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SUSTAINABLE CONSTRUCTION INTO THE NEXT MILLENNIUM: ENVIRONMENTALLY FRIENDLY AND INNOVATIVE CEMENT BASED MATERIALS

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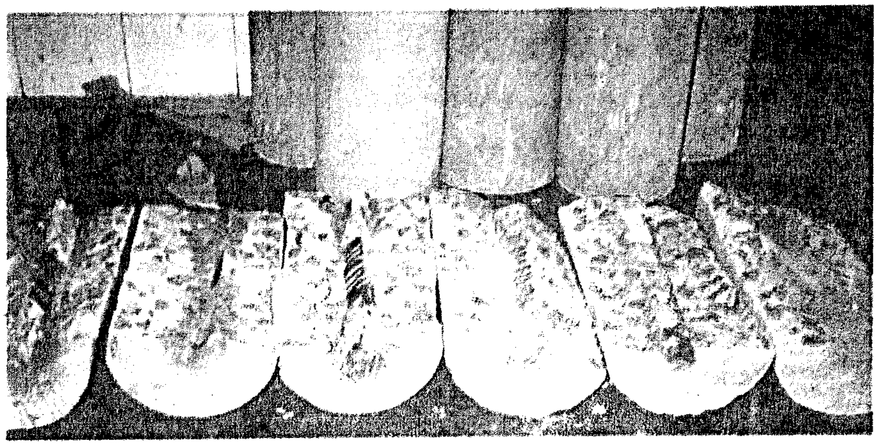

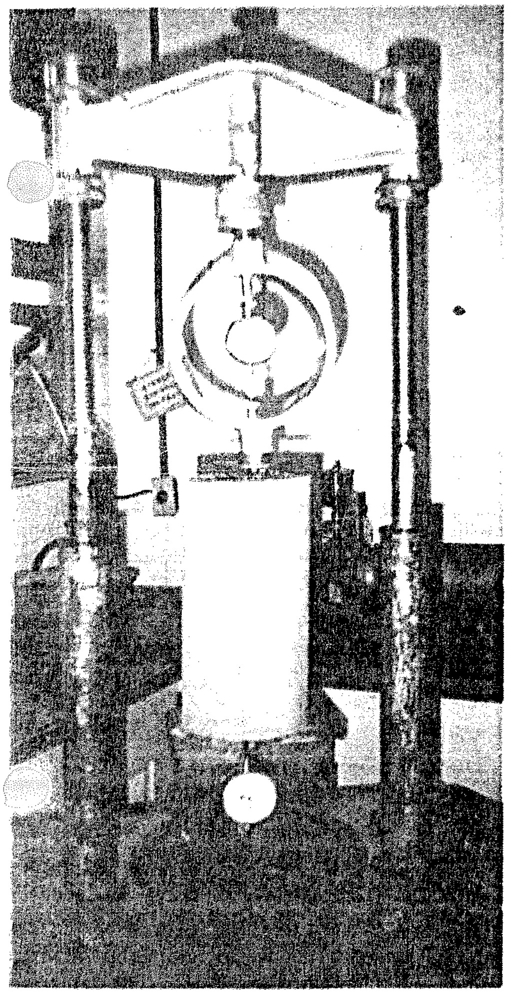

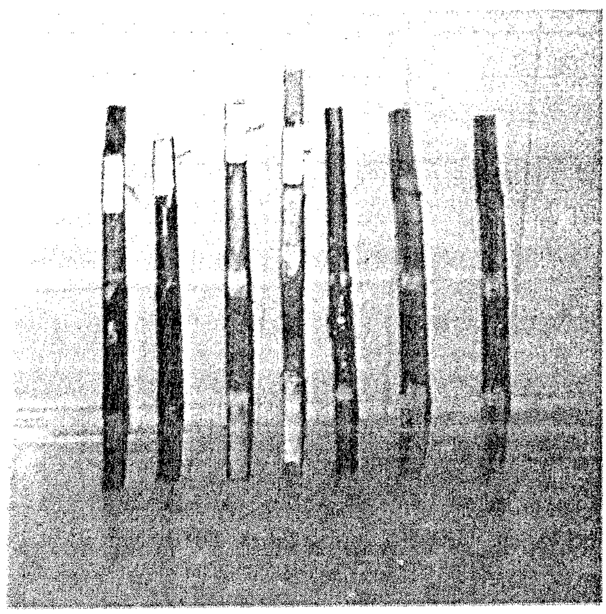

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USE OF AN ACRYLIC PAINTING TO INCREASE THE DURABILITY OF REINFORCED CONCRETE IN A SEAWATER ENVIRONMENT

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ABSTRACT

One of the most aggressive environments for reinforced concrete is the contact with seawater. The chlorides present in seawater penetrate into the concrete and the possibility to armatures corrosion increases significantly. In this study an acrylic painting was used to protect the concrete and decrease the diffusion of chlorides. We used two concretes with different compositions. One composition respects the exigencies of European standardisation for this environment and the other one no. The acrylic painting was applied in one or two coats. The specimens were put in contact with seawater 18 days after casting. We maintained the immersion for 90 days. In order to accelerate the durability test, three immersion solutions were used. The first one was seawater, the second one was seawater more 35 g/dm^3 of sodium chloride and the third one was seawater more 70 g/dm^3 of sodium chloride. After the immersion period we determined the chloride content at three depths (5, 10 and 15 mm) to have the chloride profile. The diffusion coefficient was determined taking into account the chloride profile. The results obtained for the diffusion coefficients show that one coating is not enough to prevent the chloride penetration. Better results were achieved with two coatings. The normal concrete presents better behaviour than the ameliorated concrete related with chlorides diffusion. The chlorides diffusion increases with the concentration of sodium chloride in the solution in contact with the concrete.

Keywords: acrylic painting, reinforced concrete, durability, seawater, chlorides diffusion.

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INTRODUCTION

The increase of degradation of reinforced concrete in a seawater environment is well-known [1, 2]. The major problem is the corrosion of steel. The degradation of reinforced concrete is only possible if the aggressive agents can penetrate in an easy way. As seawater is mainly composed by salts, with basically chlorides, the penetration of these substances was analysed.

In our study we used immersion tests [3]. We tested different types of concretes, with different types of superficial coats and in salt liquid environments with different degrees of aggressiveness. The use of an acrylic painting to protect the concrete is the first purpose of this work. First we characterise the materials used in the specimens preparation. The way to obtain the samples for the chemical analysis is described. With the results of chemical analysis, the chlorides profiles are drawn and the diffusion coefficients are determined. Afterwards, we determine the K parameter and we made estimations of service life of the concretes of the study [4].

Tests

Based on [5] we formulated two concretes, one mentioned as normal and another one mentioned as ameliorated with a composition that respects the exigencies for seawater environments. The normal concrete has 280 Kg/m^3 of cement and a water-cement ratio of 0,65. The ameliorated concrete has 320 Kg/m^3 of cement and a water-cement ratio of 0,55. The cement was a type I, class 42,5. Tables 1 and 2 show the compositions of the two concretes.

Table 1 - Composition of normal concrete

MATERIALS	QUANTITIES (Kg/m^3)
Aggregate 5-20	1232.9
Sand 0-2	730.6
Cement	280
Water	168

Table 2 - Composition of ameliorated concrete

MATERIALS	QUANTITIES (Kg/m^3)
Aggregate 5-20	1232.9
Sand 0-2	730.6
Cement	280
Water	168

The slump for the normal concrete was 3 cm and for the ameliorated concrete was 1 cm. With the fresh concrete we did cubic specimens with 10x10x10 cm^3. Six reservoirs were used to put the specimens in seawater. The seawater used was from the North of Portugal with the following composition: 35 g/dm^3 of salt from which 27 g/dm^3 are of sodium chloride.
Three types of solutions were used:

Type 1 - Seawater;
Type 2 - Seawater + 35 g/dm^3 of sodium chloride;
Type 3 - Seawater + 70 g/dm^3 of sodium chloride.

To protect the concretes against the seawater environments an acrylic painting was used. The product selected was Sikagard Betoncolor. In each reservoir we placed five specimens: three without paint, one with one single coat of paint and one with two coats of paint. The specimens were introduced in the reservoirs when they had 18 days. The immersion has a duration of 90 days. Every month the seawater solution was renewed.

To determine the chloride content of the specimens we removed some powder. With a 30 mm drill (Fig. 1), one hole was made (Fig. 2). Firstly we drilled till 5 mm of depth and we collected the powder. Afterwards, we continued drilling till 10 mm of depth and the powder was collected. Finally, we drilled till 15 mm and we collected the last sample of powder.

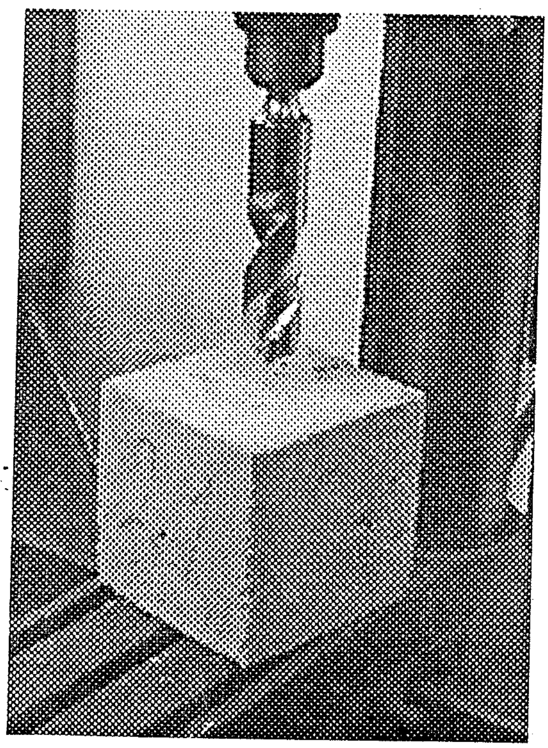

Figure 1 - Drilling a specimen

Figure 2 - Hole made in a specimen.

Chlorides profiles

Examples of the chlorides profiles are presented in figures 3 to 5. To estimate the chloride content at the surface we used the exponential approximation as the quadratic polynomial approximation did not give so good adjustment.

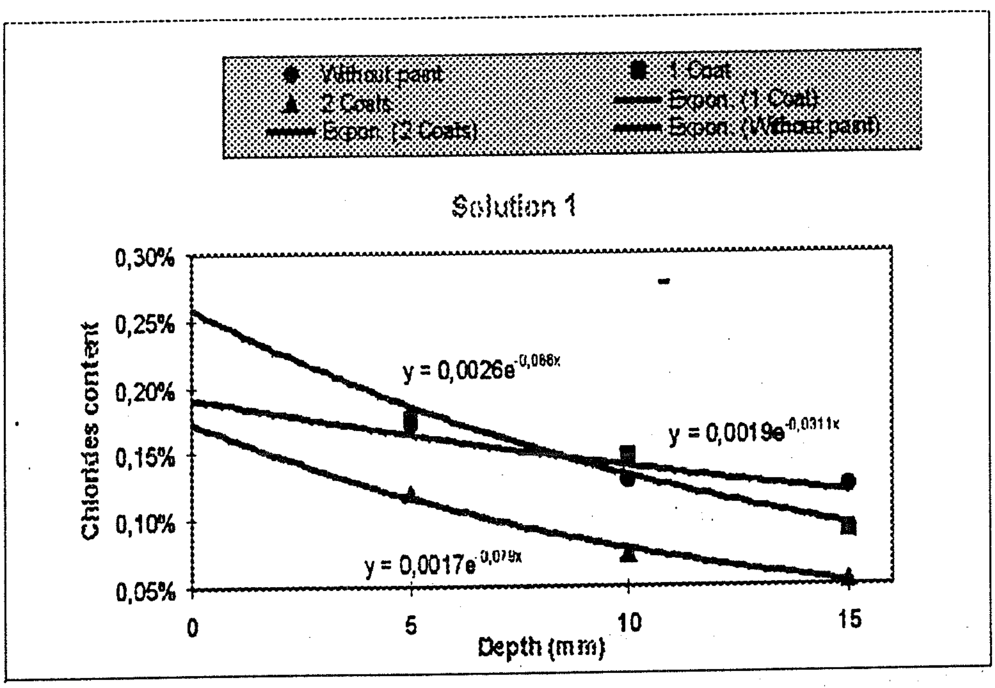

Figure 3 - Chlorides profiles for normal concrete - Solution 1.

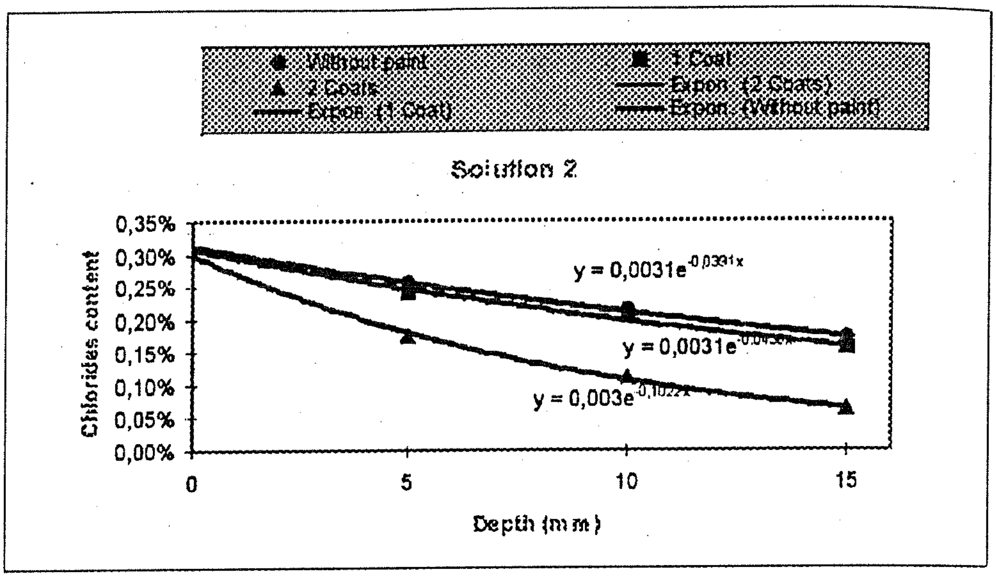

Figure 4 - Chlorides profiles for ameliorated concrete - Solution 2.

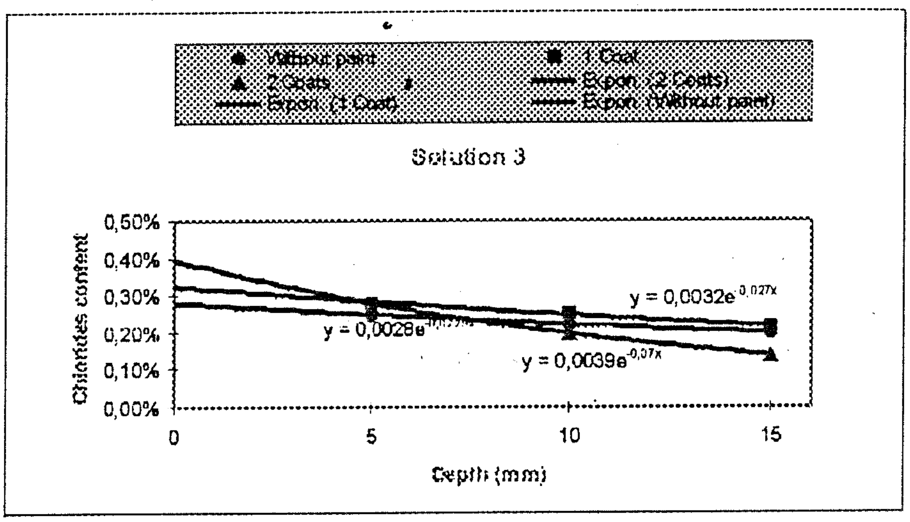

Figure 5 - Chlorides profiles for ameliorated concrete - Solution 3.

Diffusion coefficient

Taking into account the chlorides profiles obtained (Fig. 3 to 5), the chloride concentration at surface was calculated, as shown in table 3.

Table 3 - Chlorides concentration at surface

TYPE OF PAINTING	NORMAL CONCRETE			AMELIORATED CONCRETE		
	N1	N2	N3	A1	A2	A3
Without paint	0.19	0.30	0.23	0.27	0.31	0.28
1 coat	0.26	0.41	0.26	0.18	0.31	0.32
2 coats	0.17	0.31	0.25	0.24	0.30	0.39

With the results of the immersion tests we can determine the diffusion coefficient using the following relationship [6]:

$$C_x = C_S - (C_S - C_0)\ erf\left(\frac{x}{2\sqrt{Dt}}\right) \qquad (1)$$

Where:

x - depth in the concrete;
t - time;
D - diffusion coefficient;
C_x - chlorides concentration at a depth x and time t;
C_S - chlorides concentration at the surface and time t;
C_0 - initial chlorides concentration;
erf - an error function.

The initial chlorides concentration in the two concretes was 0,01 %. Figures 6 and 7 present the diffusion coefficients obtained. They show that the diffusion coefficient:

- decrease with the increase of acrylic painting coats;
- has the lowest value in the case of solution type 2;

is on the whole constant in all solution types for ameliorated concrete with two coats.

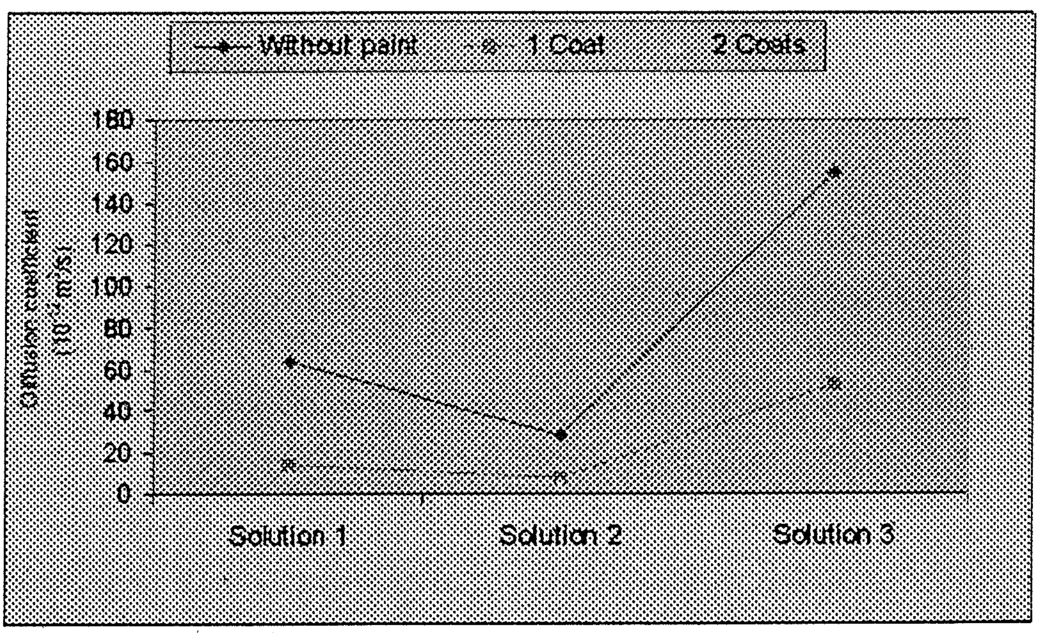

Figure 6 - Variation of diffusion coefficient with the type of solution and with the protection of normal concrete.

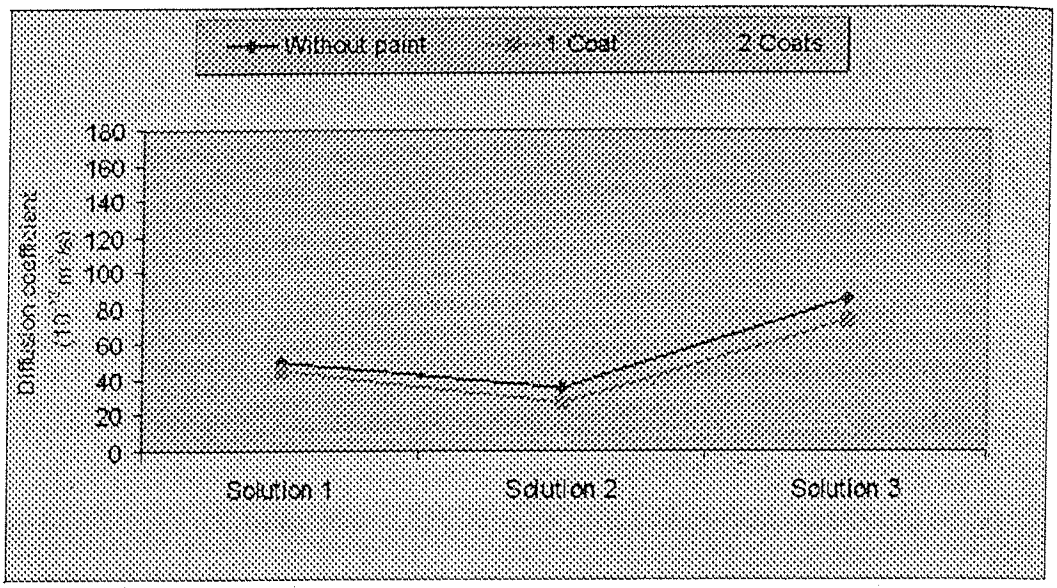

Figure 7 - Variation of diffusion coefficient with the type of solution and with the protection of ameliorated concrete.

Life time estimation

After the determination of the diffusion coefficient we determined the penetration parameter K, using the following relationship:

$$K = 2\sqrt{D}\ erf^{-1}\left(\frac{C_S - C_r}{C_s - C_0}\right) \qquad (2)$$

Where C_r is the reference chlorides concentration.

In [5] we find that the maximum allowed value (C_r) is 0,4 % related to cement weight. For normal concrete, in this study, this value is 0.049 % related to concrete weight. For ameliorated concrete we have 0,0546 %.
With the penetration parameter K it is possible to estimate the variation of depth of penetration with time:

$$x = K\sqrt{t} \qquad (3)$$

Figures 8 and 9 show the variation of depth of penetration with time for the two tested concretes. The analysis of what will happen at one hundred years shows that with two coats the maximum depth of penetration will be 103 mm here as for the normal concrete this value is only 42 mm. Without paint the depths of penetration are higher. All the values are higher than 146 mm, except for normal concrete and solution 2 where the depth of penetration is only 96 mm. There is a tendency for the normal concrete to present better behaviour than ameliorated concrete. This concrete called ameliorated with lower water/cement ratio and with higher compressive resistance, seams to have less durability than the so-called normal. A. Neville in a recent publication [7] alerts to the possibility that durability is not directly connected with the water/cement ratio.

Conclusions

From the results of the tests and the calculations performed in this study, it is possible to obtain the following conclusions:

- one coat of acrylic paint is not sufficient for a considerable decrease of the chlorides diffusion coefficients;
- with two coats we found an average of 83% of decrease of the chlorides diffusion coefficients;
- the ameliorated concrete with better compressive resistance and with lower water/cement ratio presented higher chlorides concentrations than the normal concrete;

for solutions 1 and 2 the results are similar with one or two coatings when compared without paint, but for solution 3 the chlorides diffusion coefficients decrease significantly with one and even more with two coatings.

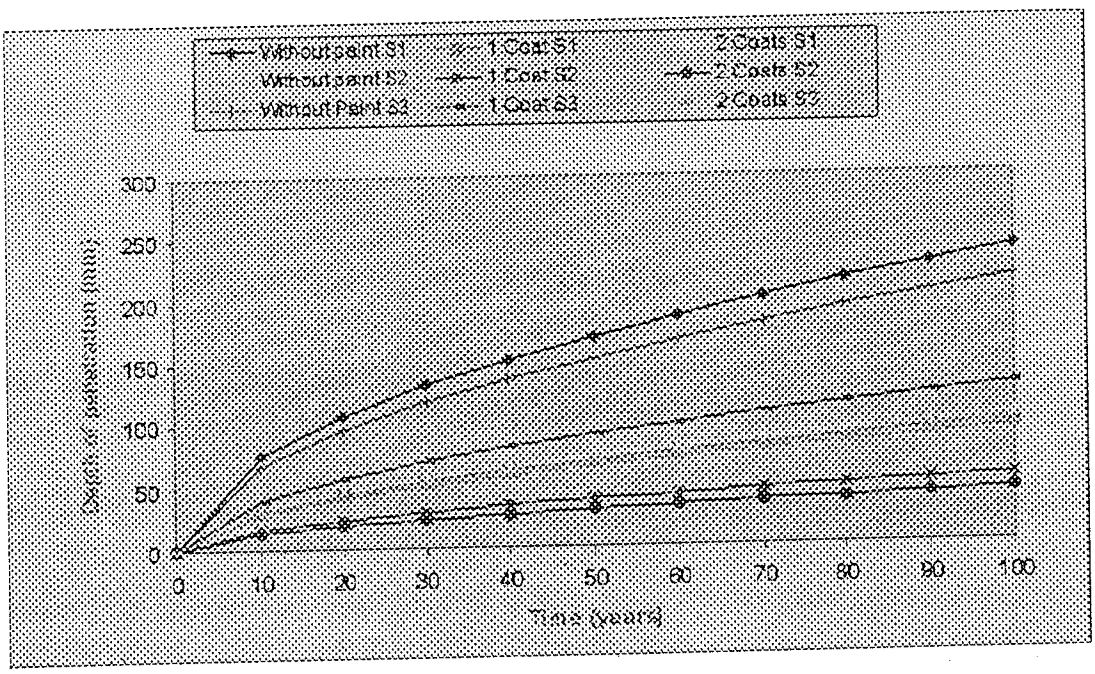

Figure 8 - Variation of depth of penetration with time for normal concrete.

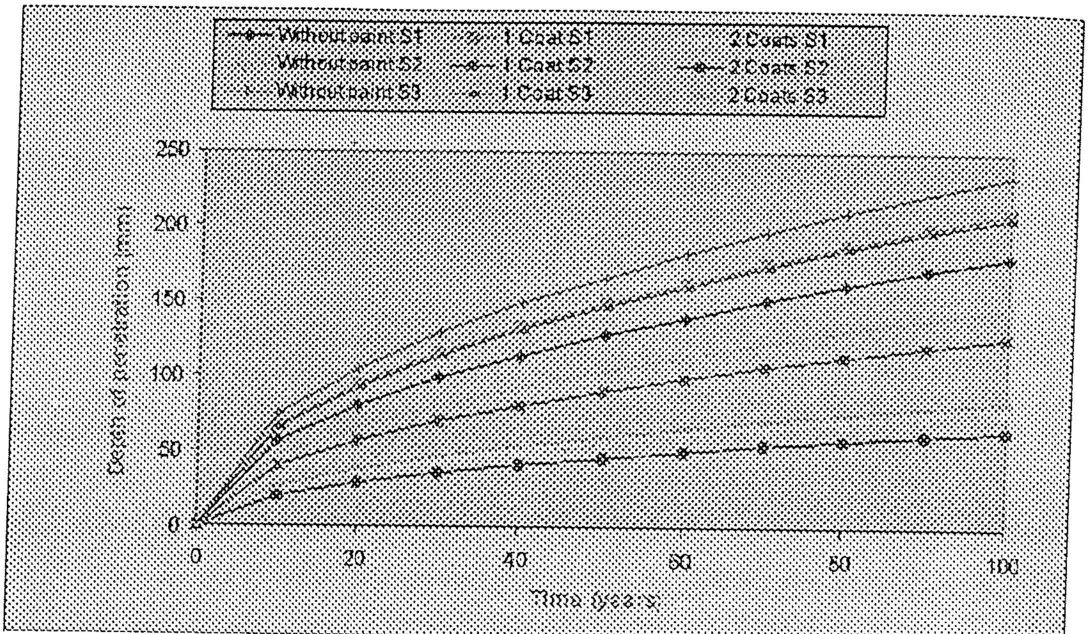

Figure 9 - Variation of depth of penetration with time for ameliorated concrete.

- the diffusion coefficient has the lowest value for solution type 2. The value of D is higher in solution type 3 than in solution type 1 that consists only in seawater.
- the three adopted depths for powder collection proved to be the right approach for chorides diffusion penetration.
- the adopted way to obtain the samples for chemical analyses through drilling proved adequate to assess de degradation of concrete structures in maritime environments.

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