Water Repellent Treatment of Building Materials
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Influence of Water Repellent Treatment on Drying of Concrete

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Abstract

Drying of concrete cylinders with two different water-cement ratios has been measured. Part of the cylinders remained untreated and another part was surface treated by a water repellent agent (pure silane). Based on the drying data the moisture diffusion coefficient for untreated and impregnated concrete has been calculated by means of an inverse analysis. The diffusion coefficient of water repellent concrete is nearly constant and low as compared to untreated concrete. Impregnation slows down the drying process considerably and results in a nearly homogeneous moisture distribution in the untreated concrete. Water repellent impregnation of drying concrete leads to an internal redistribution of the pore water in the untreated part.

Keywords: drying, diffusivity, moisture profiles, internal redistribution

1 Introduction

Surface treatment of concrete is a severe intervention into the moisture exchange with the environment. The drastic decrease of capillary suction has been well established. Less data are available concerning the influence on drying.

In this contribution two types of concrete have been impregnated with a water repellent agent. It was tried to reach two different depths of penetration of the agent. Then moisture loss has been measured on impregnated and untreated compagnion specimens as function of time.

By means of an inverse analysis it should be possible to determine the diffusion coefficients of treated and untreated concrete. When these values are known the moisture loss and the resulting moisture distribution can be determined. A rigorous numerical analysis may also show the risk of a water repellent surface treatment.

2 Preparation of specimens and drying experiments

Two types of concrete specimens with water-cement ratio of 0.4 and 0.5 have been prepared. From cast slabs with an age of about one year, cylinders with a diameter of 70 mm and a layer of 90 mm have been drilled. All surfaces with the exception of one circular front surface have been sealed. In this way unidirectional drying was enforced.

One third of the prepared cylinders remained untreated for reference values. One third was traditionally treated by spraying the surface with the water repellent agent (pure silane). In this case a penetration depth of about 1 mm has been achieved on both types of concrete. The remaining third of the drilled cores has been put in contact with silane for several hours. The penetration depth in concrete with a water-cement ratio of 0.4 increased slightly and reached 1.1 mm. For the concrete with a water-cement ratio of 0.5, however, the final penetration depth was 4 mm.

After two weeks of reaction time the untreated and the impregnated cylinders were placed in 45% RH at 20 °C. The moisture loss under these environmental conditions was gravimetrically followed.

3 Transport model and numerical simulation

3.1 Description of the model

The size and the shape of pores present in a porous material exert a direct influence on the transport mechanism of water molecules. Despite the knowlegde of the basic individual phenomena involved, like capillary transport, diffusion, surface diffusion, etc., it is not yet possible to assess quantatively the influence of each of mechanisms involved on the global moisture transfer in a porous material such as concrete, mortar or brick. At the macroscopic level (i.e. in a representative finite volume of the porous material), the afore-mentionned difficulty can be circumvented by defining a concentration-dependent transfer coefficient, which integrates all contributions of the different mechanims in the global mass transfer. In this phenomenological description, the transient moisture flow can be described according to the Fick's law. If w represents the specific moisture content of the porous body (mass per unit of volume), the Fick's law is described by the following partial differential equation :

$$\frac{\partial w}{\partial t} = \mathrm{div}(D(w) \cdot \mathrm{grad}\ \mathrm{w}) \tag{1}$$

in which $D(w)$ is the moisture transfer coefficient depending on the actual moisture content w which is itself function of the pore humidity h.

Equation 1 is used since at lest two decades by many authors to describe the moisture transfer in porous building materials, such as cement-based materials, brick or natural stones in a realistic way [1-5].

In case of a concrete element with a treated covercrete, the global porous system must be considered as a superposition of two different porous materials, characterized by their own sorption-desorption isotherms and their moisture transfer parameters. In this layered element, the two materials may be in equilibrium with the same relative humidity, but this may lead to totally different moisture contents. In other words, the moisture content w cannot be anymore used as potential to describe the moisture flow process in such complex porous systems. In this case, pore humidity h may be used as potential to overcome this problem. At a constant temperature, an infinitesimal variation of the pore humidity (dh) can be related to a corresponding infinitesimal variation of the moisture content (dw) by means of the desorption isotherm of the material [2]:

$$dh = C(h) \cdot dw \tag{2}$$

In which, *C(h)* is the co-tangent of the desorption isotherm *w(h)*, the inverse of this value represents the hygral capacity. In this way, the flow process can be described in terms of *h* by the following equation :

$$\frac{\partial h}{\partial t} = C(h) \cdot \mathrm{div}(\lambda(h) \cdot \mathrm{grad}h) \tag{3}$$

The transfer parameters *D(w)* and *λ(h)* are related by the following relationship:

$$\lambda(h)=D(w(h))/C(h) \tag{4}$$

The formulations in terms of *D(w)* (Eq.1) and *h* (Eq. 3) are equivalent only if the temperature is constant and if the porous structure is not influenced by aging effects such as hydration in case of young mortar.

For simulating the drying process of a porous system, equation (3) must be solved conjointly with adequat boundary conditions and initial conditions.

In our case, the fixed potential boundary type is used, namely the humidity at the surface of the drying element is the same as the surrounding atmosphere

$$h_s = h_{ext} \tag{5}$$

Where h_s is the humidity at the exposed surface and h_{ext} the relative humidity of the surrounding atmosphere.

The porous system is assumed to be in equilibrium with 100% RH (*h*=1) because the test specimens were moist cured before the beginning of the drying process.

In the numerical analysis, equation (3) is used in its intregral formulation [6]. In a conveniently small finite element volume ΔV of the flow region, equation (3) can be written as follows :

$$\frac{\partial}{\partial t}\int_{\Delta V} h dv = \int_{\Delta V} C(h) \cdot \mathrm{div}(D(w(h)) \cdot C^{-1}(h) \cdot \mathrm{grad}h) dv \tag{6}$$

The porous system is discretized into a finite number of subdomains to obtain a set of equations which can then be solved numerically by an adequate numerical method for the unknown $h_j(t_i)$ which is the humidity in the finite volume ΔV_j at drying time t_i.

3.2 Determination of the moisture diffusivity from experimental data

In the resolution of the problem, we suppose that the moisture diffusivity *D(w(h))* can be expressed by a mathematical function as follows [4]:

$$D(w(h))=f(h,p_1,...,p_k) \qquad (7)$$

where h is the potential (humidity) and $p_1,...,p_k$ are a priori unknown parameters, which must be estimated from experimental data.

The shape of the transfer coefficient of concrete is assumed to be an exponential function:

$$D(w(h)) = p_1 + p_2 \cdot \exp(p_3 \cdot h) \qquad (8)$$

The best parameters can be obtained by comparing the calculated time dependent moisture loss curve to the corresponding experimental data, and looking for the best fit. This can be realized by minimizing the functional quadratic error:

$$E(\{p_i\}) = \sum_{\text{drying-times},\tau_l} (q_{cal}(\tau_l) - q_{\exp}(\tau_l))^2 \qquad (9)$$

4 Results

4.1 Diffusion coefficient

First of all, moisture diffusivities of the untreated specimens (w/c 0.40 and 0.50) are determined according to the above described numerical technique.

In the second phase, the moisture diffusivities of the water repellent layer is determined. In this case, depending on the water-cement ratio and on the way on which the water repellent agent is applied, a thickness of the impregnated concrete is assumed. In the modelisation, the whole specimen is regarded as a two layered system consisting on the superposition of the bulk untreated material covered with a thin layer of impregnated concrete.

In Fig.1 the moisture loss of drying concrete specimens with a water-cement ratio of 0.5 is plotted as function of drying time. Next to the experimentally determined values solid lines represent the best fit of diffusion equation (3) with equation (8) for *D(h)*. The upper curve represents drying of untreated concrete. If the water repellent agent has penetrated 1.5mm and 4mm into the concrete, the drying rate is considerably slowed down.

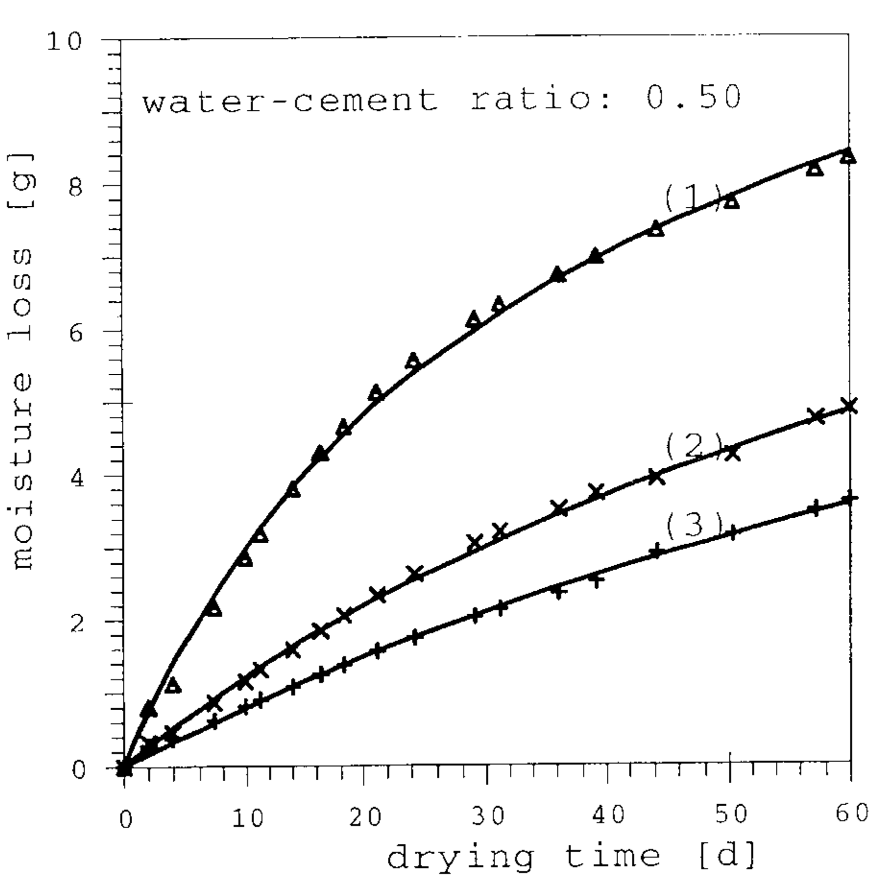

Figure 1: Moisture loss of untreated concrete with a water - cement ratio of 0.5 (1) and concrete with a water repellent layer of 1.5 mm (2) and 4 mm (3)

Similar results are shown in Fig.2. In this case the untreated concrete has a water-cement ratio of 0.4 and the thickness of the impregnated layers is 1.0 and 1.1 mm.

From the best fit between experimental results and numerical simulation, the diffusion coefficient of both the untreated concrete and the impregnated concrete can be determined. In Fig.3 results are shown. The diffusion coefficient of concrete shows as usual a strong dependence on ihumidity. In contrast to this well-known behavour the diffusion coefficient of the impreg-

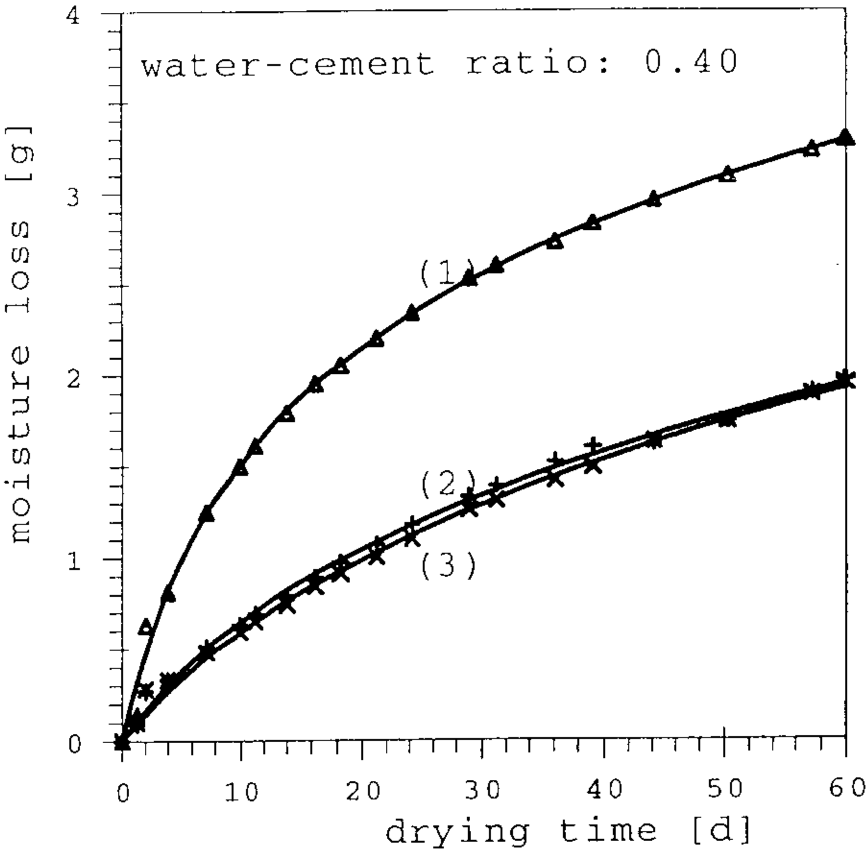

Figure 2: Moisture loss of untreated concrete with a water - cement ratio of 0.4 (1) and concrete with a water repellent layer of 1.0 mm (2) and 1.1 mm (3)

nated concrete is practically constant. At low humidity, the diffusion coefficient of the untreated concrete and the impregnated concrete are nearly the same. This indicates that in both cases diffusion is controlled by vapour migration.

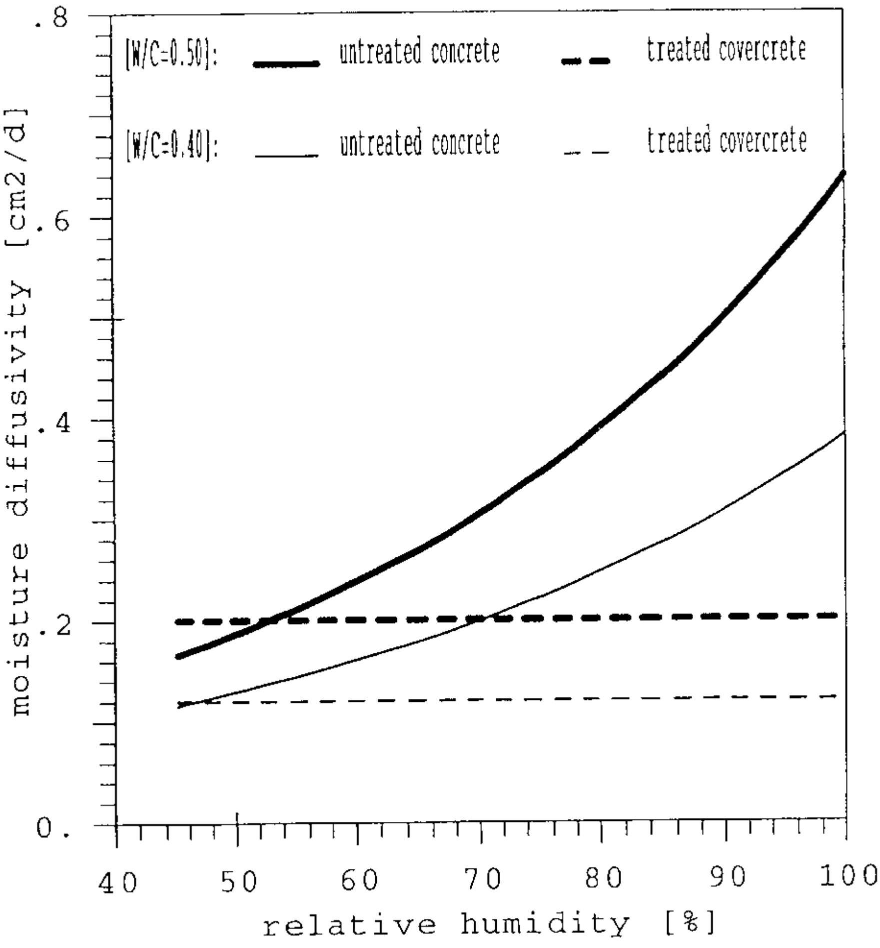

Figure 3: Diffusion coefficient for untreated and impregnated concrete

4.2 Moisture distribution

By means of the diffusion coefficients determined under section 4.1, the moisture profile as function of drying time can be calculated. In Fig.4 the moisture distribution after a drying time of 3 days, 7 days, 1 month, 3 monthes and 1 year are plotted for the concrete with a water-cement ration of 0.5.

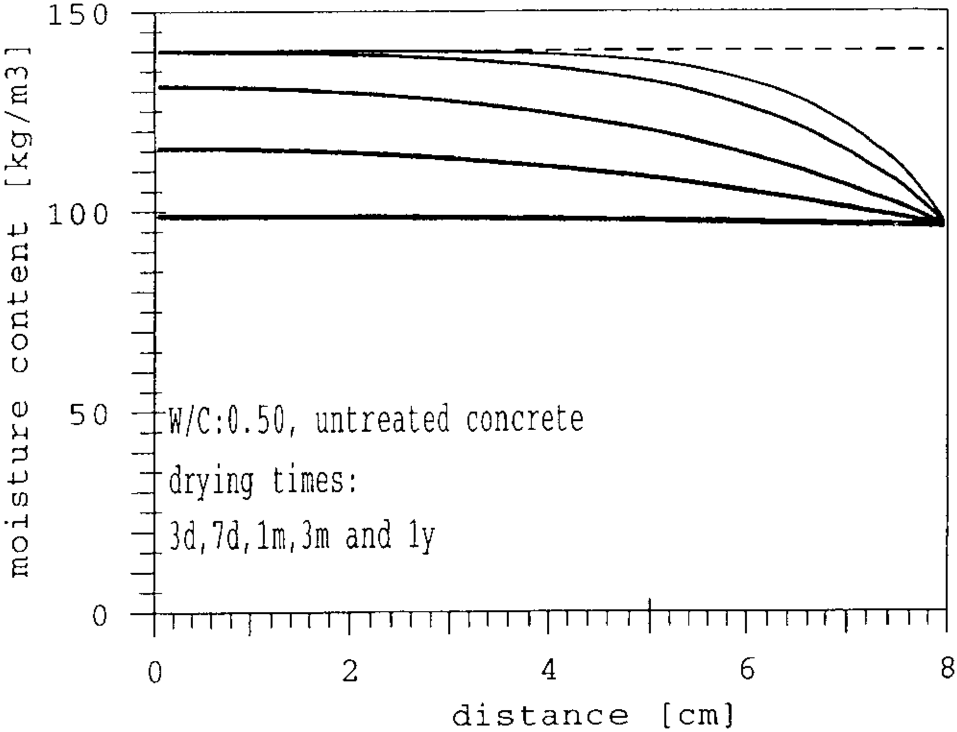

Figure 4: Moisture distribution in drying concrete with a water-cement ratio of 0.5 after 5 selected durations of drying.

If we assume that a layer with a thickness of 5 mm has been impregnated, time-dependent moisture profiles as shown in Fig.5 are obtained. The water repellent layer slows down the drying process and leads to nearly constant moisture content in the untreated concrete behind the layer. The moisture gradient in the non treated concrete becomes very small. This may have a significant influence on warping.

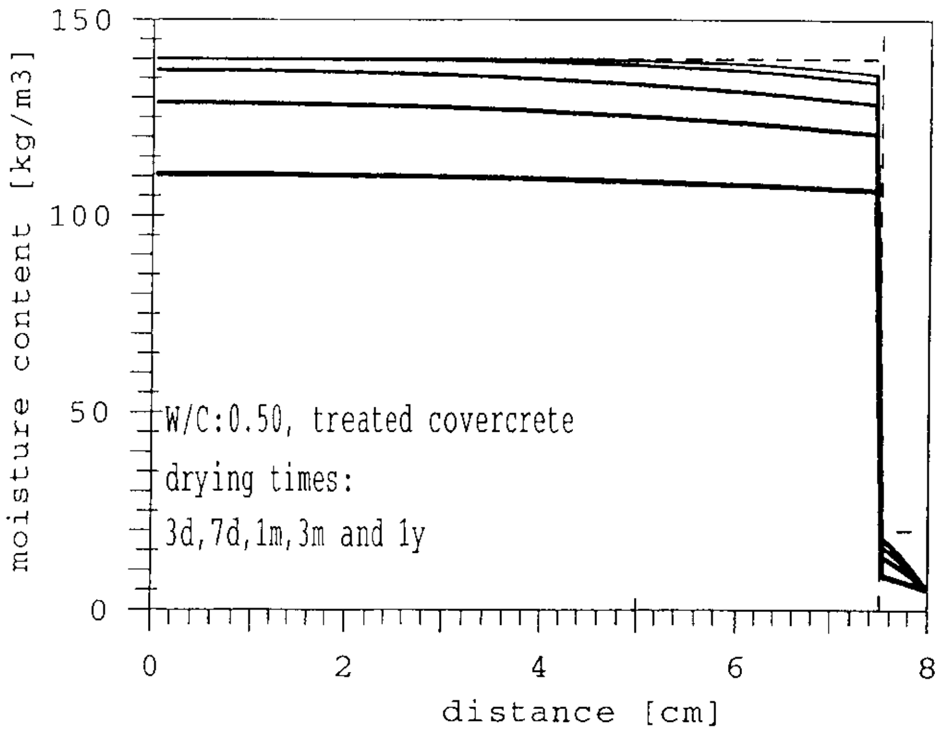

Figure 5: Moisture distribution in drying concrete (water-cement ratio = 0.5) with an impregnated layer of 5 mm thickness after 5 selected durations of drying.

4.3 An example

Let us assume that a concrete element with a thickness of 40 mm is exposed to drying conditions (40% RH, 20 °C) at two opposite surfaces. The resulting moisture distribution after a drying time of 6 monthes is indicated in Fig. 6 by a dashed line. It is further assumed that at that time the concrete element is surface treated with a water repellent agent. It is assumed that the penetration depth of the water repellent agent is 10 mm.

The surface treatment leads to a redistribution of the moisture in the untreated concrete. While in the centre the moisture content further decreases close to the impregnated layer the moisture content increases quickly. After about one year a nearly homogeneous moisture distribution in the untreated part of the element is reached.

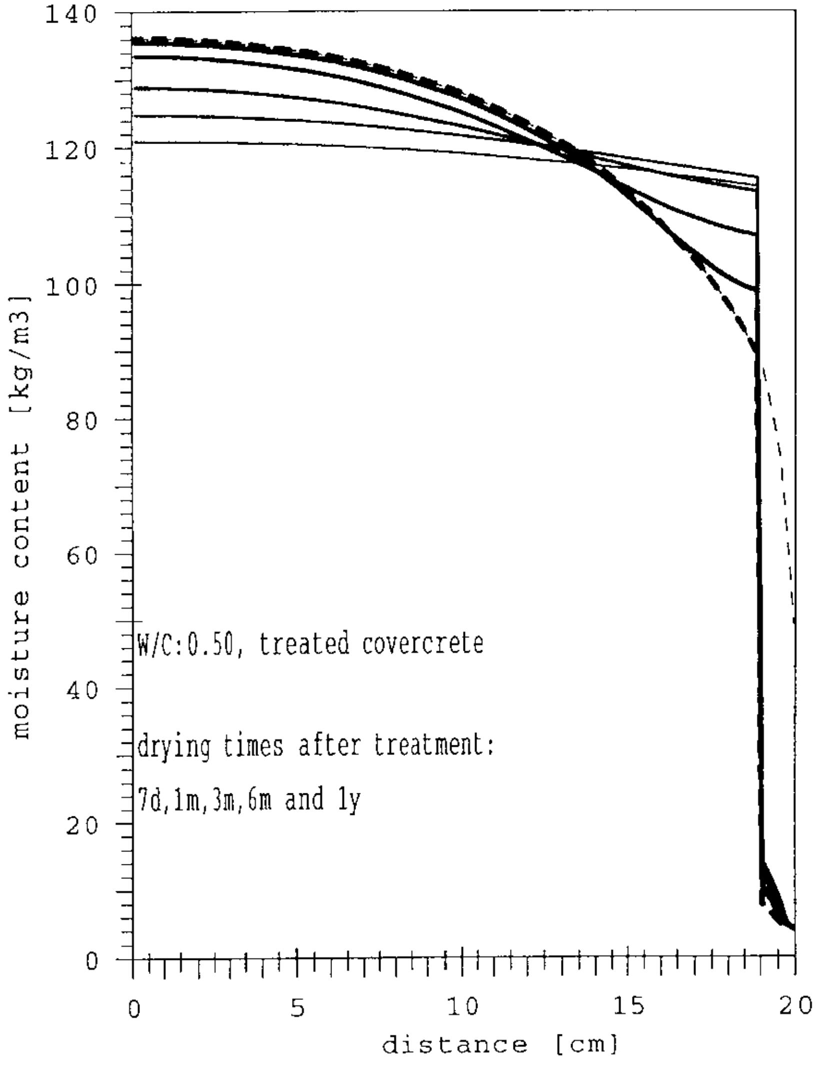

Figure 6: *Moisture distribution in a drying concrete element (water-cement ratio=0.5) which is impregnated after 6 months of drying with a water repellent agent.*

This internal redistribution of moisture leads to a complex state of eigenstresses. Further numerical and experimental investigations will show to which extent this process may cause damage of impregnated concrete elements.

5 Conclusions

From experimental drying data, moisture diffusivities of treated and untreated concrete can be determined by means of an adequate inverse analysis.

The moisture diffusivity of water repellent treated concrete is constant and very low as compared to the untreated concrete.

An application of water repellent agent on a concrete surface element leads to an internal moisture redistribution in the bulk of the material. The moisture gradient in the untreated part is significantly reduced.

Further experimental studies and numerical analyses are needed to investigate the risk of a water repellent treatment with respect to damage of concrete.

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