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Moisture Diffusion Coefficient of Impregnated Concrete

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Abstract

In order to understand the mechanisms of water repellent agents it is important to have reliable data on how the moisture diffusion coefficient is affected by hydrophobic treatment. The results from the experiment described below will be used as input data in a project aiming at creating a computer model for simulations of moisture and material transport in impregnated concrete structures. Two types of concrete with water/cement-ratio 0.8 and 0.45 have been investigated with the cup-method to determine the moisture diffusion coefficient. Half of the specimens have been completely impregnated with triethoxy(2,4,4-trimethylpentyl)silan by capillary suction and the other half were left untreated. This silan is one of the most common used water repellents on the Swedish market. Four different saturated salt solutions are used to create relative humidity (RH) between 85 % and 97 % inside the cups while the surrounding environment holds 50 % RH. Three cups for each situation and in addition two cups with pure water give a total of 50 cups. The loss of weight has been monitored ones a week until stable results were obtained.

1 Introduction

In order to understand the mechanisms of water repellents it is important to have reliable data on how the moisture diffusion coefficient is affected by hydrophobic treatment. The material properties of untreated concrete are well documented but what happens with the moisture fixation and transport mechanisms when the concrete turns from hydrophilic to hydrophobic which is the case for the surface layer when treated with a water repellent?

In [1] the overall purpose of this PhD-project to create a prediction model is described. The results from the experiment described below will be used as input data in a project aiming at creating a computer model for simulations of moisture and material transport in impregnated concrete structures.

The approach is to create a two layer model where the material properties is established separately for each layer and then combined with the correct thickness of the impregnated layer in order to simulate the real situation.

2 Method

2.1 Preliminary remarks

The moisture diffusion coefficient has been measured with the dry cup method [2, 3]. This method has been used before [4] on silan treated concrete but only with pure water in the cups and not completely impregnated. In this investigation four different saturated salt solutions have been used stretching from relative humidity (RH) 85.1 % to 97.6 %. The following salts were used inside the cups giving the RH as follows for 20 ºC [5].

- KCl (85.1%)
- $BaCl_2$ (91.0%)
- KNO_3 (94.6%)
- K_2SO_4 (97.6%)

Two cups with pure water has also been used to create 100 % RH. With a surrounding environment of 50 % RH it is possible to establish how the moisture diffusion coefficient depends on RH. Using Kirchhoff's potential it is thereby in theory possible to calculate the moisture diffusion coefficient in a range from 50 % to 100 % RH. The theory is described in section 2.3.

2.2 Preparation of cups

Two types of concrete with water/cement-ratio 0.8 and 0.45 have been used in this experiment. Both were cast from a Portland cement in 150 mm cubes and conditioned for a month in 70 % RH. The maximum size of aggregate

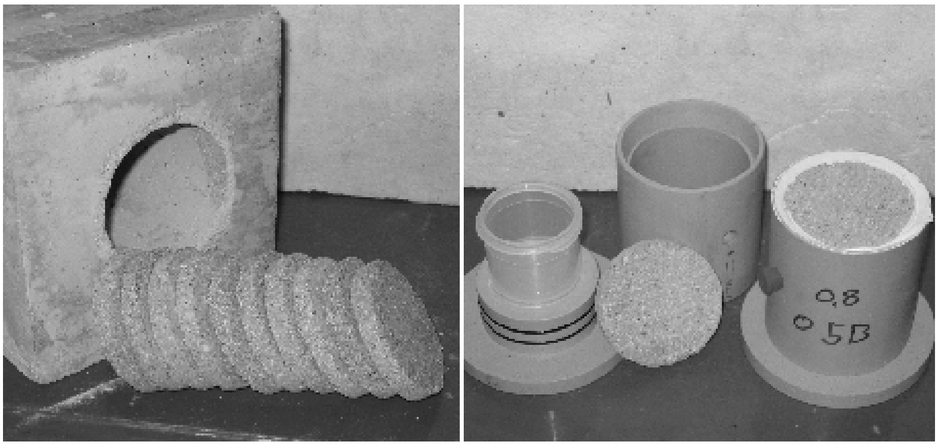

Figure 1: On the left hand side a photo showing a 150 mm cube with a few concrete plates. On the right hand side a photo of a cup that was used in this experiment and the different parts of it

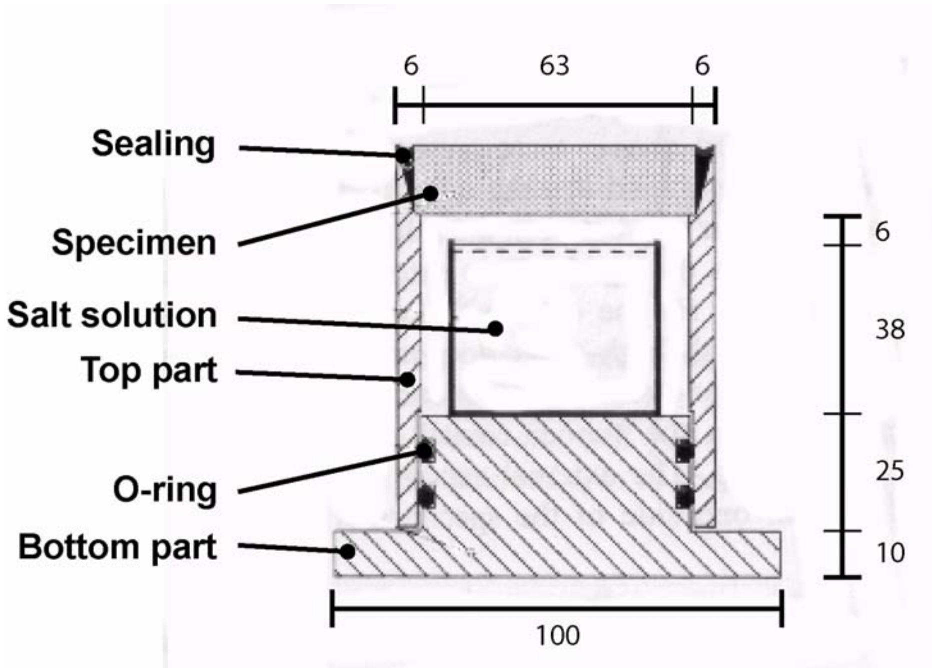

Figure 2: A drawing of the dry cup used in the experiments, numbers given in mm. [6]

was set to 4 mm. A 63 mm core was drilled out of the cube and cut into 10 mm thick plates (Figure 1). Half of the specimens have been completely impregnated with triethoxy(2,4,4-trimethylpentyl)silan by capillary suction and the other specimens were left untreated. The penetration depth of the silan in the plates was verified by cracking the specimens and dipping it in water. The plates were mounted on to the cups with a sealant in order to secure a one dimensional flow.

Four different saturated salt solutions were used as mentioned above. Three cups for each situation and in addition two cups with pure water give a total of 50 cups. The loss of weight has been monitored ones a week until stable results were obtained. The setup is shown in Figure 1.

2.3 Theory

In this method two different constant humidity levels are created on each side of a test specimen. In this setup the specimens consist of circular plates according to Figure 2.

The mass flow rate is measured by weighing the cup regularly, thus registering the weight change of the cup. The diffusion coefficient is then calculated from Fick´s first law in one dimension and steady state diffusion [7]:

$$q = -D_v \frac{dv}{dx} \tag{1}$$

where q [kg/m^{2}s] is the moisture flow, D_v [m^2/s] the diffusion coefficient and dv [kg/m^3] the difference in vapour content over the distance dx [m]. This is the ordinary way to establish the moisture diffusion coefficient but then it is only possible to determine the diffusion coefficient for certain intervals and not as a continuous function of RH. There is of course possible to increase the amount of cups and saturated salt solutions and thereby achieve smaller intervals and a higher accuracy but it would take a lot of time and effort. Another more efficient way to approach this problem is to use Kirchhoff's flow potential [2, 3]:

$$\psi = q \cdot dx \tag{2}$$

where ψ [kg/ms] is the Kirchhoff's flow potential. The potential is then plotted against RH and mean value curve is drawn. The gradient to this curve divided with the vapour content for saturated air at 20 ºC [8], according to eq. (3), represents the moisture diffusion coefficient (Figure 3).

$$\frac{d\psi}{dv} = -D_v \text{ where } v = v_S(T) \cdot \phi \tag{3}$$

where v_s [g/m^3] is the vapour content of saturated air at a given temperature and ϕ is the relative humidity.

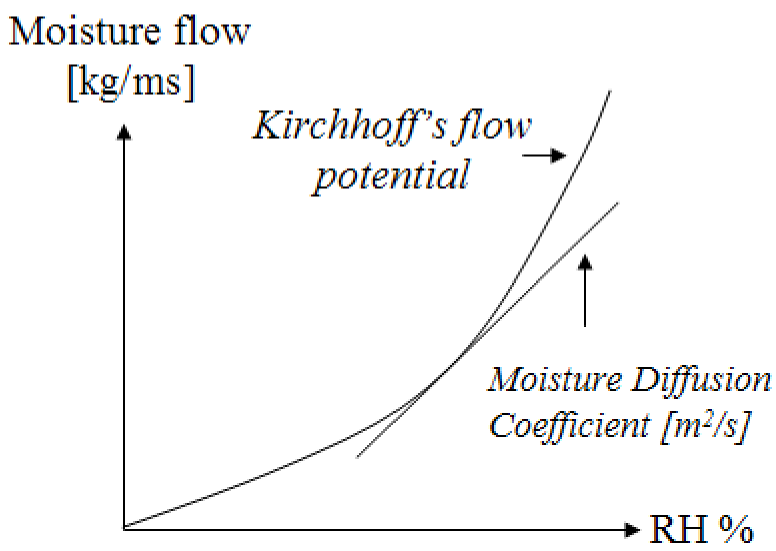

Figure 3: Kirchhoff's flow potential as a function of RH. The moisture diffusion coefficient is given as the gradient multiplied with the vapour content in saturated air at a given temperature

2.4 Influence of air column

In theory the RH inside the cup is given by the saturated salt solution. However, this value is only valid very close to the solution surface and if the air inside the cup is not circulated the RH right under the concrete plate will not be the same as close to the solution surface. This has to be considered in the calculations. Figure 4 shows a basic drawing of the setup for the calculations.

Eq. (1) combined with eq. (3) can be rewritten into:

$$q = -D_v \frac{(\phi_1 - \phi_2) \cdot v_s}{dx} \Rightarrow \phi_1 = \phi_2 - \frac{q\frac{dx}{D_v}}{v_s} \tag{4}$$

With a known moisture flow, the moisture diffusion coefficient of air [9] and a measured thickness of the air column it is now possible to calculate the reduction of RH as the air column causes for each cup.

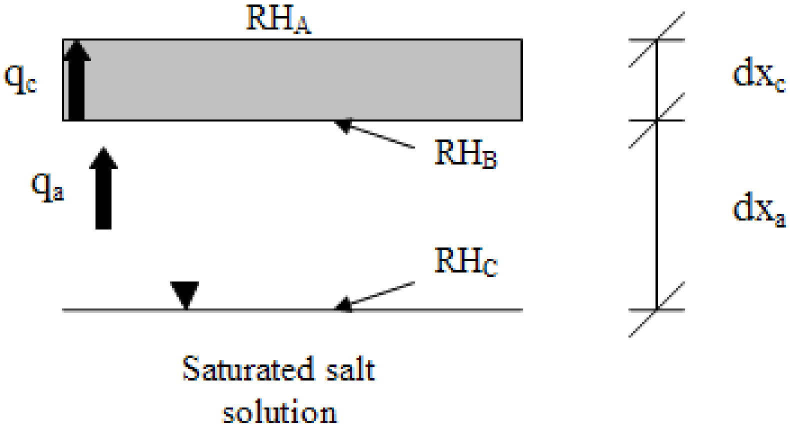

Figure 4: Picture of the concrete specimen, air column and the saturated salt solution. Using the fact that the moisture flow q_a=q_c makes it possible to use equation (3) to calculate the influence of the air column

3 Results

3.1 Preliminary remarks

For different reasons such as insufficient mounting and handling, six cups have been removed from the results. Because of the high change in flow over 97 % RH and thereby increasing uncertainty about the accuracy of the results, the diffusion coefficient is only presented from 50 % to 97 % RH.

3.2 Kirchhoff's flow potential

Figure 5 shows how the potential increases with increasing humidity. The values for the untreated cups correspond well to [2] for both w_0/c = 0.8 and w_0/c = 0.45. Interesting to notice is that the differences between the treated w_0/c = 0.8 and w_0/c = 0.45 were so small that they were represented with the same mean value curve. This will be discussed further in the evaluation of the results.

3.3 The moisture diffusion coefficient

From Kirchoff's flow potential the moisture diffusion coefficient was derived according to the theory part described in section 2.2. Figure 6 shows the results. The diffusion coefficient for the treated specimens could maybe be approximated with a constant and the deviation from a straight line between 90 % and 100 % RH, that this experiment indicate, must be further investigated before it can be established as a fact.

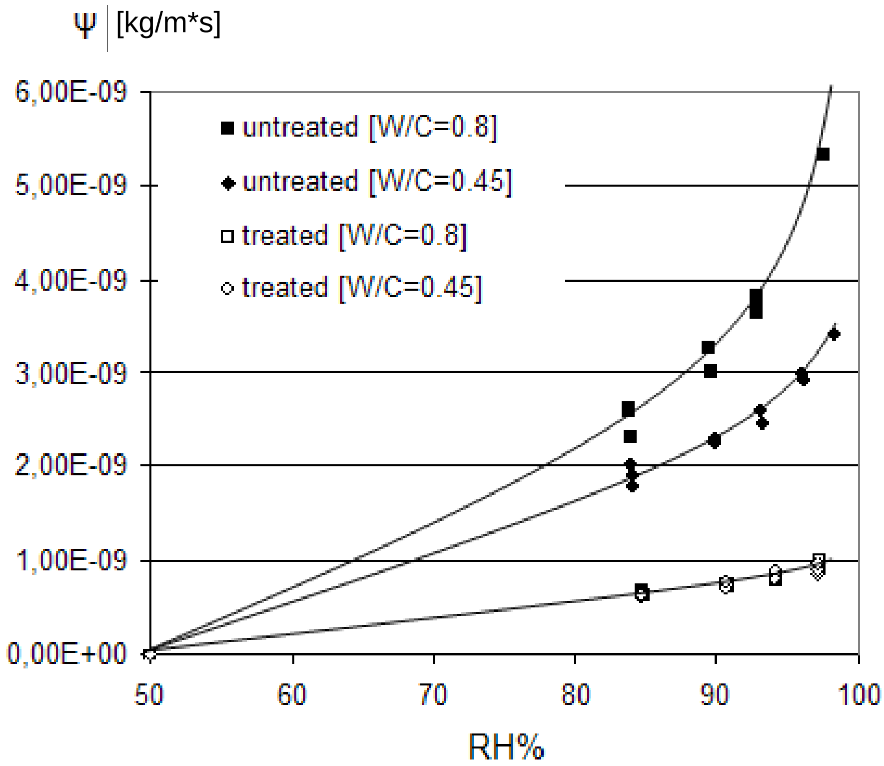

Figure 5: Kirchhoff's flow potential. The measured weight loss presented as kg/ms. The curve represents the mean value and it is used to establish the moisture diffusion coefficient

4 Discussion

The main purpose of this investigation was to get knowledge on how a silan treatment affects the moisture diffusion coefficient. The results were presented in the previous chapter and they will be used in the future to make simulations on the same type of concrete that were used in this investigation. It will be interesting to see if a computer model with this data could be used to predict the moisture content over time with different penetration depths of the silan and varying humidity outside.

Beside the numerical results there are two questions that arise during the analysing of the results:

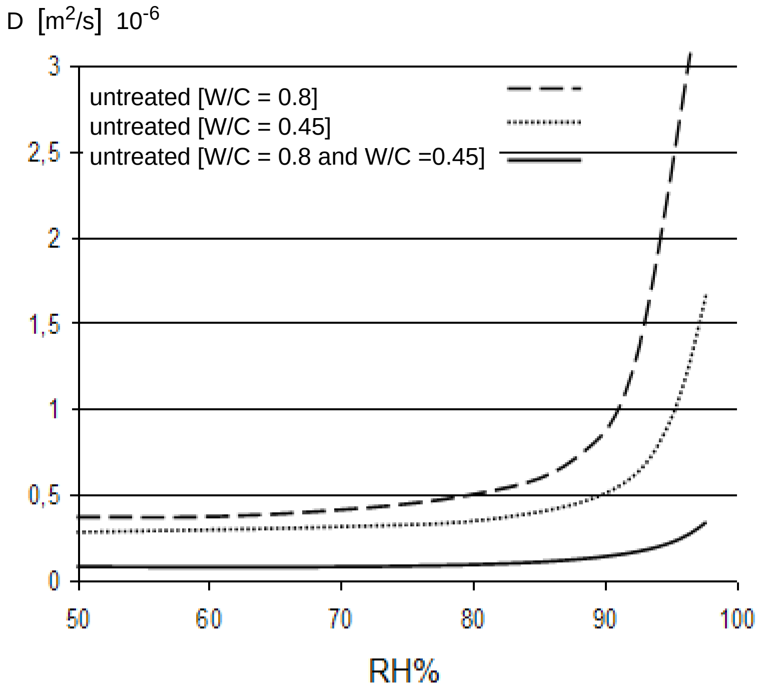

Figure 6: The moisture diffusion coefficient as a function of *RH* based on the results presented in Figure 5 and calculated according to [2]

- For untreated concrete the diffusion coefficient has an exponential increase between 85 % and 100 % RH. The silan treated specimens, on the contrary, showed a near to constant increase in the lower RH as well as in the higher one. Is it possible to approximate the diffusion coefficient with a constant for a silan treated layer of concrete?
- Why did the two w_0/c-ratios give the same result for the treated specimens?

In the case of the first question it is not possible to answer it with only this investigation to back it up. However, in [10] the same conclusion is drawn based on inverse analysis. The diffusion coefficient of the treated layer is approximated with a constant and the conclusion is that the transport of water vapour is the only transport taking place and thereby it is linear function of the difference in RH which thereby gives a constant gradient. This seems reasonable and the deviation in this cup measurement could maybe

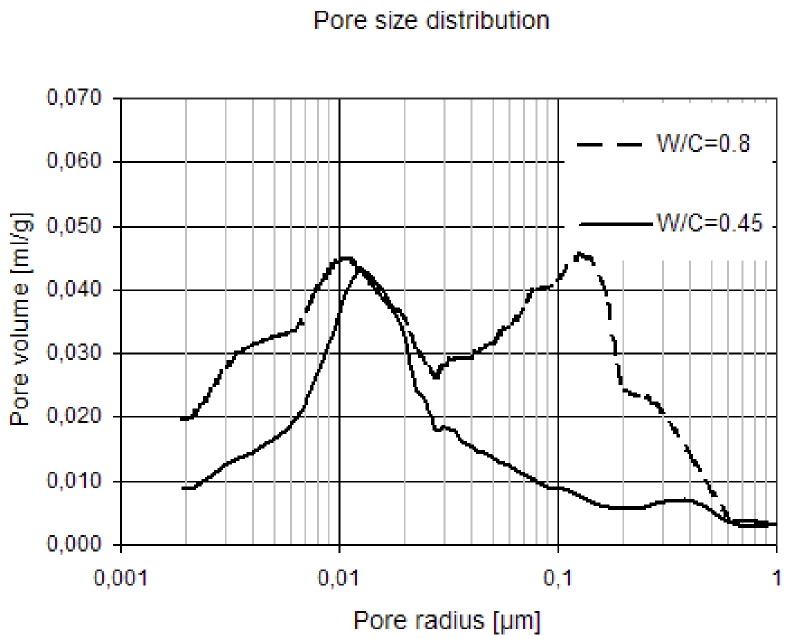

Figure 7: MIP of the two different types of concrete that were used. Below a pore radius of 20 nm the two curves are similar which indicates that the silan treatment could have shut off the bigger pores, see Figure 6 for comparison

be explained with a non complete treatment of the capillary pores. This remains to be seen.

The second question is more difficult and nothing in the literature indicated that the same constant diffusion coefficient could be used for treated concrete with high as well as low w/c-ratio. It is not a secrete that a water repellent is more efficient on a high w_0/c-ratio but it is a big difference between w/c = 0.8 and w/c = 0.45 in the capillary porosity. To find out why this strange result came out of this experiment, a mercury intrusion porosimetry (MIP) was made and the results actually gave a possible explanation, Figure 7.

The MIP curves indicate that below 20 nm the two different concrete types have a similar pore system. One way to interpret this is that the silan treatment has shut off the larger pores and the main part of the vapour transport takes place in the narrower pore system which more or less remains untreated.

5 Conclusions

Based on this investigation the following conclusions can be drawn:

- The dry cup method with the use of Kirchoff's potential in the calculations is an efficient way of measuring the moisture diffusion coefficient.
- The moisture diffusion coefficient for isooctylsilan treated concrete is close to constant and not nearly as dependent on the RH as untreated concrete.
- Vapour transport is the dominant transport mechanism, even at high RH for isooctylsilan treated concrete.
- The vapour transport of isooctylsilan treated concrete is highly reduced compared to untreated concrete and its larger capillary pores are shut off.

These conclusions are based on one investigation using 50 specimens. More experiments are needed to establish them as facts.

6 Acknowledgement

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7 References

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