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THE HYGRIC PERFORMANCE OF CERAMIC BRICK EXPOSED TO BORDERLINE DYNAMIC CONDITIONS

ODDZIAŁYWANIE WILGOCI NA CEGŁĘ CERAMICZNĄ W SKRAJNYCH WARUNKACH DYNAMICZNYCH

Abstract

The actual moisture content of a ceramic brick under changing borderline conditions is experimentally determined. The results of an experiment are compared with the results of numerical simulation. A simplified model for evaluating the actual moisture content of a hysteretic building material is suggested.

Keywords: hygric performance, sorption hysteresis, simplified model, ceramic brick

Streszczenie

Określono eksperymentalnie rzeczywistą zawartość wilgoci w cegle ceramicznej w zmiennych, skrajnych warunkach. Wyniki eksperymentu porównano z rezultatami symulacji numerycznej. Zaproponowano uproszczony model oceny rzeczywistej zawartości wilgoci w histerezowym materiale budowlanym.

Słowa kluczowe: oddziaływanie wilgoci, histereza sorpcji, model uproszczony, cegła ceramiczna

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1. Introduction

In simulations of the hygrothermal performance of a building structure, the actual moisture content of building materials is most frequently calculated by means of the main adsorption curve. However, under real circumstances, materials in building structures are exposed to changing borderline conditions and, due to hysteretic effects, their actual moisture content corresponds with the scanning curves between the adsorption and desorption isotherm. Therefore, an application of the main adsorption curve in hygrothermal simulation results in the underestimation of the moisture content of a structure. The reasons why the sorption hysteretic effects are not commonly involved in hygrothermal simulation tools are as follows:

1. Integration of a model of hysteretic behaviour into simulation tools would make the existing, rather complex, models even more complex and time-consuming.
2. Some models of hysteretic behaviour need additional material parameters describing the primary adsorption/desorption scanning curves that are not commonly available.

In this paper, the actual moisture content of a ceramic brick in changing borderline conditions is experimentally determined. The results of this experiment are compared with the results of numerical simulation. A simplified model for evaluating the actual moisture content of a building material exposed to dynamic borderline conditions is suggested.

2. The experimental part

The measurements were done for a ceramic brick. The tested brick is commonly used burnt clay brick delivered by a Slovak manufacturer. Its basic material parameters – bulk density, total open porosity and capillary moisture content as well as water vapour sorption isotherms – were determined in the previous work [1]. The water vapour main adsorption and desorption isotherms as well as the scanning curves were determined by the standard gravimetric desiccator method which consists in conditioning the samples in desiccators under constant relative humidity (RH) and temperature (23°C) until static equilibrium is achieved [2]. The water vapour resistance factor was measured by the standard dry-cup (0– 53% RH – silica-gel and climatic chamber) and wet-cup (100–53% RH – water and climatic chamber) methods [3].

The dynamic test consisted in monitoring mass changes of brick samples exposed to changing RH in the climatic chamber. The test was performed with 7/17-hour changes between 84.5 and 26.5% RH. The temperature during the tests was kept at a constant value of 23.0 ± 0.5°C (Fig. 1). The relative humidity and temperature in the climatic chamber were registered at one-minute intervals. Simultaneously, three brick specimens (100.8 x 101.9 x 26.38 mm, 101.8 x 101.6 x 24.23 mm and 101.2 x 101.6 x 26.04 mm) were tested. The specimens were sealed on all but two surfaces by epoxy resin in order to guarantee 1D water vapour flow. The mass of the samples was weighed at chosen time intervals by electronic balance with the accuracy of 0.01g. The air flow velocity near the samples varied between 0.20 and 0.30 m/s. On the basis of the similarity relations and the Lewis relation, the value of the surface film coefficient for diffusion $\beta = 5.6.10^{-8}$ s/m was determined and used in simulations.

After finishing the dynamic test, the samples were oven dried at the temperature of 105°C in order to determine their dry mass and moisture content during the test.

3. Simulation of hysteretic behaviour

Several algorithms have been developed for predicting the hysteretic effects during the cyclic moisture adsorption and desorption of capillary-porous materials. In the previous work [1], it was shown that in the case of ceramic brick, the use of the Slope algorithm [5] gave acceptable coincidence between the measured and predicted scanning curves.

The advantage of the Slope method [5] is its simplicity as well as the fact that it only uses the main adsorption and desorption slopes for the prediction of the scanning curves. According to this algorithm, the moisture content in time (N+1) is given by equation (1):

$$u(\varphi_{N+1}) = u(\varphi_N) + C \cdot (\varphi_{N+1} - \varphi_N) \tag{1}$$

where for the process of adsorption C is described by relation (2):

$$C = \frac{du_{ads}}{d\varphi} \cdot \frac{u_{des}(\varphi_{N+1}) - u_m(\varphi_{N+1})}{u_{des}(\varphi_{N+1}) - u_{ads}(\varphi_{N+1})} \tag{2}$$

and for the process of desorption by relation (3):

$$C = \frac{du_{des}}{d\varphi} \cdot \frac{u_m(\varphi_{N+1}) - u_{ads}(\varphi_{N+1})}{u_{des}(\varphi_{N+1}) - u_{ads}(\varphi_{N+1})} \tag{3}$$

where:

u – moisture content [m^3/m^3],
φ – relative humidity [-],
u_{ads} – moisture content corresponding to the main adsorption curve [m^3/m^3],
u_{des} – moisture content corresponding to the main desorption curve [m^3/m^3].

In the suggested simplified model, the Slope algorithm is used for an evaluation of the "mean scanning curves" calculated as the mean of the scanning desorption and adsorption curves of a material under cyclic RH changes. The main adsorption and desorption isotherm from 98% RH are approximated by a relation of the van Genuchten type:

$$u_m(\varphi) = A \cdot \left(1 - \left(\frac{\ln\varphi}{B}\right)^{n1}\right)^{-n2} \tag{4}$$

or by its modified version [1]:

$$u_m(\phi) = A \cdot \left(1 - \left(\frac{\ln(\phi + 0.02)}{B}\right)^{n1}\right)^{-n2} \tag{5}$$

where:

$A, B, n1, n2$ – parameters (Tab. 1)

The first scanning desorption and adsorption curves are estimated according to the relations (1)-(3), starting from the adsorption moisture content corresponding to the maximum achieved RH (RH$_{\max}$) in a considered layer of structure. The "mean scanning curve" related to the RH$_{\max}$ is described by the van Genuchten equation (4) where its parameters are obtained by fitting the mean curve between the scanning desorption and adsorption curve. The whole process for ceramic brick and RH$_{\max}$ = 80% is illustrated in Fig. 1. The resultant parameters of the curves are presented in Tab. 1.

Table 1

Parameters of van Genuchten equations for tested ceramic brick

	A [m^3/m^3]	B	n1	n2	
Main adsorption	0.07056	0.037	2.0	0.35088.	Eq. (5)
Desorption from 98% RH	0.07056	0.06	1.22	0.33898	Eq. (5)
Mean scanning curve (RH_{max} = 80%)	0.37	0.00006	0.57	0.594	Eq. (4)

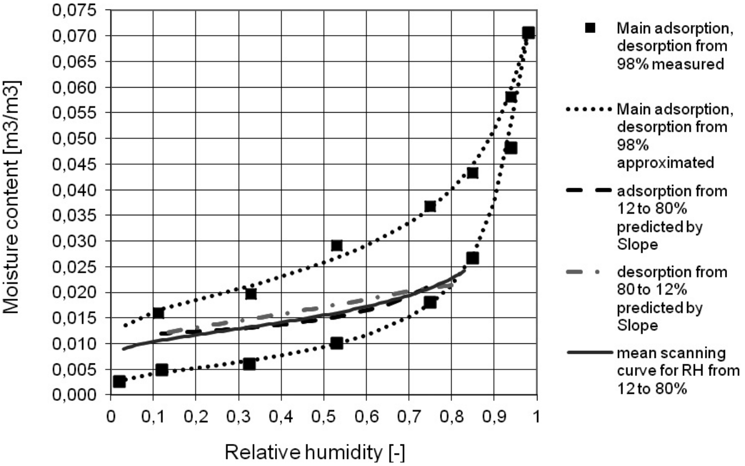

Fig. 1. Illustration of generation of "mean scanning curve" (ceramic brick, RH_{max} = 80%)

Rys. 1. Ilustracja wytwarzania „średniej krzywej skaningowej" (cegła ceramiczna, RH_{max} = 80%)

In this way, a set of "mean scanning curves" corresponding with particular RH_{max} values can be obtained.

Numerical simulation of the hygrothermal performance of the tested brick was done by simulation tool NEV3M. It is a modification of the former 1-D simulation tool NEV3 [5] based on the solution of two coupled equations for heat and moisture transfer. In simulation tool NEV3M, the moisture storage of a material is described by a set of "mean scanning curves" corresponding with the maximum RH value achieved in the considered layer.

With the aim to evaluate the suggested simplified approach, an additional simulation, based on a more complex description of hysteretic behaviour, was done. For this purpose, the Mihalka 1D simulation tool for the calculation of heat and water vapour transfer [6] was applied. The Mihalka tool can allow for hysteretic effects due to the integration of the Pedersen empirical model [7] into numerical calculation. Its drawback is, however, that it does not involve the enthalpy of evaporation. In the Pedersen model, the moisture content in time (N + 1) is calculated according to equation (1) where C is given by equation (6) during the process of adsorption:

$$C = \frac{\gamma_{ads} \cdot (u - u_{ads})^2 \cdot \left(\frac{du_{des}}{d\varphi} \right) + (u - u_{des})^2 \cdot \left(\frac{du_{ads}}{d\varphi} \right)}{(u_{des} - u_{ads})^2} \tag{6}$$

and C is given by equation (7) during the process of desorption:

$$C = \frac{(u - u_{ads})^2 \cdot \left(\frac{du_{des}}{d\varphi} \right) + \gamma_{des} \cdot (u - u_{des})^2 \cdot \left(\frac{du_{ads}}{d\varphi} \right)}{(u_{des} - u_{ads})^2} \tag{7}$$

where:

γ_{ads}, γ_{des} – parameters fitted according to the measured first adsorption and desorption scanning curve. In the considered case of ceramic brick, $\gamma_{ads} = \gamma_{des} = 0.75$.

4. Results and discussion

The determined basic material properties of the brick as well as its water vapour resistance factor values (μ) are presented in Table 2.

Table 2

Basic material properties and water vapour resistance factor values of tested ceramic brick

Bulk density [kg/m^3]	Open porosity [-]	Capillary moisture content [m^3/m^3]	μ (dry cup) [-]	μ (wet cup) [-]
1,370	0.42	0.37	12.0	5.9

In numerical simulations, water vapour resistance factor moisture dependence was approximated by the following relation:

$$\mu(\varphi) = \frac{1}{a + b \cdot \exp(c \cdot \varphi)} \tag{8}$$

where:

a, b, c – parameters: $a = 0.072$, $b = 0.0028$, $c = 4.66$

A comparison of the calculated and measured time course of the specimen mass during the dynamic test is shown in Fig. 2 (specimen 2) and Fig. 3 (specimen 3). Calculations were done with the use of the suggested simplified model, the main adsorption curve, the desorption curve from 98% RH and the Mihalka simulation tool. The obtained maximum and minimum values of moisture content during the quasi-steady-state period of the dynamic test are presented in Tab. 3.

Table 3

Obtained maximum and minimum values of average moisture content of tested bricks

	u_{max} [m³/m³] of specimen			u_{min} [m³/m³] of specimen		
	1	2	3	1	2	3
Main adsorption	0.0153	0.0152	0.0158	0.0073	0.0073	0.0071
Simplified model	0.0198	0.0198	0.0202	0.0129	0.0129	0.0128
Mihalka	0.0223	0.0223	0.0236	0.0121	0.0122	0.0128
Measured	0.0188	0.0177	0.0197	0.0116	0.0117	0.0124

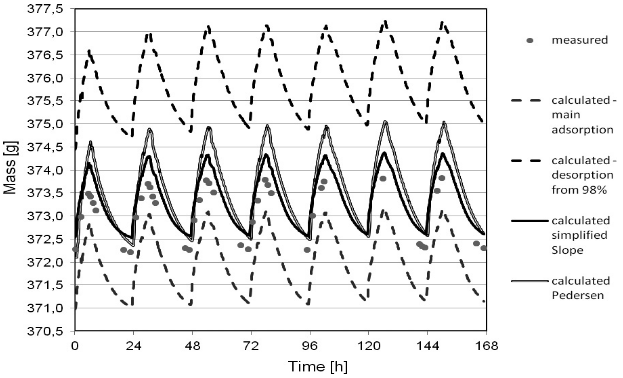

Fig. 2. Comparison of the measured and simulated time course of the specimen mass during the dynamic test (specimen 2)

Rys. 2. Porównanie mierzonego i symulowanego czasu dla masy próbki podczas testu dynamicznego (próbka 2)

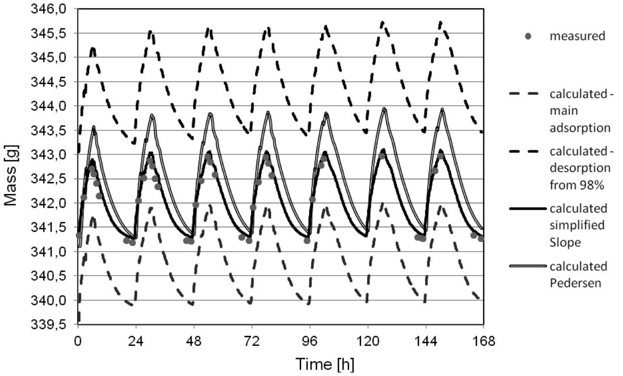

Fig. 3. Comparison of the measured and simulated time course of the specimen mass during the dynamic test (specimen 3)

Rys. 3. Porównanie mierzonego i symulowanego czasu dla masy próbki podczas testu dynamicznego (próbka 3)

The results suggest that, for the tested brick, the hysteretic effects are noticeable and that using the main adsorption curve underestimates the moisture content. It is in accordance with the previous experimental results for ceramic brick delivered by other manufacturers [8, 9].

The coincidences between the measured results and those obtained by the simplified model are acceptable. However, accordance is worse for specimens 1 and 2 than for specimen 3 (Tab. 3, Fig. 2,3). It can be partly explained by the non-homogeneity of the tested material and partly by the fact that the calculated specimen moisture content/mass is very sensitive to the applied moisture storage function. The results of the dynamic test simulation also confirm that the processes of adsorption and desorption can be described by the same moisture storage function.

The results obtained by the Mihalka simulation tool are slightly shifted towards higher values of moisture content/mass. The shift can be explained by the fact that the enthalpy of evaporation is not considered in this tool and consequently the existing changes of temperature during the water vapour uptake/release as well as their effect on the relative humidity in the material are not involved, either.

5. Conclusions

The moisture content of a ceramic brick in changing borderline conditions is experimentally determined. The measurements confirm the evident effect of the hysteretic behaviour on the moisture content of a ceramic brick.

A simplified approach to the evaluation of the moisture content of a hysteretic building material is suggested in comparison with the experiment. Taking the sensitivity of the calculated moisture content to the applied moisture storage function into account, accordance between the results of the simplified model and the experiment is satisfactory. However, for more general conclusions regarding its applicability, further tests, covering other ranges of relative humidity and different types of building materials, should be performed.

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