COMPARISON OF DIFFERENT METHODS TO EVALUATE MOISTURE TRANSPORT COEFFICIENT IN CEMENT BASED MATERIALS

M.Saeidpour[1], L.Wadsö[1]

[1] *Lund University, Building Materials, Lund, Sweden*

Introduction

In view of importance of water transport to the durability of structures a lot of research has been undertaken both experimentally and theoretically on the prediction of diffusion in cement pastes, mortars and concrete during last decades see for example[1, 2]. There are two principally different methods to measure transport properties of cement-based materials. In steady-state methods (for example the cup method) a potential difference is applied over a certain thickness of a sample and one waits until steady state is reached. In non-steady state methods (for example the sorption method) the mass gain or loss of sample as a function of time is measured and the diffusivity is evaluated. In the cup method the vapour content is the natural potential (driving force) to use as different relative humidities are created on two sides of the sample, while in sorption methods the moisture content is the relevant potential as the mass change of whole sample is measured. Because of this the two types of measurements give transport coefficient expressed using different potentials, but recalculations from one to the other are possible using the sorption isotherm.

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

$$J = -D_c \frac{dc}{dx} \tag{2}$$

$$D_v = D_c \frac{dc}{dv} \tag{3}$$

$$\frac{dc}{dv} = \frac{\rho}{v_s} \frac{du}{d\varphi} \tag{4}$$

Here J ($gm^{-2}s^{-1}$) is mass flux D_v (m^2s^{-1}) and D_c (m^2s^{-1}) are transport coefficients with vapour content and concentration as potentials, respectively v is vapour content (gm^{-3}), c is moisture content (gm^{-3}), v_s is vapour content at saturation (gm^{-3}), ρ is density of the material (gm^{-3}) and $\frac{du}{d\varphi}$ is the slope of sorption isotherm [3].

A complication with transport properties for cement based material is that the supplementary cementitious materials (SCMs) that are used significantly change the micro and nano structures of the C-S-H and this will affect transport properties. Due to today's increasing use of blended cements there is a need to increase the fundamental understanding of the transport properties of blended cements, including an increased understanding of the correlation between results from different methods to measure transport coefficients.

In the present paper we present the first results from a study of the influence of SCMs on the sorption and transport properties of cement pastes and mortars. The measurements have been made with one steady-state method and one non-steady state method. The measurements presented have been made in desorption and in small relative humidity intervals and will thus also give information about the concentration dependence of the transport coefficients. The influence of W/C ratio and differences between the different materials are also discussed, as in the non-Fickian behavior of the non-steady state results.

Experimental

The samples used for the cup measurements were cement mortars with three different binders: ordinary Portland cement (OPC) (CEMI), OPC with 10% silica fume and OPC with 70% slag (CEMIII) with water to cement ratios of 0.4 and 0.5. The samples were cylindrical discs with a diameter of 64 mm and a thickness of approximately 12 mm which were drilled and cut from casted blocks that had hydrated under sealed

conditions for 90 days. Before the measurements the discs were partially saturated by absorbing water from wet clothes to ensure that the measurements were made under desorption. The discs were placed as lids on cups and sealed with vapour tight sealant. The cups contained saturated salt solutions with different relative humidities (100, 97.6, 94.6, 85.1, 54.4 and 33.1%). To improve the cup method a new carbon dioxide free setup for measurements was built; this also features a reduced external boundary layer resistance. The cups were placed in boxes with 75.3 % relative humidity and the mass of each cup was regularly determined without changing the climate in the boxes. When the mass change rate was constant the steady state flux had been reached and the diffusion coefficient could be calculated.

The samples used for the sorption method were cement pastes with same binders and water-cement ratios as for the cup samples. Samples were cast in stainless steel tubes (height 1 or 2 mm, inner diameter 5.5 mm). The samples were hydrated in sealed containers at 20 ºC for 90 days and then partially saturated by absorbing water from wet clothes for two weeks. In the sorption method the mass change of samples exposed to different RH steps in a sorption balance is measured and the diffusivity in different moisture content intervals is measured using an equation based on Fick's law. As the samples are weighed it is also possible to simultaneously determine the sorption isotherm.

Results and discussion

The diffusivity (moisture content as potential) (D_c) was measured and diffusion coefficient (D_v) with vapour content as potential was calculated using the slope of the sorption isotherm (also measured with the sorption method). The D_c and corresponding D_v calculated for the OPC paste with W/C=0.5 is shown in Fig1.

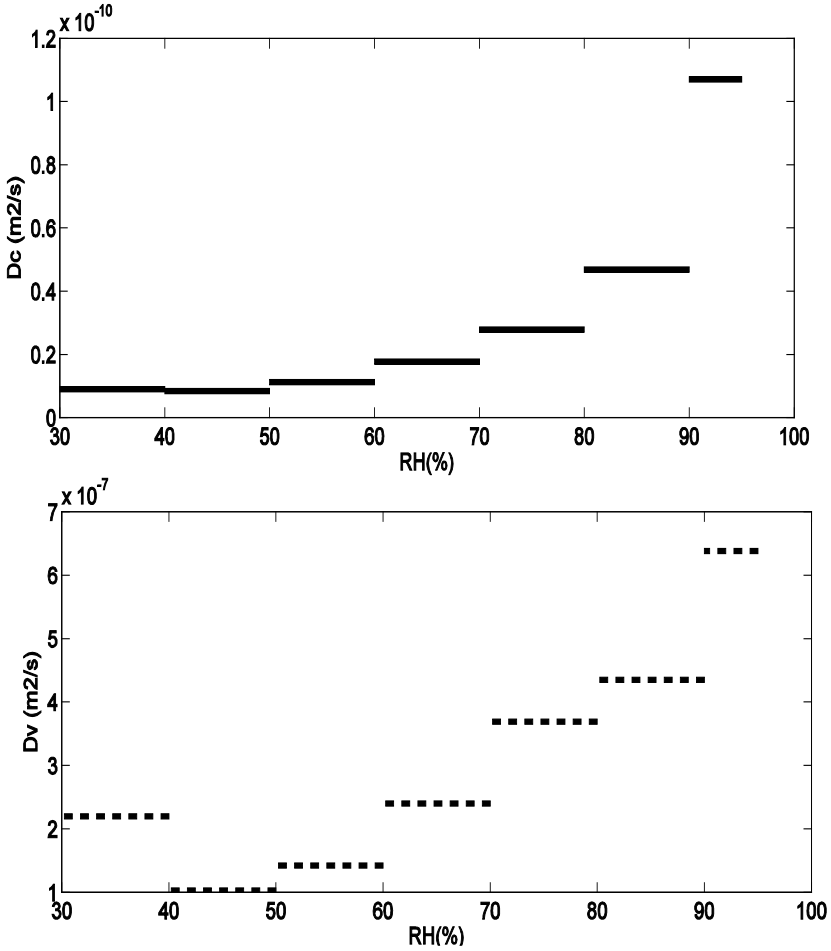

Fig. 1: The diffusivity (D_c) measured with the sorption method and the corresponding diffusion coefficient (D_v) calculated for OPC paste W/C=05.

The sorption method results showed that Fick's law cannot completely describe the mass change. The main problem is that there the time scales for the final sorption are much longer than expected from the initial part of the results. In this case a special care should be taken to use the correct part of the curve to calculate diffusivity [4]. As our analysis of the non-Fickian results is not finished some care should be exercised in interpreting the results of our sorption results. Comparison of the sorption method results with cup method is complicated due the presence of aggregates and also the interfacial transition zone (ITZ) [5] in mortar samples, but a qualitative comparison shows that the results from two methods is rather similar, as is seen in Fig 2.

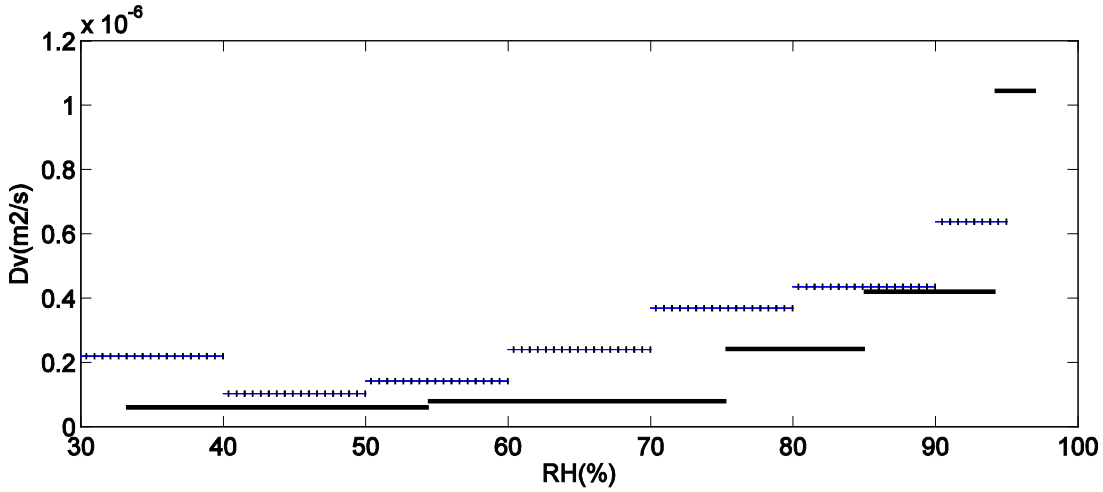

Fig. 2: Diffusion coefficient measured with sorption method (.....) for OPC paste W/C=05, and cup method for OPC mortar W/C=0.5. Both samples were in desorption

The results of cup method for different relative humidity intervals and different cement binders are shown in Fig 3. The reduction in the diffusion coefficient in the present of silica fume and slag is about a factor 10. The results of both the sorption method and the cup method in different relative humidity intervals both show in samples with OPC binder below 75% relative humidities there is a small increase of D_v with increase in relative humidity, while at higher RH intervals there is a strong increase of D_v with relative humidity.For samples with W/C=0.5 ratio there is a sharper increase in D_v at higher relative humidities than for the samples with W/C=0.4. In the presence of SCM's the situation is different and in samples with slag and silica the diffusion coefficient less affect with increase in relative humidity (Fig 3).

As mentioned above, the detailed interpretation of the present results is complicated by that the sorption results show clear non-Fickian behavior. It is not at present clear how macro-transport coefficients should be calculated from non-Fickian sorption results. In the present study we have use the first linear part of mass change rate of sorption curve to evaluate the diffusivity with equation based on second Fick's law, but there are clearly other methods to do this calculation. The non-Fickian aspect of the sorption results is discussed in another paper to this conference [6].

A second complicating factor is the aggregate and the transport associated with ITZ. Because of size constraints it was not possible in the present study to run both cup and sorption measurements with either paste or mortar, and the interpretation results is therefore not-trivial. However, at least for the OPC 0.5 the decrease of the diffusion caused by the aggregate of the mortars seems to be offset by the increased transport in the ITZs, as the results from the two methods are rather similar.

A third complication in the evaluation of the present results is that a whole sorption measurement series is made on one specimen that goes through an RH-program, but for the cup measurements we used three specimens for each RH-interval. As there is a spread in material properties (and possibly also errors in the sealing of some cups), there will be a spread in the cup results that needs to be evaluated. For the present evaluation we used the mean of all measurements in each RH-interval.

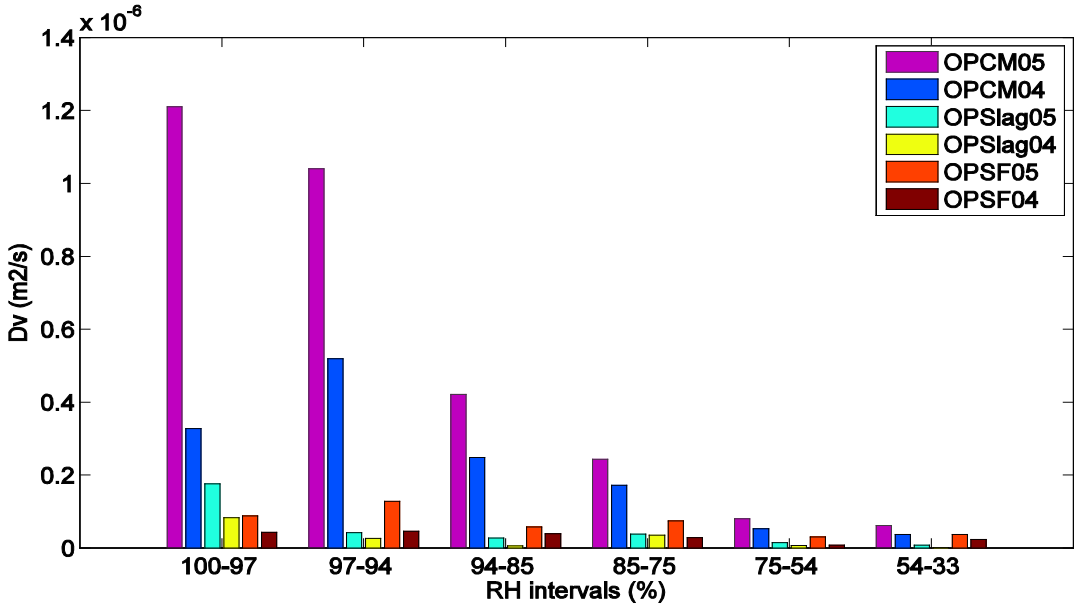

Fig. 3: Diffusion coefficient of six mortar samples with different binders and two different W/C ratios (0.5 and 0.4) (see legend) from cup measurements.

ACKNOWLEDGEMENTS: We acknowledge the support of the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement 264448.

REFERENCES:

1. Xi, Y., et al., Moisture diffusion in cementitious materials Moisture capacity and diffusivity. Advanced Cement Based Materials, 1994. 1(6) 258-266.
2. Baroghel-Bouny, V., Water vapour sorption experiments on hardened cementitious materials. Part II: Essential tool for assessment of transport properties and for durability prediction. Cement and Concrete Research, 2007. 37(3) 438-454.
3. Nilsson, L.-O., *8 - Durability concept; pore structure and transport processes*, in *Advanced Concrete Technology Set*, N. John, et al., Editors. 2003, Butterworth-Heinemann: Oxford. p. 3-29.
4. Wadsö, L., Measurements of water vapour sorption in wood. Wood Science and Technology, 1993. 28(1) 59-65.
5. Jiang, J.-y., G.-w. Sun, and C.-h. Wang, Numerical calculation on the porosity distribution and diffusion coefficient of interfacial transition zone in cement-based composite materials. Construction and Building Materials, 2013. 39(0) 134-138.
6. Wadsö, L. and M. Saeidpour, Evidence for non-Fickian sorption in cement based materials. TRANSCEND conference, 2013.