Fracture Mechanics of Concrete Structures,
Proceedings FRAMCOS-2, edited by Folker H. Wittmann,
AEDIFICATIO Publishers, D-79104 Freiburg (1995)

INFLUENCE OF DRYING INDUCED DAMAGE ON THE HYGRAL DIFFUSION COEFFICIENT

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Abstract

In most hygral analyses the drying process and crack formation due to shrinkage stresses are treated as independent processes. It has often been speculated that crack formation and damage in the highly stressed outer layers of a drying concrete element ought to increase the rate of drying. Comparative tests have been carried out on concrete cylinders with and without hygral damage. Drying induced damage has been prevented in half of the samples by using flat cylindrical specimens. In these short cylinders, hygral stresses cannot be built up because of the curvature of the end faces. The damaged zone in long cylinders has a slightly increased hygral diffusion coefficient. The variation of the hygral diffusion coefficient due to shrinkage damage, however, is small enough so that it can be neglected in most practical cases. This result justifies the assumption of drying process and crack formation being uncoupled.

1 Introduction

In many civil engineering applications it is necessary to carry out a rigorous hygral analysis in order to prevent uncontrolled cracking. The first step in such an analysis is the realistic prediction of the time-dependent moisture distribution in a concrete element or in a complete structure. Pihlajavaara (1965) and Bažant and Najjar (1971) have shown that the drying process can be described by means of the theory of non-linear diffusion with a concentration dependent diffusion coefficient.

The moisture dependent diffusion coefficient can be determined from drying experiments by inverse analysis (Wittmann et al., 1989). Some results obtained in this way from experiments on ordinary concrete having three different W/C ratios have been described by Wittmann (1990). Alvaredo (1994) has used the same method to determine diffusion coefficients of different types of concrete.

The moisture dependent diffusion coefficient allows us to predict the time-dependent moisture distribution under given boundary conditions. If the coefficient of hygral dilatation and the non-linear fracture mechanics parameters, i.e. fracture energy and strain softening, are known, warping (Alvaredo, 1995 and Alvaredo et al., 1995), shrinkage, and hygral crack formation of drying concrete elements (Alvaredo, 1994) can be predicted.

In most hygral analyses so far, drying process and crack formation have been considered to be uncoupled. This means that crack formation in the outer layers of concrete is considered to have no or only a negligible influence on the moisture diffusion. Bažant and Raftshol (1982) have developed a model in order to estimate the influence of real cracks on drying. Later, Bažant et al. (1987) described experiments to check the theoretical predictions. They have introduced real cracks with a constant width and a regular spacing into a reinforced concrete beam. The micro-cracking initiated by shrinkage in unbent companion specimens has been assumed to be negligible. The measured relative weight loss during drying showed a small but significant influence of real cracks with a crack mouth opening of about 0.1 mm.

In this contribution, the influence of microcracking in the drying outer layer on the hygral diffusion coefficient shall be studied. In case this effect turns out to be small it is justified to deal with drying and damage under hygral gradients as uncoupled processes.

2 Preparation of specimens and experiments

In order to study the influence of damage on the diffusion coefficient cylindrical specimens of concrete with a diameter of 80 mm and a length of 400 mm were prepared. From these cylindrical specimens with a height of 20 mm and 320 mm were cut. All specimens were kept under water until the age of seven days. The end faces of the cylinders were covered by an expoxy coating. In this way, radial symetry of the drying process is achieved. In addition, identical tests have been carried out on drilled cores, taken from cubes and made with the same concrete.

Drying does not provoke any noticeable damage in the short specimens because hygral stresses are strongly reduced due to the curvature of the end faces. The long specimens, however, have a zone in the centre where hygral stresses are fully developed.

Concrete was mixed with a water/cement ratio of 0.5 and a cement content of 350 kg/m^3. The diameter of the maximum aggregate was 32 mm while the size distribution was close to a Fuller curve.

After seven days water curing the specimens were subdivided in three groups and placed in rooms with different relative humidities: 75%, 60% and 45%. The temperature was kept constant at 20°C. The water loss under these conditions was followed as function of time by weighing after regular intervals. All experimental results are compiled in an internal report (Helbling, 1995).

3 Experimental results

The observed difference of drying rate of short undamaged and long damaged cylinders is small and partly shaded by the usual scatter of experimental results. The effect is slightly more pronounced when measured on cast specimens as compared to results obtained on drilled cores.

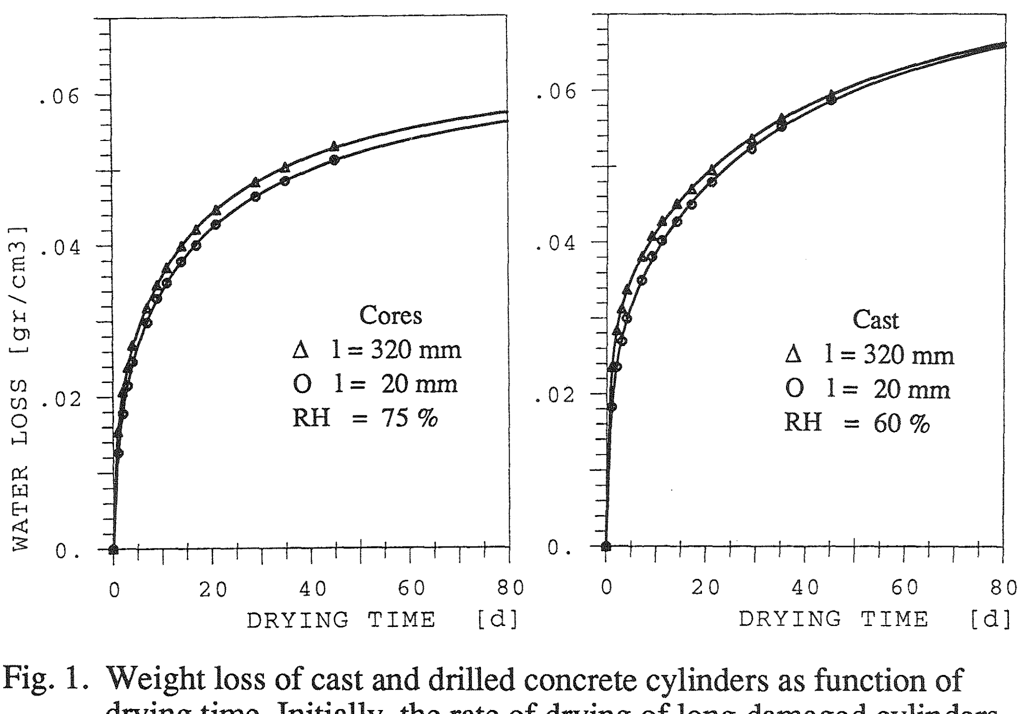

Fig. 1. Weight loss of cast and drilled concrete cylinders as function of drying time. Initially, the rate of drying of long damaged cylinders is slightly higher.

In Fig. 1, results of two drying series are shown as an example the weight loss of drilled cores with a diameter of 80 mm in an environment of 75% RH and the weight loss of cast cylinders placed in an environment of 60% RH is plotted as function of drying time. Mean values of three individual drying tests for short and long specimens, respectively, are shown in Fig. 1. It can be seen that the longer specimens initially dry slightly quicker. This increased drying rate is attributed to shrinkage induced damage.

The solid lines shown in Fig. 1 have been obtained by a best fit of the parameters of the following equation to the experimental values:

$$\Delta W = \frac{a_1 t}{b_1 + t} + \frac{a_2 t}{b_2 + t} \tag{1}$$

4 Evaluation of experimental results and discussion

It is assumed that the moisture dependence of the diffusion coefficient of an undamaged element can be expressed by the following equation:

$$D_1(W) = A_1\, exp\left(A_2 \frac{W}{W_0} \right) \tag{2}$$

W_0 stands for the moisture content at saturation.

Further, for the sake of simplicity, it is assumed that the undamaged concrete is a homogeneous material with the same D(W) all over the volume. This means the well-known border effect is not taken into consideration.

In the case of the long and damaged specimens it is assumed that the diffusion coefficient in the outer layer (thickness d=15 mm) is increased and can be written in the following way:

$$D_2(W) = D_1(W) + B_1\, exp\left[B_2 \frac{W}{W_0} \right] \tag{3}$$

$D_1(W)$ the diffusion coefficient for the short undamaged drilled cylinders has been determined as on the basis of experimental results shown in Fig. 1 by inverse analysis. The obtained values for A_1 and A_2

are given in the following equation:

$$D_1(W) = 0.9 \bullet 10^{-4} exp\left[12.92 \frac{W}{W_0}\right] \tag{4}$$

A similar procedure but based on the drying experiments of long damaged drilled cylinders leads to the following diffusion coefficient:

$$D_2(W) = D_1(W) + 4.5 \bullet 10^{-5}\, exp\left[12.21 \frac{W}{W_0}\right] \tag{5}$$

Results shown by equ.(4) and equ.(5) are graphically represented in Fig. 2.

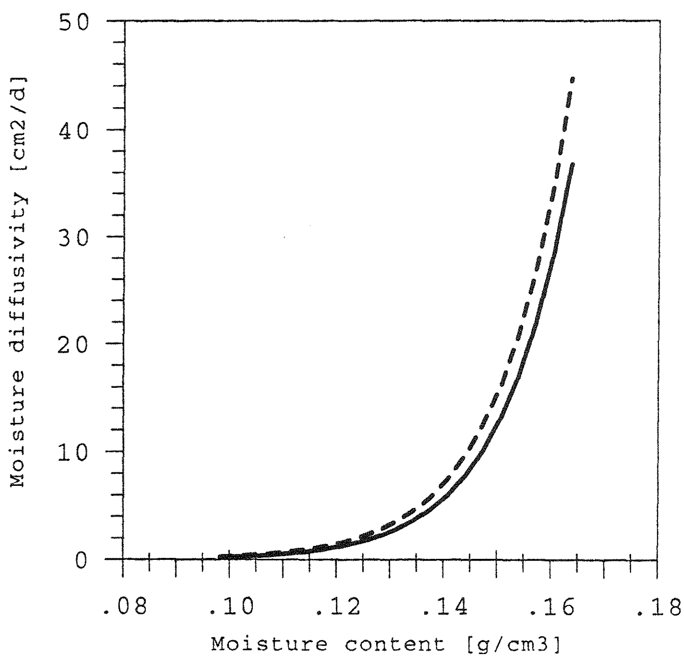

Fig. 2. Moisture dependent hygral diffusion coefficient of concrete. The dashed line indicates the slightly increased diffusion coefficient of concrete damaged by shrinkage stresses

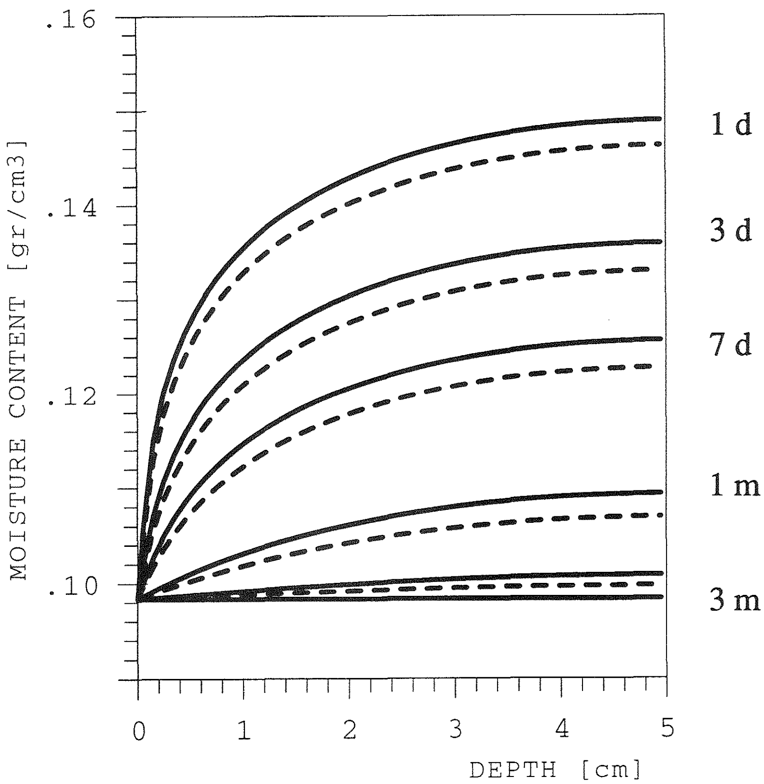

Fig. 3. Moisture distribution after different durations of drying in damaged (dashed lines) and undamaged (solid lines) concrete

Using the diffusion coefficients of the damaged and undamaged material the time dependent moisture distribution has been calculated. The result is shown in Fig. 3. A modest influence of surface damage due to shrinkage can be observed.

5 Conclusions

It has been shown that damage in the outer layers of drying concrete specimens originated by hygral stresses increases slightly the rate of drying.

This effect is very small and will remain within the usual scatter of material properties in most cases.

We may conclude that it is justified to consider drying process and crack formation to be uncoupled.

Acknowledgement
I gratefully acknowledge support by coworkers. Dr. H. Sadouki has carried out the inverse analysis and A. Helbling was responsible for the precise measurements

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