These mechanisms of degradation are carbonation, penetration of chlorides, freeze/thaw attack and chemical attack.

Previous studies [4, 5] showed a significantly decrease of the chloride ion penetrability when an acrylic painting was used to protect the concretes. The chloride ion penetrability was measured following an ASTM standard [6]. Two concretes were used on these studies, concrete 1 classified as C12/15 and concrete 2 classified as C30/37. The chloride ion penetrability for concrete 1 was classified as high, even when concrete 1 was protected with an acrylic painting. In concrete 2, the chloride ion penetrability was high without painting and moderate with an acrylic painting. However, acrylic painting is not enough to obtain low or very low chloride ion penetrability as defined in the standard [6].

TESTS

Materials

The concrete was a cement content of 360 kg/m^3 and the water-cement ratio (W/C) was 0,45. The cement was a normal Portland cement, CEM I 42,5 R [7]. The composition of the concrete is presented on table 1.

Table 1 Composition of the concrete.

Materials	Quantities (kg/m^3)
Gravel 5 - 15	886
Sand 0 - 2,5	1005
Cement	360
Water	162

The slump of the concrete was 15 mm. With the fresh concrete, cylindrical specimens with 150 mm of diameter and 300 mm of height were made for the tests of absorption of water by capillarity. For the freeze-thaw attack and for the sulphates attack cubic specimens of 100x100x100 mm, were made. For the oxygen permeability a slab with 400x800x50 mm, was made. After, the specimens for this test were cut with a drilling machine (Figure 1). These specimens were a diameter of 50 mm and an height of 40 mm.

Figure 1 Drilling machine.

To protect the concrete an acrylic painting was used. As recommended by the furnisher two coats were applied, separated by five hours (Figure 2).

Figure 2 Application of the acrylic painting.

With the fresh concrete also six cubic specimens of 150x150x150 mm, were made. These cubic specimens were tested in compression at 28 days. The analyse of the results showed that the concrete could be classified as C33/43. The mean was about 47 MPa.

Absorption of water by capillarity

The tests of absorption of water by capillarity were made following a recommendation of RILEM [8]. The specimens were maintained inside a stove at a temperature of 40±5ºC, for 15 days, till constant mass. After the specimens were removed from the stove and before the placing of the lower face in contact with water, they waited sufficient time to cool till the temperature of the laboratory room. After the determination of their mass the specimens were put in contact with water. The level of the water in the recipient was 5±1 mm above the lower face of the specimens.

The evaluation of the absorption of water by capillarity was made by the determination of the mass of the specimens at 3, 6, 24 e 72 hours after begin of the test. Figure 3 shows the results of the absorption of water obtained with the specimens without and with acrylic painting. The results are the mean of three specimens. The absorption of water by capillarity is smaller for the specimens with protection. At begin of the test, the difference of the absorption of water between the specimens without and with protection is about 20 g. At the end of the test this difference attained 32 g.

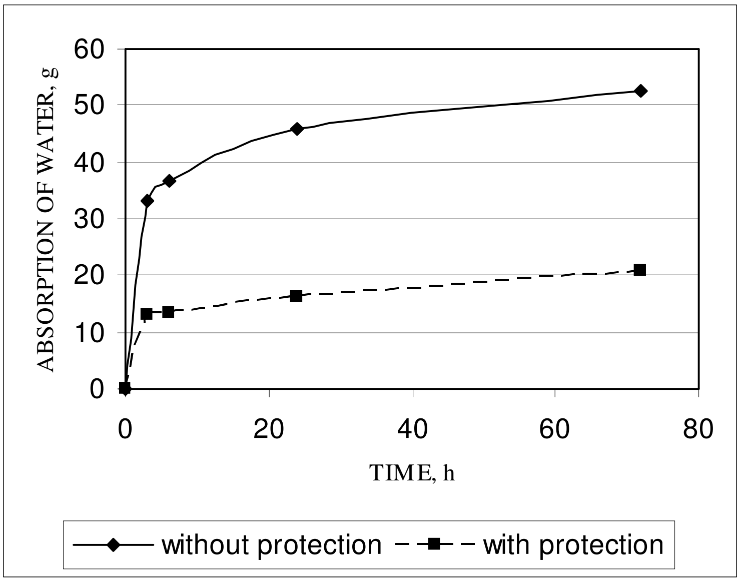

Figure 3 Variation of the absorption of water by capillarity with the time.

Permeability to oxygen

For the determination of the permeability to oxygen, the Leeds cell was used (Figure 4). The height and the diameter of each specimen were noted. The lateral faces of the specimens were covered with a silicon varnish. This silicon varnish hardened for 24 hours.

The specimens were put at the test cell with the help of a rubber ring. After the oxygen circulated under a pressure of 0,34 MPa. Every five minutes, measures were made till the flux was stable. This was, when the difference between two successive measures was less than 3%. The time that the soap-bubbles took to go through a way, of 10 cm in a pipette, with 5 mm of diameter, was noted. Figure 5 show the details of the equipment.

The calculations of the permeability coefficient were made with the Hagen-Poiseuille equation (1):

$$K = \frac{2\upsilon\eta L * 10^{-5}}{A\left(P_1^2 - P_2^2\right)} \qquad (1)$$

K - Permeability (m^2)
υ - Flux of the fluid (m^3/s)
A – Transversal section (m^2)
L – Thickness of the specimen (m)
η – Dynamic viscosity ($Ns.m^{-2}$)
P_1 – Absolute pressure of the fluid at the entrance of the specimen ($N.m^{-2}$)
P_2 – Absolute pressure of the fluid at the exit of the specimen (atm. p.) ($N.m^{-2}$)
(The dynamic viscosity of oxygen at 20ºC is $2.02 * 10^{-16}$ $Ns.m^{-2}$)

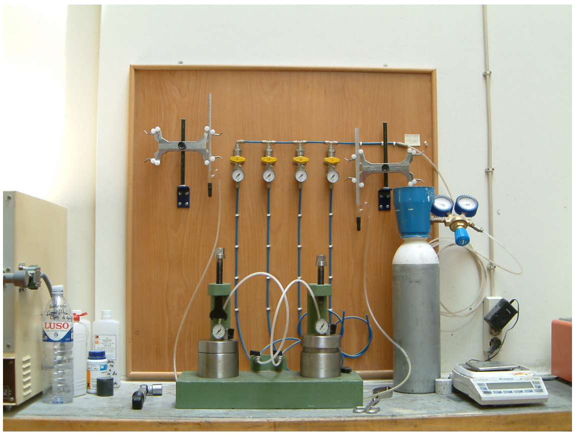

Figure 4 Equipment for determination of permeability to oxygen.

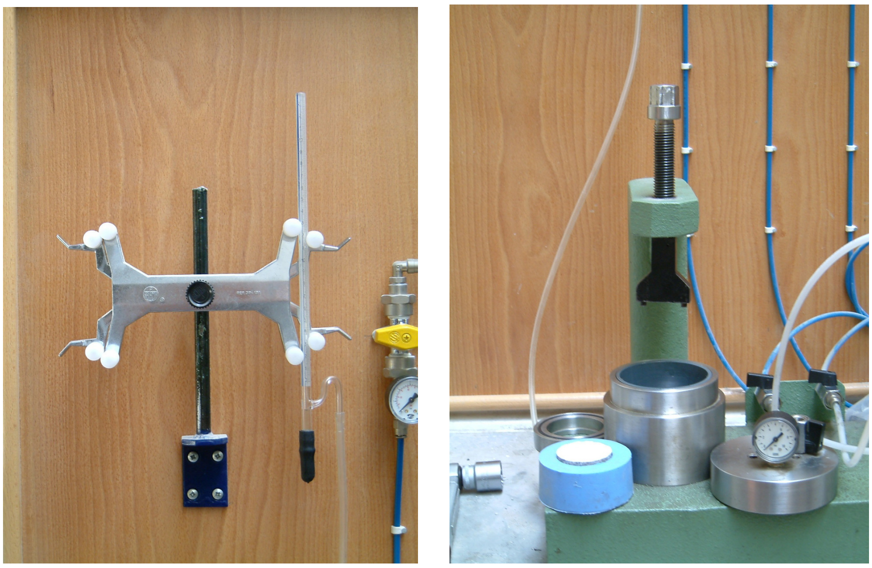

Figure 5 Details of the equipment.

Figure 6 presents the oxygen permeability coefficients of the specimens without and with acrylic painting. For the concrete without protection the average of oxygen permeability coefficient was 3,395x10^{-17} m^2. With the protection the same coefficient decreased to 1,963x10^{-17} m^2. The protection of a concrete with an acrylic painting decreased the oxygen permeability of this concrete of about 42 %.

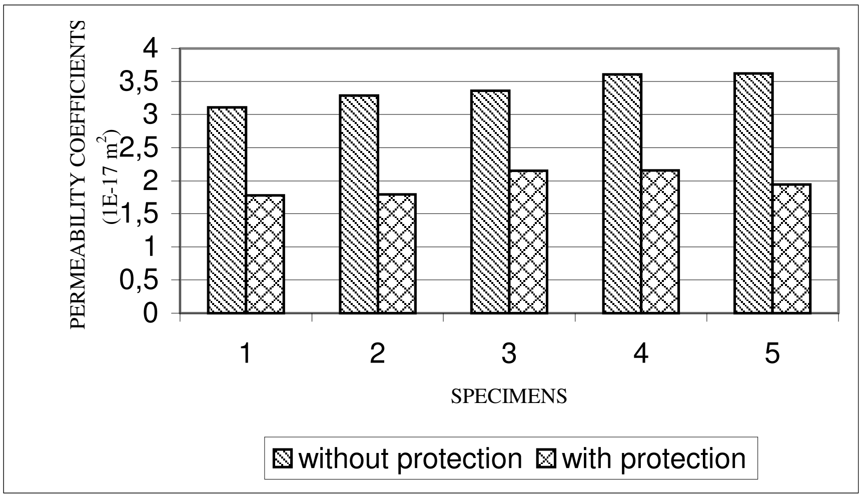

Figure 6 Oxygen permeability coefficients for the specimens without and with protection.

Sulphate attack

The sulphates can appear in the concrete by two origins: inside or outside sources [9]. The Portland cement has calcium sulphate as constituent. The water present in concrete could also have sulphates. Regarding outside sources of sulphates, there are many possibilities: atmospheric pollution, soils, industrial solid wastes, water used by industries, water from rivers and lakes, and seawater.

The tests were made following an ASTM standard [10] with some adaptations. A sodium sulphate solution was used, prepared as recommended by the standard. The volume of the solution was at least five times the volume of the immersed specimens. The saturated solution of sodium sulphate covered the immersed specimens to a depth of at least 15 mm.

The procedure of the tests consists on cycles of immersion in the prepared solution of sodium sulphate for not less 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 dying oven. According the mentioned standard the temperature of the oven shall have been brought previously to 110±5ºC. The test of specimens with an acrylic painting 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±5ºC. The specimens were dried at this temperature until constant weight. After, the specimens were immersed again in the prepared solution of sodium sulphate.

Ten cubic specimens with 100x100x100 mm were used for the evaluation of the resistance to sulphate attack. Five specimens were not protected and five were protected with an acrylic painting. A total of five cycles was made. The variation of weight of the specimens was not significant. The visual observation showed important degradation at the end of the fourth cycle. At this moment the acrylic painting begin to pickle from the concrete. The results of this test did not show any increase on the resistance of the concrete to the sulphate attack by the use of an acrylic painting.

Freeze-thaw

The freeze-thaw tests were made following the ASTM standard [11] with some adaptations. The tests consists on submit eight specimens (four without protection and four with protection with acrylic painting) to two hours cycles with positive temperature inside water (20ºC) on the first hour and negative temperature (-17.7ºC) on the second hour. Figure 7 represents the schema of the freeze-thaw cycles. The specimens were placed on the freeze-thaw apparatus (Figures 8 and 9). Every 72 hours the specimens were removed to the apparatus and were weight and observed. A total of 300 cycles were made.

The variation of weight was not significant. After the cycle number 220 the non protected concrete begin to present some cracks. The protected specimens only presented some cracks after the cycle number 270.

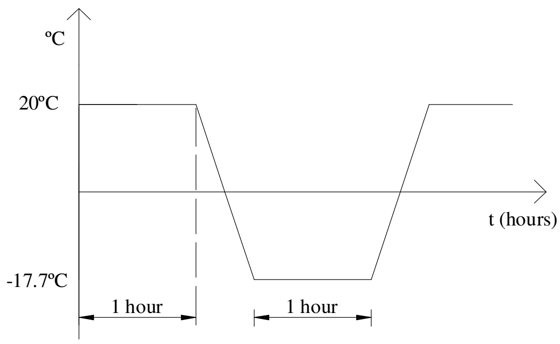

Figure 7 Schema of the freeze-thaw cycles.

Figure 8 Apparatus for the freeze-thaw tests.

Figure 9 Specimens on the apparatus before the test.

CONCLUSIONS

The protection of concrete with polymeric paintings could be a good solution to increase durability. However, it is important to select an adequate polymer. The use of acrylic painting does not seem to be adequate to all aggressive environments. For example, during the tests of resistance to sulphates, the acrylic painting did not perform very well. For the other tests, the acrylic painting increased the durability of the concrete. The better behaviour was for tests of absorption of water by capillarity and permeability to oxygen. In the first, the decrease of water absorbed by protected specimens, at the end of the test, was about 61 %. The permeability to oxygen of the specimens with an acrylic painting decreased by 42%. Regarding sulphate attack and freeze-thaw tests, the benefits of the protection were not evident. The mechanism of degradation on these two cases is similar. There are expansive reactions inside the concrete. So, cracks appear along with other problems like the superficial pickle of the concrete. It is true that acrylic painting decreases the quantity of water and other substances that go inside the concrete, but do not block the entrance of them. Another problem was that the concrete used was very compact. When expansive reaction occurred inside the concrete, there was no place to accommodate the expansions.

REFERENCES

1. PERKINS, P. H., Repair, Protection and Waterproofing of Concrete Structures, E & FN Spon, London, 1997, 233 pp.

2. SALTA, M. M., Improving the durability of concrete structures, Proceedings of 12th European RMC Congress, ERMCO – European Ready Mixed Concrete Organisation, Lisbon, Portugal, 1998, pp 535-544.

3. CEN, EUROPEAN COMMITTEE FOR STANDARDISATION, Concrete – Part 1: Specification, Performance, Production and Conformity, EN 206-1, Brussels, Belgium, 2000, 64 pp.

4. AGUIAR, J. B. AND SOUSA M. B., Use of an acrylic painting to increase the durability of reinforced concrete in a seawater environment, Proceedings of the

International Conference Sustainable Construction into the Next Millennium: Environmentally Friendly and Innovative Cement Based Materials, Federal University of Paraíba, João Pessoa, Brazil, 2000, pp 626-634.

5. AGUIAR, J. B. AND DIAS J. A., Penetrability of chloride ions in concrete protected by an acrylic painting, Proceedings of the International Conference on Innovative Materials and Technologies for Construction and Restoration, University of Lecce, Lecce, Italy, 2004, pp 223-228.

6. ASTM, AMERICAN SOCIETY FOR TESTING AND MATERIALS, Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration, C 1202, West Conshohocken, USA, 1997, 6 pp.

7. CEN, EUROPEAN COMMITTEE FOR STANDARDISATION, Cement - Composition, Specifications and Conformity Criteria for Common Cements, EN 197-1, Brussels, Belgium, 2000, 35 pp.

8. RILEM, RÉUNION INTERNATIONALE DES LABORATOIRES D'ESSAIS ET DE RECHERCHES SUR LES MATÉRIAUX, Absorption of water by capillarity, CPC11.2, 2nd. Ed., Cachan, France, 1982.

9. SKALNY, J, MARCHAND, J AND ODLER, I., Sulfate attack on concrete, E & FN Spon, London, 2002, 217 pp.

10. ASTM, AMERICAN SOCIETY FOR TESTING AND MATERIALS, Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate, C 88, West Conshohocken, USA, 1999, 5 pp.

11. ASTM, AMERICAN SOCIETY FOR TESTING AND MATERIALS, Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing, C 666, West Conshohocken, USA, 1997, 6 pp.