The study of thermal and moisture behavior of autoclaved cellular concrete

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Abstract: In most cases, building materials contain, after their incorporation into a structure, a certain amount of moisture that affects their thermal insulation properties, mechanical properties and ultimately their life. In case of autoclaved aerted concrete (AAC), a large amount of moisture is introduced into the material already during its manufacture (shipping moisture of cellular-concrete products often exceeds 35%). After the erection of a building structure and starting its use, the amount of integrated moisture is often very high, which leads primarily to the degradation of thermal insulation properties. The paper deals with the study of thermal and moisture behavior of different types of AAC products for masonry structures, especially in terms of changes in thermal insulating properties of the materials depending on moisture content and also depending on temperature.

Keywords: AAC, autoclaved aerated concrete, thermal conductivity, moisture, hygroscopic sorption properties

INTRODUCTION

Thermal and technical properties of porous building materials depend on their moisture contents after incorporation in the structure. The porous system of the majority of building materials is open (fully or partially) and allows the transport of moisture and its prospective accumulation. The moisture in greater part of the common building materials causes the growth of thermal conductivity value and the degradation of thermal insulating properties as a result. The dependence of thermal conductivity on moisture is typical for every material. The thermal conductivity of a building material depends among others on the properties of the porous structure of the material (shape, distribution of pores, openness of the porous system, total porosity,…), on its bulk density and chemical and mineralogical composition. In the area of hygroscopic moisture, the gradual sorption of moisture into the walls of the pores takes its course as the porous system of the building material is filled up, at first in monomolecular and subsequently in multi-molecular layers. The absorbed moisture results in volume changes of the material caused by the change in capillary pressure depending on the saturation of the capillary system of moisture. After the maximum hygroscopic moisture has been achieved, the capillary system becomes filled with moisture. Capillary conductivity occurs and the resulting value of the thermal conductivity is strongly influenced by the sinuosity of the capillary system being unequally filled with moisture [1, 7].

TEST SPECIMENS AND WORK METHODOLOGY

Two different kinds of AAC materials that are available on the EU market were selected for studying hygrothermal behavior of AAC materials. The purpose was to cover the widest possible range of commonly used kinds of porous concrete based on silica sand and fly-ash. These were as follows:

- four kinds of sand based AAC: P1.8-300, P2-350, P2-400, P2-500,
- two kinds of fly-ash based AAC: P2-420, P4-580.

All products made of autoclaved aerted concrete were obtained from the individual manufacturers. Laboratory test specimens were prepared from each kind of porous concrete with the defined dimensions:

- 5 specimens 300x300x50mm for determination of heat conductivity factor,
- 5 specimens 40x40x160mm for determination of bulk density and hygroscopic sorption properties.

The properties of selected AAC specimens were determined at different values of moisture and at different temperatures. Six different values of moisture level were selected altogether (0%, 3%, 6%, 10%, 20%, 40%). The first four moisture values were selected as the values of moisture close to the sorption moisture values of the porous concrete. The 20% and 40% moisture values were selected as the values of moisture corresponding to shipping and post-production moisture of the AAC.

Individual temperatures (mean temperatures), at which measurements were taken, were selected within the range of -10 °C to 40 °C and were graded in 10 °C steps. The temperatures were selected with regard to fulfilment of the actual conditions to which the products made of AAC are usually exposed. The study of hygrothermal characteristics was carried out on the test specimens:

- Determination of hygroscopic sorption characteristics of test specimens.
- Determination of dependence of thermal conductivity on moisture (the moisture in selected levels 40%, 20%, 10%, 6%, 3%, 0% wgt. was incorporated in test specimens for these measurements.)
- Determination of dependence of thermal conductivity on temperature (the measurements were taken at temperatures of -10°C, 0°C, 10°C, 20°C, 30°C, 40°C).

DETERMINATION OF HYGROSCOPIC SORPTION PROPERTIES

The determination of hygroscopic sorption properties was carried out in compliance with EN ISO 12571 "*Hygro thermal performance of building materials and products – Determination of hygroscopis sorption properties*". The test specimens were dried up to a constant weight in order to determine the adsorption curve. While the constant temperature of 23°C was maintained, the test specimens were gradually inserted in a number of test environments with gradually increasing relative humidity of the air. Four levels of environmental moisture were selected (33%, 55%, 75%, 98%). The 98% relative humidity was the initial point for desorption. This humidity was achieved by adsorption of the desiccated test specimen. While the constant temperature of 23°C was maintained, the test specimens were gradually inserted in a number of test environments with gradually decreasing relative humidity of the air. The same moisture values were selected as those for determination of the adsorption curve (33%, 55%, 75%, 98%). The test results are indicated in Table 1 and in Fig. 1.

Table. 1. Equilibrium adsorption values in % at temperature of +23°C

Sample / type		Relative humidity [%]				
		0	33	55	75	98
P1,8-300	Adsorption	0,00	1,57	1,96	2,36	7,49
	Desorption	0,00	2,07	2,55	3,35	7,50
P2-350	Adsorption	0,00	1,69	1,99	2,30	7,21
	Desorption	0,00	2,26	2,69	2,99	7,20
P2-400	Adsorption	0,00	1,68	2,07	2,46	6,35
	Desorption	0,00	1,95	2,21	2,74	6,38
P2-500	Adsorption	0,00	1,44	1,65	2,06	6,08
	Desorption	0,00	1,51	1,75	2,21	6,18
P2-420	Adsorption	0,00	2,25	2,48	3,26	9,67
	Desorption	0,00	2,69	3,18	4,39	9,84
P4-580	Adsorption	0,00	3,48	4,15	6,10	14,59
	Desorption	0,00	3,60	5,30	7,64	14,75

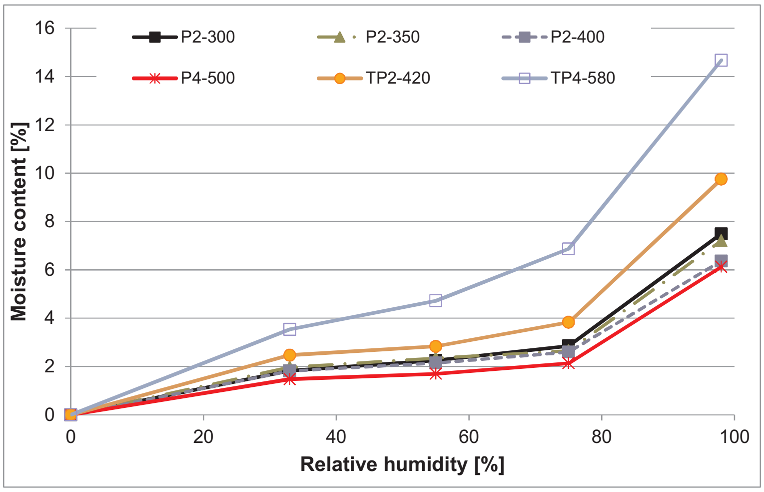
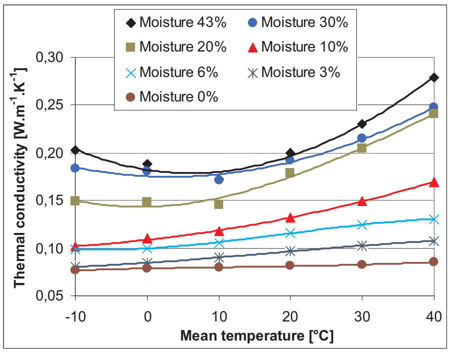


Fig. 1. Curves of equilibrium adsorption moisture values for individual types AAC at temperature of +23°C

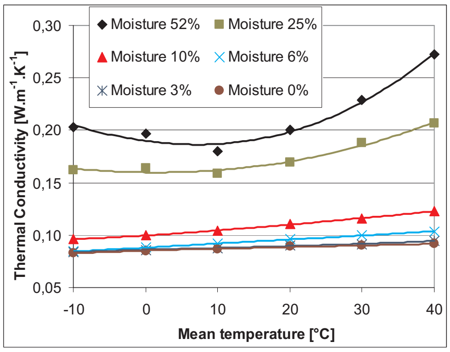
The measured moisture curves indicate that the fly-ash types of porous concrete are more sensitive to air humidity than the sand types of porous concrete. Especially, the fly-ash porous concrete P4-580 indicates the higher sensitivity to air humidity from under low values of relative humidity. In the case of AAC on sand base, the moisture sensitiveness versus the increasing bulk density of test specimens was decreasing. The reverse dependence was found out in fly-ash AAC materials; the ascending moisture sensitivity occurred with the growing bulk density.

STUDYING THERMAL INSULATING PROPERTIES

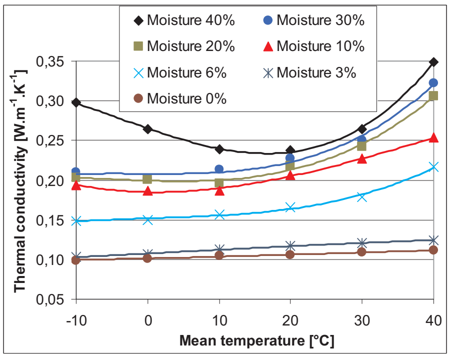
The determination of thermal conductivity was carried out according to ISO 8301 „Thermal insulation – Determination of steady-state thermal resistance and related properties – Heat flow meter apparatus“. The measurement was executed for mean temperatures of –10°C, 0°C, 10°C, 20°C, 30°C and 40°C at a temperature gradient of 10 K.



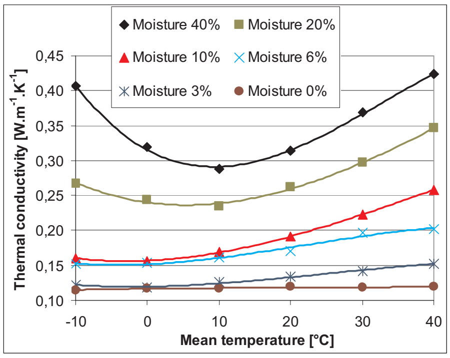
Sample P1,8-300 (sand based AAC)



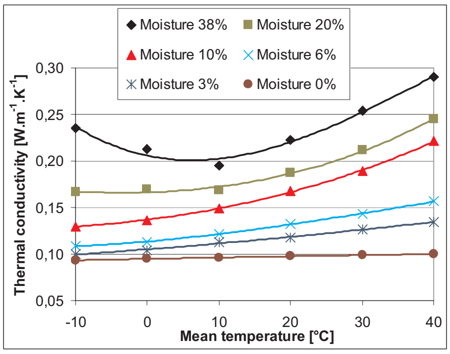
Sample P2-350 (sand based AAC)



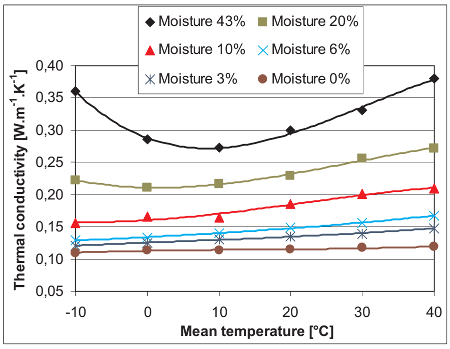
Sample P2-400 (sand based AAC)



Sample P2-500 (sand based AAC)



Sample *P2-420 (fly ash based AAC)*



Sample P4-580 *(fly ash based AAC)*

Fig. 2. The dependence of thermal conductivity on temperature in AAC specimens (see above) was determined at various values of moisture and the temperature gradient of 10 K

The defined amount of moisture was always installed in the test specimens before the commencement of the measurement. Particularly, there were six levels of moisture, 40%, 20%, 10%, 6%, 3% and 0%. The specimens got desiccated or moistened so that their moisture approximates to the values of the selected moisture as much as possible. Subsequently, the specimens were wrapped in foil in order to prevent the moisture from escaping (Fig. 4). The specimens were weighed before and after the measurements in order to compute the change of moisture during the measurement. The determined thermal conductivity for individual types of AAC are indicated in Figures 2.

EVALUATION OF MEASURED VALUES

According to ČSN EN ISO 10456, it is possible to convert the temperature values determined at certain boundary conditions (λ_1, R_1) into the values corresponding to other conditions (λ_2, R_2). The following applies in the case of conversion into another material moisture:

$$\lambda_2 = \lambda_1 \,.\, F_m \qquad (1)$$

whereas F_m represents the moisture conversion factor:

$$F_m = e^{f_u (u_1 - u_2)} \qquad (2)$$

where:

- u – weight moisture [kg·kg^{-1}],
- f_u – conversion factor for weight moisture [kg·kg^{-1}], which according to le EN ISO 10456, tab. 4, equals to f_u = 4 kg·kg^{-1} .

In the given case, the value of thermal conductivity in desiccated state (at the reference temperature of +10°C) $\lambda_{10,dry}$, was selected as the initial state 1 when it can be supposed that $u_1 \approx 0$. It was found out that with the use of a conversion factor for the weight moisture f_u = 4 kg·kg^{-1} , the computed dependence of the thermal conductivity on moisture is different from the measured values. That is why the calculation of an optimum value of the conversion factor for weight moisture f_u for each test specimen was carried in such a way that the sum of squares of the deviations measured and calculated is minimal (the least squares method). The computing results are presented in the following graph (Fig. 3).

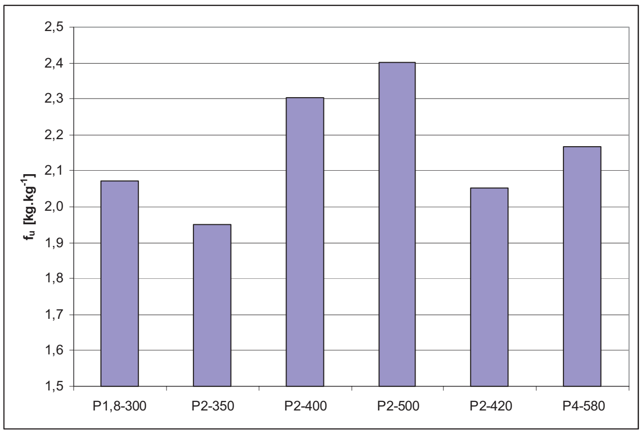


Fig. 3. Summary of the conversion factor computed values for weight moisture f_u for individual test specimens

As you can see in Fig. 3, the computed values of the conversion factor for weight moisture are approximately half in comparison to the values tabulated according to EN ISO 10456. The average value of the conversion factor for weight moisture $f_{u,aver}$ equaled to 2.16 (for all test specimens).

CONCLUSION

It was found out in the course of studying the hygrothermal behaviour of AAC that the materials made of fly-ash AAC respond to moisture more sensitively than those made of sand AAC. In the case of AAC on sand base, the moisture sensitiveness versus the increasing bulk density of test specimens was decreasing. The reverse dependence was found out in fly-ash AAC materials; ascending moisture sensitivity occurred with growing bulk density.

The determination of dependence of thermal conductivity depending on various values of moisture and temperature showed unequivocally that the effects of moisture and temperature has a synergic action. The thermal conductivity was increasing with ascending moisture. The heat conductivity factor was increasing at moisture values above 20% at negative temperatures (due to phase changes in the moisture contained in the porous system). It was also found out in the test specimens that their moisture sensitivity is lower than the values of moisture characteristics determined according to EN ISO 10456.

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