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Assessment of a new method for determining the relationship between effective diffusivity and moisture concentration – Exemplified by autoclaved aerated concrete of four density classes

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ABSTRACT

The main purpose of the study was to assess the usability of a new calculation technique for determining the relationship between effective moisture diffusivity and moisture concentration. Four types of autoclaved aerated concrete, differing in their densities, were chosen as model porous media. The drying curves and the moisture distribution for samples that had different drying times were determined experimentally. The results obtained were used in a numerical procedure to give an estimation of the diffusion coefficient. The dependence of the coefficient on the moisture concentration was approximated by a polygonal chain. An entirely satisfactory correlation with experimental data was obtained by the application of an eight-segment polygonal chain. It was found that the diffusion coefficient was a decreasing function with respect to the moisture concentration in the low moisture content range. It reached a minimum and then increased together with the moisture concentration. It was also concluded that the greater the density of the tested porous material the lower its effective diffusivity.

1. Introduction

Moisture processes within porous building materials have been analyzed by a number of researchers, because moisture affects many of the main properties of such materials. Moisture can significantly change their technical parameters, such as strength (e.g. [1,2]), frost-resistance (e.g. [3,4]), thermal conductivity (e.g. [5–7]), and others. Biological and chemical degradation processes in cement-based materials are directly associated with water transport.

The processes of water transport inside porous materials are quite complex, and therefore it is not easy to describe their courses and the time-dependent moisture distribution in building components. At low and moderate moisture levels, water is transported in the gas phase. However, several mechanisms of molecular transport appear simultaneously (mainly diffusion, effusion, and laminar transport). Their particular shares in the overall moisture flow depend on the material's porosity, and they change according to the moisture's increase. The mechanisms of water flow in the liquid phase appear incrementally (mainly as surface diffusion and capillary transport). After crossing the so-called point of critical moisture, only the mechanism of capillary suction is responsible for water transport.

Many attempts at creating the most precise description of these complicated processes have been made in recent decades. In the literature, various models have been suggested and research techniques tested in order to determine transport coefficients that can describe the behavior of different porous materials, e.g. [8–18]. At the same time, there are many works, in which an attempt is made to link microstructural parameters with parameters describing moisture transport, e.g. [19–29].

In practical applications, these processes are usually modeled using a moisture diffusion equation (Fick-type equation). This approach consists of modeling all the aforementioned mass transport mechanisms using a single Fick-type flux, that combines all of these mechanisms. In this approach, the mass flux is proportional to the gradient of the moisture content. The proportionality factor, by analogy to Fick's law, is called the effective diffusion coefficient, and is designated as D_{eff}. It is treated as a cumulative coefficient, describing jointly all partial processes that contribute to the global flow in a variable manner, depending on the dampness level and the specific structure of the pore system.

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Nomenclature

D	diffusion coefficient (m^2/s)	T	temperature (K)
D_{eff}	effective diffusion coefficient (m^2/s)	t	time (s)
RH	air humidity (%)	z	spatial coordinate (m)
ΔRH	air humidity change (%)	$2R$	mean pore size (μm)
c	moisture concentration (kg/m^3)	P_c	total porosity (%)
c_o	initial moisture concentration (kg/m^3)	ε	tortuosity (–)
j	mass flux ($kg/(m^2\ s)$)	V_p	pore volume (cm^3/g)
H	sample height (m)		

In order to obtain a correct estimation of the moisture disposal process, it is essential to identify the model parameters. In the case of the diffusion equation, the most important is the estimation of the effective diffusion coefficient, D_{eff}, over a wide range of moisture content.

Usually, this coefficient is assumed to be constant [30–32]. One of the well-known methods of determining the constant diffusion coefficient's value relies on the solution of the one-dimensional diffusion equation using the Fourier method. This solution has the form of an infinite function series. Assuming a long time for the process, only the first term of the series is taken, and this form of function is compared with the experimental data to obtain the effective diffusion coefficient (e.g. [31]). Another method involves taking a rectilinear section on a graph containing data of the change in mass as a function of the square root of time (e.g. [32]). The angle of inclination provides information about the value of the constant diffusion coefficient. These methods have their limitations. The main drawback is that with their aid, only one mean value of the diffusion coefficient, corresponding to the studied concentration range, is determined. The worse such determined value of D_{eff} = const describes the process of moisture transport in a material, the more complex the porosity structure it is characterized by and the wider range of moisture is tested. Under certain circumstances, it is not possible at all to determine a representative value of the transport coefficient. This is the case, for example, with the $\sqrt{t}$ type method, which refers to the initial phase of the mass transfer process. This process sometimes happens so quickly, especially with the extensive-porous materials or those tested at higher temperatures, that on the $\Delta\ m = f\ (\sqrt{t})$ graph it is not possible to select a rectilinear segment, and thus it is not possible to determine an unambiguous D_{eff} value.

Assuming a constant value of the diffusion coefficient considerably facilitates its calculation, but leads to large inaccuracies, which has been mentioned many times in the literature. The discrepancies have been stressed in [33] by presenting linear and nonlinear analysis of the desorption processes taking place at different moisture levels. The analysis referred to earlier laboratory research that tested desorption processes in cement mortar at progressively changing relative air humidity, ΔRH (30% → 12%, 50% → 30%, 75% → 50%, 85% → 75%, and 97% → 85).

It has to be concluded that the effective diffusion coefficient, D_{eff}, will accurately describe the total moisture flow only if it changes its value together with the moisture concentration c (as the shares of particular component mechanisms change according to the concentration of moisture). For example, such an approach is presented in papers [34–38].

A broad review of papers concerning diffusivity in cement-based materials (cement paste, mortar, and concrete) was given in [39]. The authors provided a critical analysis of the experimental and modeling approaches used to determine the effective diffusion coefficients of such materials. They noted that, for example, for cement paste of low porosity, the diffusivity reported by different authors varied by up to a factor of five. Having compared various measuring techniques, the researchers stated that electrical resistivity measurements for low capillary porosity are up to one order of magnitude higher compared to other techniques. The conclusions drawn from the comparisons were problematic, because they concerned materials produced in different laboratories, from different ingredients, and using various technologies.

Research on various techniques of measuring diffusivity for the same group of materials can be found in papers [40–44], and also in the abovementioned papers [33,36,37]. The experiments covered three series of cement mortars of different water-cement ratios (0.50, 0.65, and 0.80), and were carried out at three temperature values (20, 35, and 50 °C).

Papers [40,41] presented research on the effective diffusion coefficient over different moisture ranges by the application of various types of the so-called cup method. In this type of research, the conditions of steady-state flow are arranged.

Papers [42–44] presented measurements concerning non steady-state conditions. The author determined values of the effective diffusion coefficient for both absorption and desorption processes performed at various temperatures and humidity ranges. Different calculation techniques were tested: $\sqrt{t}$-type, logarithmic, and half-time methods. In relation to all the mortars tested, the researcher obtained relatively good convergence of effective diffusion coefficients determined under the same conditions, but with the application of different methods.

Many papers presenting methods of effective moisture diffusion coefficient evaluation as a function of the concentration of moisture assume a known form of function type for the coefficient (for example: exponential, polynomial, and others, as well as their combinations) (e.g. [45–47]). These approximations are very useful and allow for better compatibility of the experimental and computer simulation data. However, the significant disadvantage of these methods is the character of the assumed function (monotonic character, tending to zero, instability in the case of higher degree polynomials, etc.). This type of approach fails if the dependence of the diffusion coefficient on moisture content is complicated. Therefore, a new method of evaluation of the dependence of the effective moisture diffusivity on moisture concentration was proposed in [48].

The main aim of the present work is to evaluate the variability of effective moisture diffusivity in autoclaved aerated concretes of different densities using the method described in [48,49].

2. Materials and experiments

To analyze the effective moisture diffusion coefficient, autoclaved aerated concrete (AAC) was chosen as a model system. For the experiment, four density classes of AAC, 400, 500, 600, and 700 kg/m^3, produced using sand technology, were selected. To ensure that for the production of all density classes the same raw materials and production technology were used, the same manufacturer was chosen. The individual samples varied only in their pore structure.