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Chloride Penetration into Integral Water Repellent Concrete Produced with Linseed Oil

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SUMMARY: Natural products such as olive oil have been applied to manufacture water repellent cement and lime based building materials for centuries. The efficiency of linseed oil to produce integral water repellent concrete was investigated. By addition of linseed oil to fresh concrete capillary absorption of aqueous salt solutions can be reduced significantly. But the compressive strength is reduced at the same time. For practical applications the water-cement ratio can be lowered to compensate for the strength loss. Further studies are needed in order to optimize the technology.

KEY-WORDS: Integral water repellent concrete; Service life; Linseed oil.

INTRODUCTION

Service life of reinforced concrete structures placed in marine environment is often severely reduced by chloride penetration and subsequent corrosion initiation of the embedded steel. The most efficient mechanism of chloride transportation into the pore space of concrete is capillary absorption of an aqueous salt solution [1, 2]. Once chloride has entered the pore space it may slowly migrate deeper into the porous material by diffusion driven by concentration differences. Capillary absorption can be significantly reduced and the diffusion coefficient can be lowered by water repellent treatment. There are two basically different methods to produce water repellent concrete. In most cases the surface is impregnated with a water repellent agent such as silane or siloxane [3]. As an interesting alternative, concrete can be prepared with the addition of a water repellent agent such as metal soaps [4] or silane emulsion [5] to the fresh mix. In this latter case one obtains so-called integral water repellent concrete.

Even when not in contact with chlorides, water repellent treatment may be beneficial for concrete structures as it increases its frost resistance. Recently, it has also been shown that chloride penetration is significantly accelerated if the chloride migration is combined with frost damage.

Historically cement and lime mortar have been made more durable for more than 2000 years by adding water repellent oils such as olive or linseed oil to the fresh mix [6]. For restoration of historical buildings and monuments this historical approach has gained new interest [7]. This paper describes tests made on integral water repellent concrete prepared with linseed oil. The influence of added linseed oil on strength, capillary absorption, and chloride penetration will be presented and discussed.

EXPERIMENTAL

A rather conventional concrete was prepared for this project and its composition is given in Table 1. Specimens were prepared with the basic mix, which served as reference, while 1, 2, 3, and 4% of linseed oil as related to the mass of cement were added to the other specimens using the same basic mix.

Table 1. Water-cement ratio and composition of the basic mix (mass is indicated in kg/m^3).

Water	Cement	Gravel	Sand	W/C
180	300	1191	699	0.6

Specimens for both the neat concrete, which served as the reference material, and the linseed oil containing concrete, were cast in cubic steel forms with an edge length of 100 mm. After hardening for 24 hours under a protective plastic sheet the steel forms were removed and the concrete cubes were placed in a humid room (T = 20 ± 2°C and RH ≥ 95%) for 28 days.

The compressive strength of the cubes for all types of concrete was determined at an age of 3, 7, 14, 28, and 56 days with a servo-controlled testing machine according to European standard DIN EN 12390-4 (2000-12 edition). At 28 days of curing, some of the cubes were cut into half with a diamond saw from the finished surface to the formed surface. The half cubes were then dried in a ventilated oven at 50 °C until constant weight was reached. Then the smaller side surfaces (A = 50 × 100 mm) were sealed with wax to prepare the samples for the capillary absorption test. The surface which was in contact with the steel form during hardening was put in contact with an aqueous salt solution containing 5% NaCl and the weight gain was measured at regular intervals for 7 days. The chloride profile built up after 7 days of contact with the salt solution was determined by milling thin layers step by step starting at the surface, which was in contact with the salt solution. The water soluble chloride content of the powder obtained in this way was determined analytically.

RESULTS AND DISCUSSION

Compressive Strength

Compressive strength of both the reference and the integral water repellent concrete was determined on cubes with an edge length of 100 mm as function of age. Results are shown in Fig. 1. It can be seen that compressive strength of concrete is reduced by approximately

28% with the addition of 4% linseed oil. In practical applications this reduction of compressive strength has to be compensated by reducing the water-cement ratio.

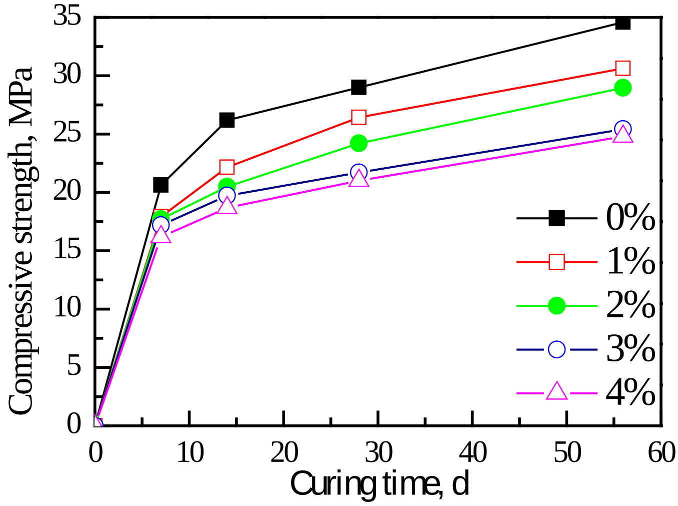

Figure 1. Compressive strength as function of age for the reference (0 %) and the integral water repellent concrete (1 – 4 %) prepared with different amounts of linseed oil added.

Capillary Absorption

Capillary absorption of the salt solution was determined gravimetrically up to 7 days as shown in Fig. 2. The capillary absorption coefficient decreases significantly due to the integral water repellent treatment. The initial capillary absorption coefficient —slope of the curve that for this type of cement samples corresponds to data collected up to one hour— of the reference concrete was A_i = 466 g/(m^2 $h^{0.5}$) while the initial coefficient of capillary absorption of integral water repellent concrete with 4% of linseed oil was found to be A_i = 192 g/(m^2 $h^{0.5}$). It can be concluded that capillary absorption and hence the uptake of aggressive agents can be reduced significantly by the addition of linseed oil. Further tests are necessary to optimize the technology and to learn to which degree capillary absorption of concrete can be reduced by addition of linseed oil.

Capillary absorption of water or an aqueous salt solution into a porous material can be described by the following equation:

$$\Delta W = A\sqrt{t} \tag{1}$$

In Eq. (1), *A* stands for the coefficient of capillary absorption. Under idealized conditions *A* may be considered to be constant. But in real materials, if gravity and the specific porous network have to be taken into consideration, the coefficient of capillary absorption *A* is not constant but depends on the duration of capillary absorption. In a heuristic way, Eq. (1) can be rewritten as follows [8], where x corresponds to the square root of time t:

$$\Delta W = a[1- \exp(-b\ x)] \tag{2}$$

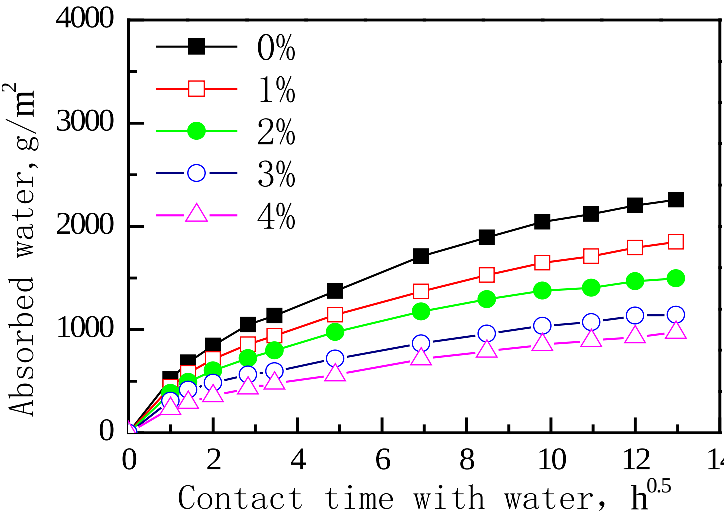

Figure 2. Capillary absorption of the reference (0 %) and of integral water repellent (1–4 %) concrete as function of square root of time.

The parameters a and b have to be determined by fitting Eq. (2) with experimental results, for example, as those shown in Fig. 2. In the simplest case, the coefficient of capillary absorption is constant. The first derivative of Eq.(2) gives the time dependence of the coefficient of capillary absorption:

$$d\Delta W/dx = A \quad (3)$$

Equation (3) takes into account the time dependence of the coefficient of capillary absorption. For t = 0 we obtain then the initial coefficient of capillary absorption A_i as the following relation:

$$A_i = a\, b \quad (4)$$

Once the values for a and b, as obtained by fitting the experimental data, are introduced into Eq. (2), the realistic time dependence of the coefficient of capillary absorption can be obtained. Table 2 lists the initial capillary absorption coefficients for both the reference and the various linseed oil containing samples.

Figure 3 shows the initial coefficient of capillary absorption as a function of linseed oil content. A linear decrease of A_i, with increasing amount of linseed oil added, can be observed within the accuracy of the measurements. This is a clear indication that capillary absorption can be further reduced by adding more linseed oil to the fresh mix.

Table 2. Initial coefficient of capillary absorption A_i as function of the percentage of linseed oil added to the fresh mix.

Linseed oil added, % Cement	a [g/m^2]	b [h$^{1/2}$]	A_i = a b [g/(m^{2}h$^{1/2}$)]
0	2400	0.1943	466.32
1	1918	0.204	391.27
2	1547	0.2234	345.60
3	1162	0.2297	266.91
4	1023	0.1878	192.12

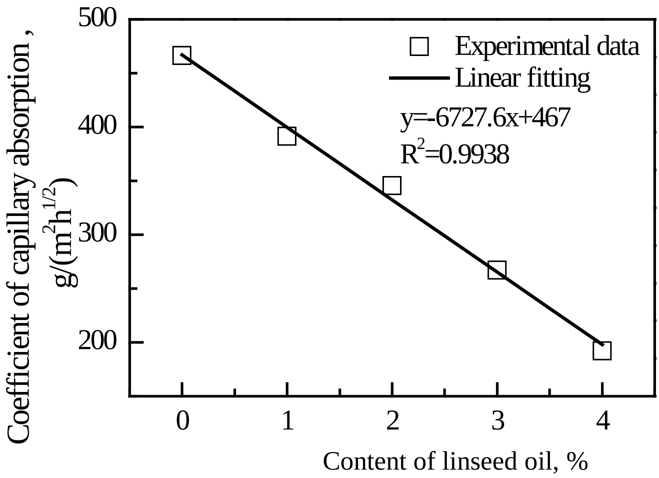

Figure 3. Coefficient of capillary absorption as function of the amount of added linseed oil.

Chloride Penetration

The amount of chloride absorbed was determined in the thin layers that were milled successively from the concrete sample surfaces in contact with the salt solution for seven days. The chloride profiles in the concrete under investigation are shown in Fig. 4. It can be seen that addition of 1% of linseed oil has little effect on chloride penetration. Obviously enough pores remain untreated and transport of salt solutions is still maintained. Addition of 4% of linseed oil, however, reduces chloride penetration significantly. Further studies will serve to determine if an efficient chloride barrier can be established by addition of a higher percentage of linseed oil.

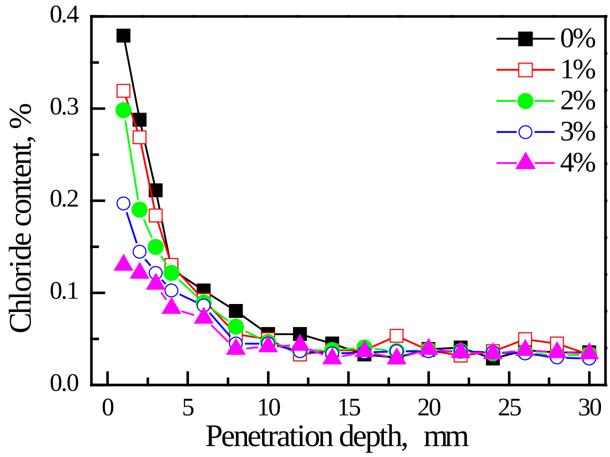

Figure 4. Chloride profiles as determined in the reference concrete (0 %) and in integral water repellent concrete with 1 to 4 % linseed oil.

CONCLUSIONS

Integral water repellent concrete can be produced by addition of linseed oil, a historical water repellent agent. However, by this addition, the compressive strength is reduced to a certain degree. This was expected, but further experiments must show whether the hydration, and hence the strength development, are only slowed down. The loss of strength can be compensated in practice, however, whenever needed by lowering the water-cement ratio.

Further studies are necessary to determine the optimum amount of linseed oil to be added with respect to water and chloride penetration. It will be of particular importance so see if a chloride barrier can be established by addition of linseed oil to fresh concrete. Ongoing studies will also confirm whether linseed oil can be successfully applied for surface impregnation to establish an efficient chloride barrier on existing reinforced concrete structures.

Acknowledgments

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