THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 2 - 2017, ISSN 1453-083X

THE INFLUENCE OF MOISTURE ON THERMAL CONDUCTIVITY FOR BUILDING MATERIALS

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ABSTRACT

The purpose of the study is to determine the influence of moisture on thermal conductivity for a range of building materials. A series of building materials and insulation materials have a porous, fibrous or granular structure, in which blanks are filled with air. If these areas are filled with moisture or water, the thermal conductivity of the material increases, and the insulation capacity decreases. The thermal conductivity of the analyzed materials was measured in accordance with ISO 8301 protocols.

KEYWORDS: water absorption; moisture; thermal conductivity

1. Introduction

The aim of the present study was to investigate the variation of thermal conductivity (k-value) with the moisture content of the autoclaved aerated concrete (AAC) blocks. We examined the thermal conductivity and the water absorption properties for three AAC specimens with different degrees of humidity. The k-value can be greatly reduced by the presence of moisture within the building materials.

The building materials are exposed to environmental influences (i.e. rain or humidity).

Due to diffusion processes as a consequence of gradients of the temperature or the humidity, the moisture content of the materials can increase. High temperatures at high moisture contents lead to a strong increase of the effective thermal conductivity because of pore diffusion. Building, structural and construction materials mostly have a porous structure.

The moisture content depends mainly on the pore ratio and the pore structure of the building materials. Materials with a high porosity can absorb and store more water than those of low porosity. Due to the pressure difference or to the capillarity, the moisture can spread into the entire volume [1].

A slight quantity of water can infiltrate into the material via the manufacturing process. Furthermore, moisture can be absorbed by the materials due to the outer weather conditions. Buildings under construction are particularly exposed to moisture stress. Precipitation has an impact on the building in different ways.

Heat transfer by conduction through the building envelope represents a major component of the total thermal load of buildings. Reducing conductive heat gain through the walls and roof by using effective thermal insulation could lead to a significant reduction in the thermal load and consequently a reduction of the overall electric energy consumption.

The thermal performance of the building envelope depends to a great extent on the thermal effectiveness of the building materials which is mainly determined by its k-value. The k-value is dependent on the material density, porosity, moisture content and average temperature difference. Published k-values and those reported by manufacturers are normally evaluated at standard laboratory conditions of temperature and humidity to allow for a comparative evaluation of the thermal performance. However, when placed in their locations in the building envelope, thermal insulation materials are exposed to different temperature and humidity levels depending on the prevailing climatic conditions, hence their actual thermal performance may substantially differ from the one predicted under standard laboratory conditions [3].

2. Experimental details

2.1. Materials

Autoclaved Aerated Concrete (AAC) is one of the most commonly used light-weight construction materials for contemporary buildings, especially due to its low density, unique thermal and breathing properties and high fire resistance. This material has, however, some disadvantages; for instance, its very high-water absorption capacity makes it susceptible to deteriorations due to water. For instance, it is often used together with incompatible plasters leading to problems at the interfaces, such as condensation, which leads to an increase in the water content of the wall section and some faults occur on the finishing. In the presence of moisture and/or water, the AAC blocks lose the thermal conductivity, and mechanical properties. In order to prevent such problems, it is essential to use waterproof and water vapor permeable plasters and/or finish coats in applications of AAC.

In order to achieve the objective of the study, three types of AAC were selected (Fig. 1). The technical specifications of the AAC samples given by manufacturer are presented in Table 1.

Table 1. *The technical specifications of the AAC samples*

Technical specifications	Sample 1	Sample 2	Sample 3
Dry bulk density kg/m^3	400	550	600
Thermal conductivity W/mK	0.092	0.13	0.15
The diffusion coefficient of water vapors	5/10	5/10	5/10
Dimensional stability mm/m	0.15	0.33	0.5
Reaction to fire - Euroclass	A1	A1	A1

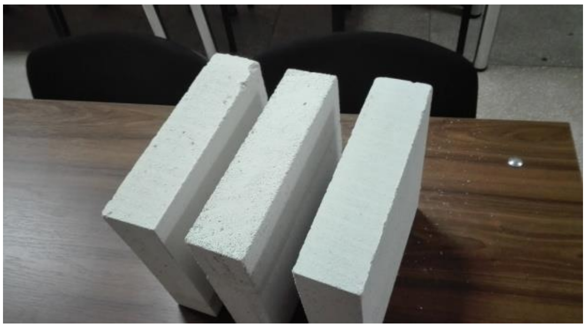

Fig. 1. *The AAC samples*

2.2. Measurement apparatus

The thermal conductivity is determined by means of the heat flowmeter method. The concept of a heat flowmeter appears in ISO 8301: 1991 [7]. The specimen under test is placed between a hot plate and the heat flowmeter which is attached to a cold plate. The apparatus is surrounded by insulation.

The hot and cold plates are maintained at suitable constant temperatures, measured by surface thermocouples. A calibration constant for the individual apparatus is derived from testing a sample of the known constant thermal conductivity. By measuring the heat flowmeter output and the mean temperature of the test sample, the thermal conductivity is calculated using this calibration constant [9].

The Hilton B480 (Fig. 2) unit is based on the heat flowmeter method described. ISO 8301:1991 gives the range of sample sizes that can be used with this method of conductivity measurement. The Hilton B480 unit is capable of holding specimens of 300 X 300 mm and 75 mm thickness.

Fig. 2. *The Hilton B480 unit*

The Fourier equation (Eq. 1) provides the relationship between the parameters of the test samples and the sections.

$$q = \lambda \cdot A \cdot \frac{\Delta T}{\Delta x} \qquad (1)$$

where: q (W) and T (K) are the heat flow and temperature difference across the sample, respectively, A (m^2) is the area through which the heat flows, x (m) is the thickness and λ is the thermal conductivity of the samples.

The thermal conductivity λ is determined with equation [9]:

$$\lambda = \frac{x \cdot \left[\left(k_1 + \left(k_2 \cdot \bar{T}\right)\right) + \left(\left(k_3 + \left(k_4 \cdot \bar{T}\right)\right) \cdot HFM\right) + \left(\left(k_5 + \left(k_6 \cdot \bar{T}\right)\right) \cdot HFM^2\right)\right]}{\Delta T} \quad (2)$$

where: x (m) is the specimen thickness, k_1, k_2, k_3, k_4, k_5, k_6, are calibration constants, HFM (mV) heat flowmeter output, $\bar{T}$ (K) is the mean temperature and ΔT (K) is the temperature difference between the hot plate temperature and the cold plate temperature.

2.2. Wetting of the samples

The moisture w (%) content of the samples can be calculated using the following equation:

$$w = \left(\frac{m_w - m_d}{m_d}\right) \cdot 100 \quad (3)$$

where: m_d and m_w are the mass of the dried and the damped samples, respectively [1].

The thermal conductivity of a wetted material depends on the moisture content of the material.

For the building materials under the given conditions, the thermal conductivity values can be determined with equation:

$$\lambda_w = \lambda_d \cdot a \cdot t \cdot w \cdot e^{(-b \cdot w)} \quad (4)$$

where: λ_w and λ_d are the thermal conductivity of the wet sample and the dried sample, respectively, a and b are constants for the material that can be determined from the experiments, t is the wetting time and w is the moisture content [1].

The samples humidification was performed according to standard EN 1609 (1997): "Thermal insulating products for building applications. Determination of the short-term water absorption by partial immersion" [8].

3. Results of experiments

The measurement of thermal conductivity and of the amount of humidity/moisture absorbed was made over a four- hour period and a one- hour step. Then the sample humidification has continued for 24 hours to determine the w_p coefficient according to EN 1609 (1997) standard.

As a result, for all AAC samples, two different curves will be presented: the moisture content as a function of the wetting time, .and the thermal conductivity change as a function of the moisture content.

Figure 3 illustrates the variation in the moisture content of sample 1 depending on the humidification time. Considering that sample 1 is characterized by the lowest density, i.e. the highest absorption capacity, a significant increase in the amount of moisture absorbed in the first humidification hour is noticed. During the other three hours, an increase in humidity occurs but not so significant due to water filling of the sample pores in contact with water.

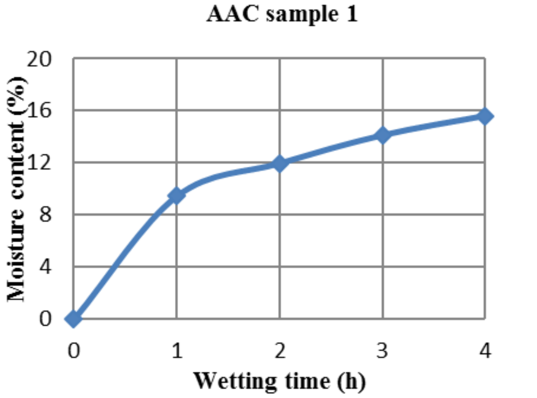

Fig. 3. *The moisture content as a function of the wetting time for sample 1*

Figure 4 shows the variation in thermal conductivity depending on the moisture content for sample 1. It can be noticed a significant increase in the thermal conductivity with the increase in moisture content, especially after the first humidification hour. For a humidity of approximately 15% the thermal conductivity increases four times.

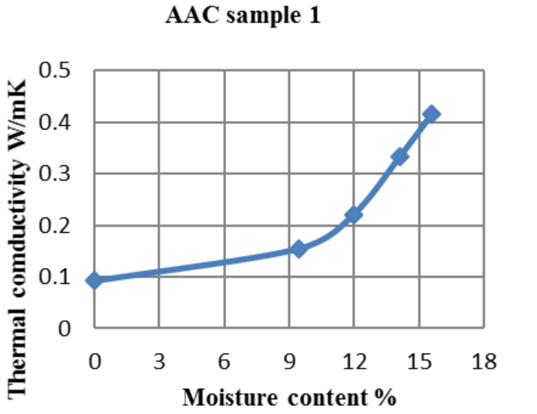

Fig. 4. *The variation of thermal conductivity vs. the moisture content for sample 1*

Figures 5 and 6 show the variation in the moisture content and thermal conductivity for sample 2. Unlike sample 1, there is a decrease in the amount of moisture absorbed due to the high density in sample 2. This is found in a lower variation in the thermal conductivity during the four hours of humidification.

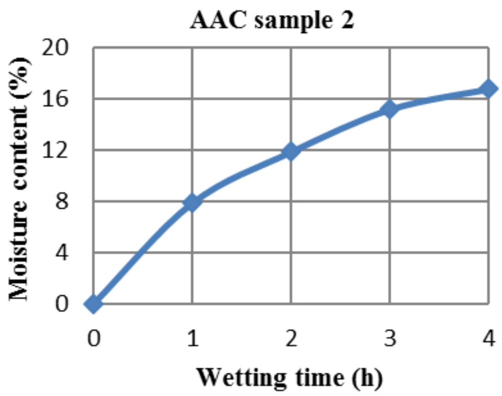

Fig. 5. *The moisture content as a function of the wetting time for sample 2*

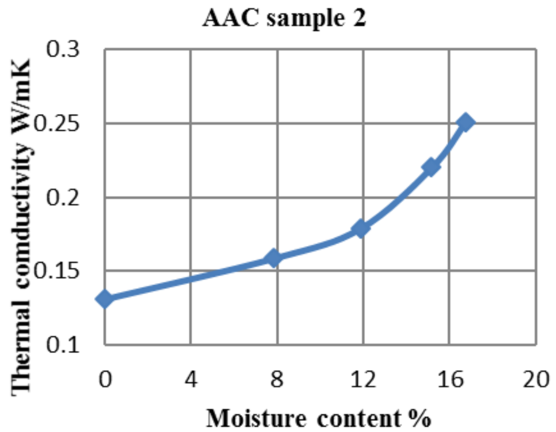

Fig. 6. *The variation of thermal conductivity vs. the moisture content for sample 2*

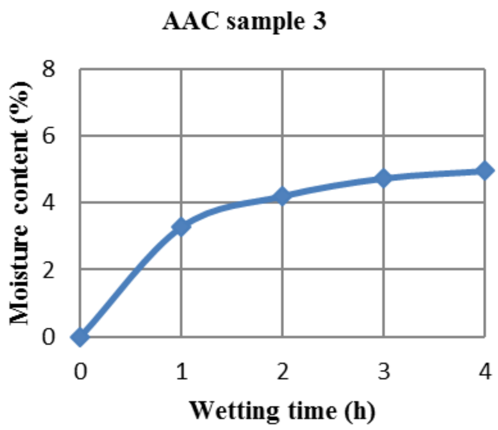

Fig. 7. *The moisture content as a function of the wetting time for sample 3*

Compared to samples one and two, in the case of the third sample which is characterized by the highest density, a very low absorption capacity is observed during the four hours of humidification (Fig. 7). Although the dry sample 3 has the highest conductivity, it does not vary significantly due to the low absorbed moisture content (Fig. 8). The low absorption capacity for sample three is accounted for by the reduced number of pores in the material.

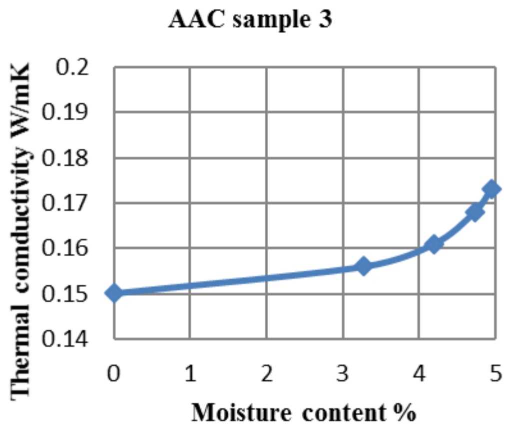

Fig. 8. *The variation of thermal conductivity vs. the moisture content for sample 3*

4. Conclusions

The main purpose of the study was to experimentally determine the dependence between thermal conductivity and moisture content for three different types of AAC. In all three cases there was an increase in conductivity depending on the degree of humidification. Sample 1, although in dry state has the lowest conductivity, in the presence of moisture it loses its insulation capacity by increasing the conductivity coefficient.

With the increase in the density of the three samples, there is a decrease in the moisture absorption capacity but at the same time a decrease in conductivity. Therefore, when using AAC blocks, increased attention has to be paid to walls finishing and moisture exposure.

Generally, AAC constructions are externally covered by moisture resistant thermal insulation layers. At the same time, it is recommended that AAC blocks be stored in areas of low humidity before use.

The use of AAC blocks in the field of construction remains a very good solution both in terms of thermal insulation and mechanical strength.

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