THERMAL AND HYGRIC PROPERTIES OF GYPSUM: REFERENCE MEASUREMENTS

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Abstract
The reference measurements of basic thermal and hygric parameters of hardened gypsum are carried out. Moisture diffusivity, water vapor diffusion coefficient, thermal conductivity, volumetric heat capacity and linear thermal expansion coefficient are determined with the primary aim of comparison with data obtained for various types of modified gypsum in the future.

Key words: flue gas desulfurization (FGD) gypsum, calcined gypsum, modified gypsum, thermal properties, hygric properties

1 Introduction

Calcined gypsum CaSO4.1/2H_2O as a low-energy material can be produced with advantage from the waste flue gas desulfurization (FGD) gypsum CaSO4.2H_2O by its dehydration at the temperatures of 110 to 150°C. Then, β-form of calcined gypsum is formed according to the equation

$$CaSO_4.2H_2O \ (110 \text{ to } 150°C) \rightarrow CaSO_4.1/2H_2O + 1\ 1/2H_2O. \qquad (1)$$

The solid structure of calcined gypsum is created by reverse hydration when gypsum $CaSO_4.2H_2O$ is again formed. This compound is relatively soluble in water, its solubility is 0.256 mg in 100 g of water at 20°C. Therefore, it cannot be utilized in exterior applications as the rain water could dissolve just the product that should safeguard the mechanical properties of the material.

The resistance of hardened gypsum against water is generally a serious problem [1]. For the utilization of gypsum elements in the exterior, it is necessary to modify it so that it would exhibit more suitable properties and longer service life. Modifications of gypsum are usually performed using polymer materials. However, generally it can be stated that the resistance of hardened gypsum against water is not yet resolved in a satisfactory way.

Therefore, our primary aim is the adjustment of basic technologies for the production of modified gypsum, particularly from the point of view of hydrophobization and the improvement of mechanical and thermal properties. In this paper, we present reference measurements of thermal and hygric properties of common gypsum that will be utilized for a comparison with various types of modified gypsum in the future.

2 Experimentals methods

2.1 Moisture diffusivity

2.1.1 Determination of the apparent moisture diffusivity from a water sorption experiment

A common water sorption experiment was carried out. The specimen was water and vapor-proof insulated on four lateral sides and the face side was immersed 2 mm in the water. Constant water level in the tank was achieved using a bottle placed upside down. The known water flux into the specimen during the suction process was then employed to the determination of the water absorption coefficient. The samples were tested in constant temperature conditions.

For the calculation of the apparent moisture diffusivity D_w [m^2s^{-1}], there was employed the following approximate relation:

$$D_w \approx \left(\frac{A}{w_c} \right)^2 \tag{2}$$

where A is the water absorption coefficient [$kgm^{-2}s^{1/2}$], and w_c is the saturated moisture content [kgm^{-3}].

2.1.2 Determination of moisture diffusivity from moistures profiles

The capacitance method [2] was employed to the measurement of moisture content, the measuring frequency was 250 – 350 kHz. The parallel electrodes of the capacitance moisture meter had the dimensions 20 x 40 mm.

The moisture profiles were determined using a common capillary suction 1-D experiment in the horizontal position, lateral sides of specimens were water and vapor-proof insulated. Moisture meter reading along the specimen was done every 5 mm. The calibration curve was determined after the last moisture meter reading, when the moisture penetration front was at about one half of the length of the specimen, using this last reading and the standard gravimetric method after cutting the specimen into 1 cm wide pieces. The final calibration curve for the material was constructed from the data of 6 samples. The moisture profiles were then calculated from the calibration curve. The measurements were done at 25°C ambient temperature. Moisture diffusivity was determining by the Matano method [3].

2.2. Water vapor diffusion coefficient

A standard cup method (dry and wet) was employed in the measurements. The water vapor diffusion coefficient *D* for cup methods was calculated from the measured data according to the equation

$$D = \frac{\Delta m \cdot d \cdot R \cdot T}{S \cdot \tau \cdot M \cdot \Delta p_p}, \tag{3}$$

where D is the water vapor diffusion coefficient [m^2s^{-1}], Δm the amount of water vapor diffused through the sample [kg], d the sample thickness [m], S the specimen surface being in contact with the water vapor [m^2], τ the period of time corresponding to the transport of mass of water vapor Δm [s], Δp_P the difference between partial water vapor pressure in the air under and above the specimen [Pa], R the universal gas constant [J mol^{-1} K^{-1}], M the molar mass of water [kg mol^{-1}], T the absolute temperature [K].

On the basis of the diffusion coefficient D, the water vapor diffusion resistance factor μ was determined:

$$\mu = \frac{D_a}{D}, \tag{4}$$

where D_a is the diffusion coefficient of water vapor in the air [m^2s^{-1}]

In the dry cup method the sealed cup containing silica gel was placed in a controlled climate chamber with 50% relative humidity and weighed periodically. For wet cup method sealed cup containing water was placed in an environment with the temperature about 25°C and relative humidity about 50%. The measurements were done at 25°C in a period of two weeks.

The steady state values of mass gain or mass loss determined by linear regression for the last five readings were used for the determination of water vapor transfer properties.

2.3 Thermal conductivity and volumetric heat capacity

Thermal properties were measured using the device ISOMET 2104 (Applied Precision, Ltd., SK). It is a multifunctional instrument for measuring thermal conductivity λ [W $m^{-1}K^{-1}$], volumetric heat capacity C [J m^{-3} K^{-1}] and temperature [°C] of a wide range of materials. The thermal diffusivity a [m^2s^{-1}] is calculated by the device from the formula

$$a = \frac{\lambda}{C} \tag{5}$$

The measurements were done using surface probes with samples, which were placed at laboratory conditions of 25°C and about 50% relative humidity. The relative moisture content by mass of the samples was about 18 %.

2.4 Linear thermal expansion coefficient

The linear thermal expansion coefficient α_T was determined in a common way using the measured length changes (Carl Zeiss optical contact comparator with a precision of ±0.5 μm) between two different temperatures: 25°C and 80°C. It was calculated from the formula

$$\alpha_T = \frac{1}{l_{o,T}} \cdot \frac{dl}{dT}, \tag{6}$$

where $l_{o,T}$ is the length at a reference temperature.

3 Material and samples

The material, which was used for reference measurements, was β-form of calcined gypsum with purity higher than 98 % of FGD gypsum, produced at the electric power station Počerady, CZ. The water/gypsum ratio was 0.627. The samples were mixed according to the Czech standard CSN 72 2301 [4].

For the measurements of particular thermal and hygric parameters, we used the following samples: moisture diffusivity – capacitance method - 6 specimens 20 x 40 x 300 mm, apparent moisture diffusivity – 4 specimens 50 x 50 x 23-25 mm, water vapor diffusion coefficient 12 cylinders with the diameter 105 mm and thickness 10-22 mm, thermal conductivity and volumetric heat capacity – 6 specimens 70 x 70 x 70 mm, linear thermal expansion coefficient – 5 specimens 40 x 40 x 160 mm.

The samples for determination of moisture diffusivity were insulated on all lateral sides by water- and vapor-proof plastic foil, the samples for measuring water vapor diffusion coefficient were also water- and vapor-proof insulated on the lateral sides by Epoxy resin.

4 Experimental results and discussion

The basic properties of the studied material for its characterization are shown in Table 1.

Table 1 Basic properties of gypsum

Bulk density [kgm^{-3}]	Matrix density [kgm^{-3}]	Open porosity [% by volume]
1019 ± 1.5%	2530 ± 2.0%	60 ± 3.4%

Fig. 1 shows typical moisture profiles determined by the capacitance method. Fig. 2 presents the moisture diffusivity dependence on the moisture content calculated using the moisture profiles and the apparent moisture diffusivity determined on the basis of the water absorption coefficient. Clearly, the agreement of both measurements is very good, the value of apparent moisture diffusivity being equal to the moisture diffusivity determined from moisture profiles for 83% of the capillary water saturation value. The results of measurements of other thermal and hygric parameters are summarized in Table 2.

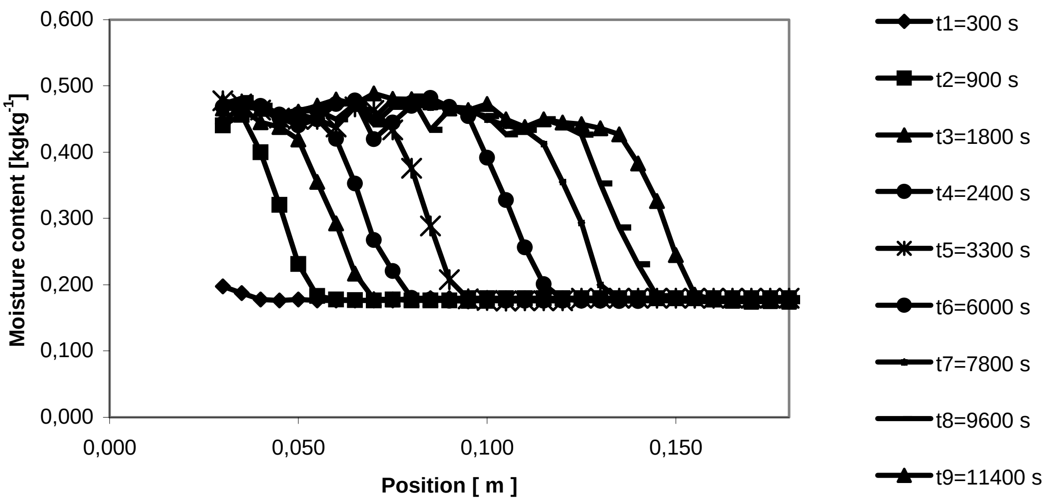

Figure 1. Typical moisture profiles in gypsum specimens

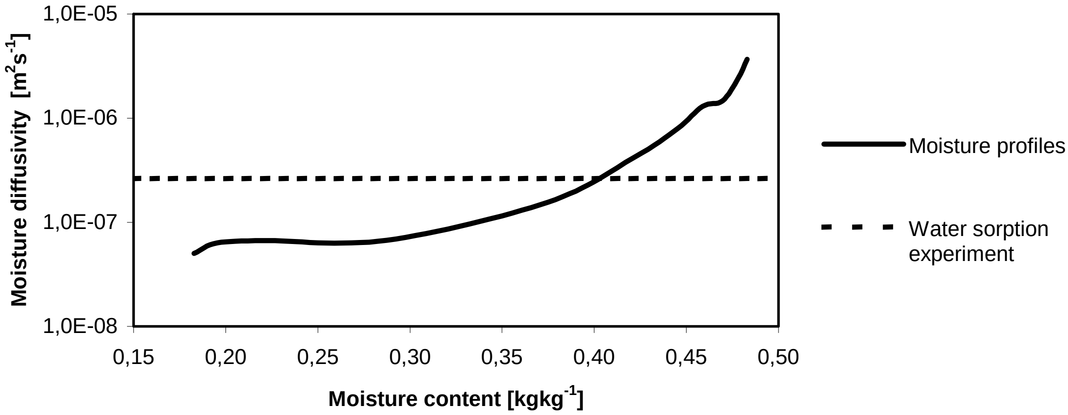

Figure 2. Moisture diffusivity of gypsum

Table 2 Other thermal and hygric properties of gypsum

Thermal conductivity $[Wm^{-1}K^{-1}]$	Volumetric heat capacity $[Jm^{-3}K^{-1}]$	Thermal diffusivity $[m^2s^{-1}]$	Linear thermal expansion coefficient $[K^{-1}]$
0.47 ± 10%	(1.60 ± 10%)E+6	(0.29 ± 10%)E-6	(7.22 ± 15%)E-6

Table 2 Other thermal and hygric properties of gypsum - continued

Water vapor diffusion resistance factor (-)	
Dry cup	Wet cup
17.3 ± 15%	5.44 ± 15%

5 Conclusions

Determination of a complete set of thermal and hygric properties of practically any type of modified gypsum is a very actual problem. Complete sets of these parameters are not available and without their knowledge it is impossible to perform any serious hygrothermal analysis of building elements based on these materials. During the development process of the various types of modified gypsum it is always necessary to assess the quality of their parameters in some way. Therefore, a set of reference measurements on common gypsum samples was carried out for the sake of future comparisons with the data obtained for modified gypsum.

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