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Moisture Diffusivity of AAC with Different Densities

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***Abstract*—**Method of determining of moisture diffusivity on two types of autoclaved aerated concretes with different bulk density is represented in the paper. On the specimens were measured one dimensional water transport only on liquid phase. Ever evaluation was done from moisture profiles measured in specific times by capacitance moisture meter. All values from capacitance meter were recalculated to moisture content by mass. Moisture diffusivity was determined in dependence on both moisture and temperature. The experiment temperatures were set at values 55, 65, 75 and 85°C.

***Keywords*—**moisture diffusivity, autoclaved aerated concrete, capacitance moisture meter

I. INTRODUCTION

THE research of moisture transport in porous building material nowadays have far-reaching relevance and hence this problem is solved by many laboratories. The concentration of moisture in porous building materials plays an important role. Because to calculate thermal and moisture parameters in capillary porous materials it´s necessary to know transport characteristic of moisture. They determine moisture transport in the given material. As main characteristic we choose moisture diffusivity. There are many experimental methods to determine of moisture diffusivity e. g. analysis of drying data, sorption kinetics and permeability measurement [1]. The experimental setup to measure sorptivity is used by many laboratories over the world. For decrypting moisture transport we didn´t use sorptivity but inverse analysis of moisture profiles. This rigorous method is based on irreversible thermodynamics. In frame of this theory was formulated transport law:

$$\vec{j} = -\rho_w D \nabla u_v \qquad (1)$$

or:

$$\vec{j} = -\rho D \nabla u_c \qquad (2)$$

where $\vec{j}$ (kg.m^{-2}.s^{-1}) is density of flux, D (m^2.s^{-1}) is diffusion coefficient, u_v (m^3.m^{-3}) moisture content of water by volume, u_c is relative concentration of water, ρ_w (kg.m^{-3}) is partial density of water , ρ (kg.m^{-3}) is bulk density of system water – skeleton.

On the base of this transport law were set one of most often used theory so called diffusion theory of moisture transport. It is only substitution equal (1) or (2) to equal continuity which give diffusion equal:

$$\nabla(D\nabla u_v) = \frac{\partial u_v}{\partial_t} \qquad (3)$$

This relation is possible to be applied on transport water in liquid phase and also vapour. In this paper we only deal with liquid phase of water.

The density of moisture flux obtained following form:

$$\vec{j} = -\rho_s \kappa \nabla u \qquad (4)$$

where κ (m^2.s^{-1}) is the moisture diffusivity, ρ_s (kg.m^{-3}) is the partial density of the porous matrix and u (kg.kg^{-1}) is the moisture content by mass.

For measuring moisture profiles it is possible to use a lot of methods. Generally it is possible to divide them on two main groups [2]. Absolute (direct) method determines real content of water from separated piece. Relative method determines moisture content by measuring other physical parameters which are connected with moisture content. In this case it is necessary to find dependence between measured values and moisture.

We can mention chemical (K. Fischer´s method, method of calcium carbide), electromagnetic (spectrometric method, nuclear magnetic resonance [3], gamma-ray method [4], radiography or scanning neutron radiography [5]), other electrical (electric resistance method [6]) or traditional physical (pycnometric, tensiometric or hygrometric) methods.

Apart from primary effects, which are moisture content and gradient of moisture content, there could be also secondary effects. In this case we accepted only influence of temperature. Other secondary effects (gradient of temperature, dissolved substance concentration, pressure gradient, external volumetric fields etc.) were eliminated. This paper would like to demonstrate importance of the temperature on liquid water transport because there are only few works which consider influence of secondary effects. One example is the work by Krischer [7], who expressed the dependence of moisture diffusivity on temperature in the form of a simple formula including the dependence of the viscosity and surface tension on temperature. But this reference is old and difficult to access.

II. MOISTURE DIFFUSIVITY

Model set in the first chapter considers only gradient of moisture as driving power for moisture transport. Constant showing the proportionality between density of moisture flux and gradient of moisture we will call moisture diffusivity coefficient κ.

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This is the parameter characterizing transport of liquid moisture in porous material. All methods for determining moisture diffusivity use one-dimensional form,

$$\frac{\partial_u}{\partial_t} = \frac{\partial}{\partial_x}(\kappa(u)\frac{\partial_u}{\partial_x}) \qquad (5)$$

where u (kg.kg^{-1}) is the moisture content by mass, t (s) is the time period and x (m) is the distance from saturated surface of the specimen [8,9]. With boundary and initial conditions:

$$u(0,t) = u_1 \qquad (6)$$

$$u(x,0) = u_2 \qquad (7)$$

Problem of moisture diffusivity calculating from moisture profiles has been solved by many years and many methods have been created how moisture diffusivity determined. For inverse analysis we use Boltzmann-Matano method [12]. This method determined moisture diffusivity from one-dimensional moisture transport and presume exclusion all other influences during measuring [9].

Boltzmann transformation transforms function two variables to function of one variable:

$$u(x,t) = \omega(\eta) \qquad (8)$$

$$\eta = \frac{x}{2\sqrt{t}} \qquad (9)$$

The advantage of the Boltzmann transformation consists of covering the partial differential equation (Eq. 5) into ordinary differential equation with new parameter η,

$$\frac{d}{d\eta}\left(\kappa(\omega)\frac{d\omega}{d\eta}\right) + 2\eta\frac{d\omega}{d\eta} = 0 \qquad (10)$$

with boundary conditions,

$$\omega(0) = u_1 \qquad (11)$$

$$\omega(\infty) = u_2 \qquad (12)$$

If we know distribution of moisture $u(x)$ in specific time t (it means t is constant and $u(x)$ is function of one variable x) we can formulate relation for the moisture diffusivity in dependence on moisture as [11]

$$\kappa(u(x)) = \frac{1}{2t\left(\frac{du}{dx}\right)_{x_0}} \int_{x_0}^{\infty} x\frac{du}{dx}dx \qquad (13)$$

where $u_x = u(x_0)$.

III. THE EXPERIMENT

A. Material specimens

For measuring we used two types of autoclaved aerated concrete P 1.8 300 and P 4 500 with different compressive strength and also bulk density. From blocks were cut specimens with sizes 40 x 20 x 300 mm. Before measurement all specimens were dried in oven at temperature 105°C to constant weight. Then all specimens were isolated by water-vapour-proof isolation over the whole surface apart from both face sides. This solution guarantees one dimensional water transport. Material properties are shown in following tables.

In the Table I are properties declared by manufacturer Xella [13]; water vapour diffusion resistance factor is stated for both wet and dry state) and in the Table 2 there are shown measured properties by Jerman et al. [14].

TABLE I
MATERIAL PROPERTIES DECLARED BY MANUFACTURER XELLA

Material	**Thermal conductivity [W.m^{-1}.K^{-1}]**	**Specific heat capacity [J.kg^{-1}.K^{-1}]**	**Water vapor diffusion resistance factor [-]**
P1.8 300	0.08	1000	5/10
P4 500	0.12	1000	5/10

TABLE II
MEASURED PROPERTIES OF USED MATERIALS

Material	**Matrix density [kg.m^{-3}]**	**Total open porosity [% - V$_{ol}$]**	**Bulk density [kg.m^{-3}]**
P1.8 300	2 451	87.4	304
P4 500	2 527	80.2	500

B. Measurement

The measurement of moisture profiles was made in conditions of one-side horizontal sample saturation. By this influence of gravity was eliminated. One-side saturation was set by sponge. It was placed in chamber which was connected with water tank. It guaranteed ideal Dirichet boundary condition. The other face side was left open so that in certain time range the boundary condition of zero moisture flux or constant moisture corresponding to the initial state could be assumed. All measurements were made under specific condition in climatic chamber, i.e. temperatures 55, 65, 75, 85°C and relative humidity 50%. For measuring moisture content was used non-destructive method. It was made by capacitance moisture meter for each 1 cm of specimens in specific time periods. Values obtained from meter were calibrated to moisture content immediately after last measuring. Then each specimen was cut to 1 cm of thickness pieces in direction of moisture flux. Moisture content by mass was obtained by gravimetric method. From values of moisture meter and gravimetric method we can find out dependence (calibration curve) between meter values and moisture contents. By this way it is possible to recalculate all capacity meter values to moisture content by mass. This setup naturally brought some inaccuracies to the whole method. First, it is factual error of used moisture meter (based on current measurements, we estimate the error of moisture meter reading approximately 0.8 - 3.4 [-]; specific value of moisture content depends on calibration curve – see chapter 3), which cannot be neglected. Second, whatever anomaly of specimen´s surface could cause subsequent distortion of measured values (we tried to avoid this by abrading it before the experiment).

C. Determination of moisture diffusivity

From measured moisture profiles in specific time and temperatures we obtained sets of data which were used as input parameters for calculating moisture diffusivity:

$$u_i = f(x,t) \tag{14}$$

Where u (kg.kg^{-1}) is the moisture content by mass, x (m) is the distance from saturated surface of the specimen, t (s) is the time of water absorption and i is the index of measurement. Moisture diffusivity in dependence on moisture content was calculated for each temperature by specialized computation programme KADET [15]. This program in the first smooth and interpolate measured data by linear filtration and from these data calculated moisture diffusivity. The smooth coefficient is unknown and it is set by user. Then the program provides recursive verification of the results by computing moisture distribution using implemented finite-element-method software TRFEL [16] and displaying it towards measured data. If there is correspondence of measured and calculated moisture profiles the computation is finish on the other hand is necessary change smooth coefficient and all process repeat. By this way we generated values of moisture diffusivity in dependence on moisture content for all measured temperatures. The dependence on temperature could be found out analytically from moisture diffusion curves.

IV. RESULTS

Values obtained by moisture meter, calibration curve, moisture profiles and recursive verification are shown only for one specimen, just to illustrate the method of evaluation of measured data. The functions of moisture diffusivity in dependence on moisture content are presented for all temperatures and for both tested materials.

Fig. 1 shows values measured by moisture meter. First 3 cm of specimen weren't measured because this part was set in apparatus and size of probe is too big.

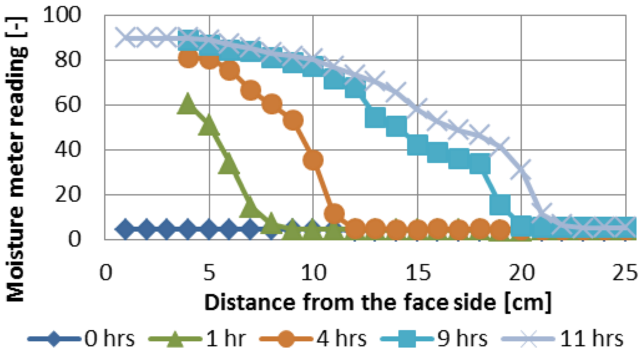

Fig. 1 Values of capacitance moisture meter

By connection values of last meter measurement and moisture content by mass (obtained by gravimetric method) we can find out calibration curve for each specimen. Calibration curve expresses the dependence between moisture meter values and moisture content by mass. So we can calculate moisture profiles in specific times.

In the Fig. 2 there is shown measured data and obtained equation also with reliability.

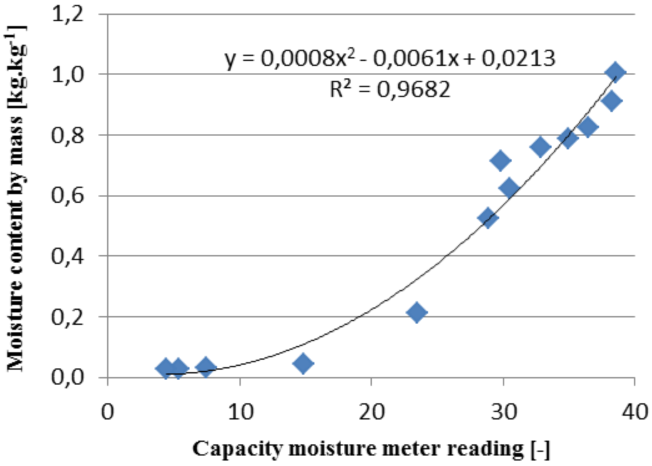

Fig. 2 Calibration curve of one specimen

By using calibration curve we have distribution of moisture content by mass on position and in specific times. At this moment we recalculated all values of moisture content by mass to moisture content by volume. From known bulk density it is easy. The moisture content by volume represented moisture distribution clearly.

Subsequently, we computed each moisture diffusivity function. Before putting all results together, thus expressing its dependence on temperature, we verified calculations towards experimental data. As an example of good agreement we present Figure 3, which is also an example of screen in KADET software [15]:

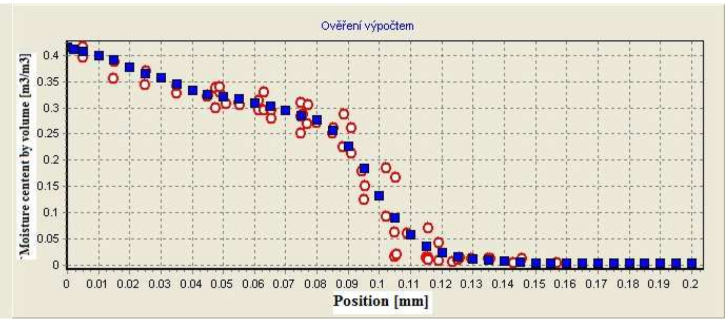

Fig. 3 Recursive verification of moisture profile

Finally by this way we calculated all values of moisture diffusivity in dependence on moisture and for set temperatures. The results are potted in Fig. 4 – 7. In each figure are two curves each for one type of measured material.

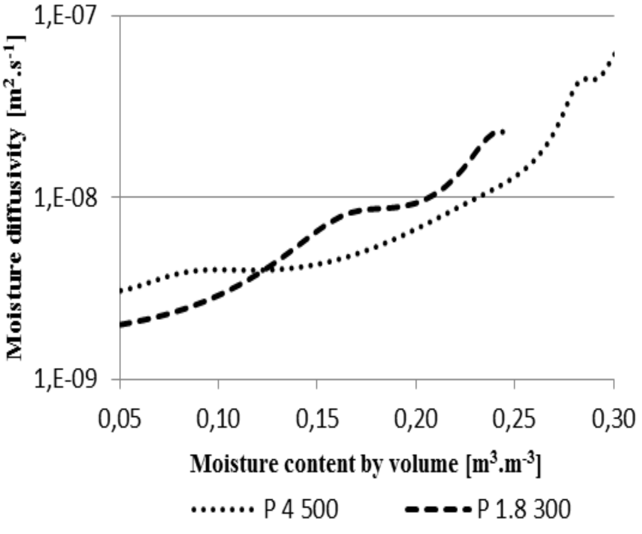

Fig. 4 Moisture diffusivity of both materials at temperature 55°C

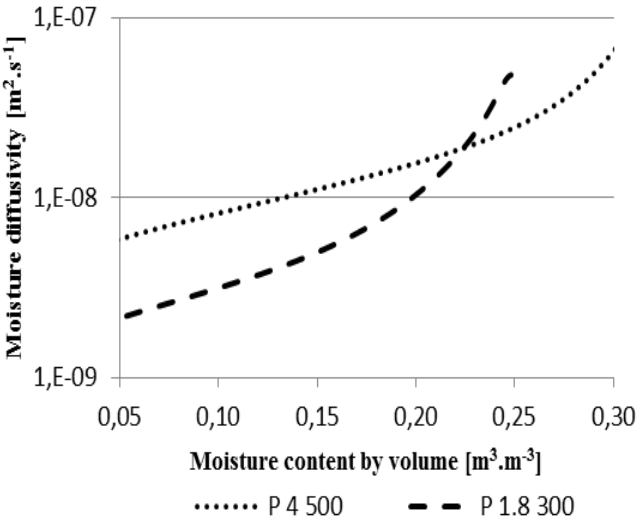

Fig. 5 Moisture diffusivity of both materials at temperature 65°C

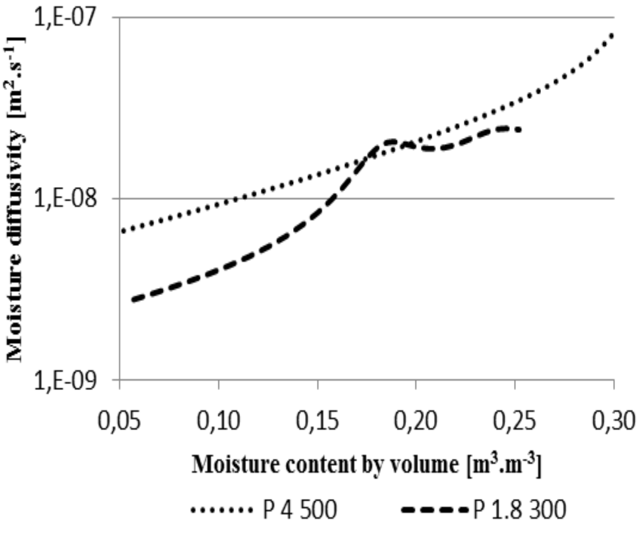

Fig. 6 Moisture diffusivity of both materials at temperature 75°C

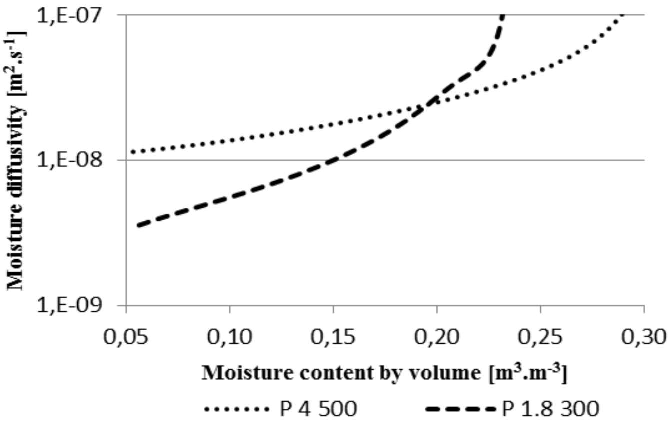

Fig. 7 Moisture diffusivity of both materials at temperature 55°C

V. CONCLUSION

The moisture diffusivity in dependence on moisture was determined for two types of autoclaved aerated concretes with different bulk density. The experiment was realized under several temperatures up to 85 °C. The results show also influence by increasing temperature. Moisture diffusivity was obtained from moisture profiles which were measured by non-destructive method. The results were verified by invers analysis.

The influence of moisture on moisture diffusivity is fundamental and it is possible to express it by exponential function. All results were calculated for whole moisture range. Computation of moisture diffusivity near dry state and saturated failed. It is caused by mathematical solution of chosen model.

The influence of temperature on moisture diffusivity is not too important but also obvious. The values of moisture diffusivity growing with higher temperatures.

Material P 4 500 have values of moisture diffusivity higher then material P 1.8 300. Even then P 1.8 300 have more pores. It is caused because material P 1.8 300 is made as thermal insulation. Hence it is hydrofobisation to protect it from moisture spreading, which decreases thermal properties. The other material P 4 500 is made as constructional material and therefore moisture spread inside more.

The analytical expression of influence moisture and temperature on moisture diffusivity will be done in future after more measurements.

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