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Examination of the Thermal Conductivity of the Wood Wool Products for Thermal Insulation of Moisture Sorption

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Abstract - The thermal conductivity coefficient strongly related to moisture of material. In contact with moisture air some materials become wet, e.g. autoclaved aerated concrete. In this paper wood wool products were conditioned in different moisture air and thermal conductivity of such prepared samples were measured. Correlation between adsorption of the moisture of wood wool samples and sample exposure to moisture was presented. Additionally, changes of λ-value of the wood wool samples of moisture sorption after process of total immersion of samples were shown. Wood wool samples were described by mechanical and physical properties. Structure and chemical composition of fibrous material was characterized by spectroscopic and microscopic technics such like XRF.

Keywords: Wood wool, Thermal conductivity, Moisture sorption, XRF.

1. Introduction

Generally moisture in buildings materials exists as a water vapour, moisture sorption and liquid water. Area of investigation in this article concerns on moisture which is a result of physico-chemical phenomena on the wide, extensive material surface of porous and capillaries. Mentioned the physico-chemical phenomena are interaction between water vapour particles and forces existing near of the material surface – this interaction causes the formation of the adsorbed water vapour film on the material surface.

Number of water vapour adsorbed from the air is strongly connected from character of the material, especially from the structure of porous, volume and total area of porous. From the other hand number of adsorbed water vapour depends on vapour pressure. To find a correlation between thermal conductivity coefficient and sorption moisture the first step it to determine moisture in sample or preparation sample with certain sorption moisture.

Among thermal insulation products on the market most of them are products with negligible sorption moisture – generally protected by sorption moisture (e.g. glass wool, stone wool). During production of such products hydrophobic agents are added thus products are protected against water. Other insulation products as expanded polystyrene (EPS), or extruded polystyrene (XPS) due to low water adsorption, because of close cell structure (Miros, 2013) such hydrophobic agents are not needful.

For examination the correlation of thermal conductivity and moisture sorption of the thermal insulation products wood wool products were taken into consideration.

2. Characteristic of Samples

Two types of wood wool products available at present on the market have been investigated. One type of the material is available of thickness of 40 – 120 mm and density around 100 kg/m^3 – in this paper marked as type R. The another type (market as F) is of thickness of 40 – 200 mm and density around 50 kg/m^3. Density of samples chosen for investigation was presented in Table 1.

Table 1. Density and dimension of wood wool samples.

Dimension of the sample: [mm]	Density [kg/m^3]	
	Sample F	Sample R
600 x 600	50	110
300 x 300	60	90

Characteristic of the samples was divided on two parts: microscopic (structure and chemical composition) and macroscopic properties (dimensional stability test, water vapour resistance factor).

2.1. Sample Structure and Chemical Composition

The chemical composition of the both samples was obtained by used to X-Ray Fluorescence method on the Rigaku ZSX PRIMUS II spectrometer (Verma, 2009, Fadleya, 2010, Streli 2010, Kubacki et al., 2013). The mass concentration was determined from the spectra at room temperature.

In table 2 the mass concentrations are presented for both samples. The most concentration was obtained for carbon and oxygen. The Na, Mg, Al, Si, P, S, Cl, K, Ca and Mn elements were detected for the both samples. In the sample R the additional elements like Fe, Ni, Nb, Cr and Mo were detected.

Table 2. The mass concentration of the both samples of the wool.

Sample R		Sample F	
element	Mass concentration [%]	element	Mass concentration [%]
C	49.0567	C	56.3633
O	46.8885	O	42.9114
Na	0.0726	Na	0.0521
Mg	0.1664	Mg	0.0364
Al	0.0180	Al	0.0749
Si	0.0817	Si	0.1440
P	2.0078	P	0.0161
S	0.2013	S	0.0685
Cl	0.0259	Cl	0.0383
K	0.0764	K	0.0777
Ca	0.2901	Ca	0.1845
Cr	0.1854	-	-
Mn	0.0401	Mn	0.0226
Fe	0.8132	-	-
Ni	0.0694	-	-
Nb	0.0018	-	-
Mo	0.0047	-	-

Besides the chemical composition analysis observation of the sample structure were performed. The OLYMPUS bx51 optical microscope was used for the analysis of the single wood fibre.

Observed samples consist of single fibres with different diameters, length and orientation (Table 3). Mean diameter obtained from the analysis of c.a. 50 fibres of the samples were respectively 31 µm for sample R and 37µm for sample F.

Table 3. Structure of the both samples of the wool.

Sample R **Sample F**

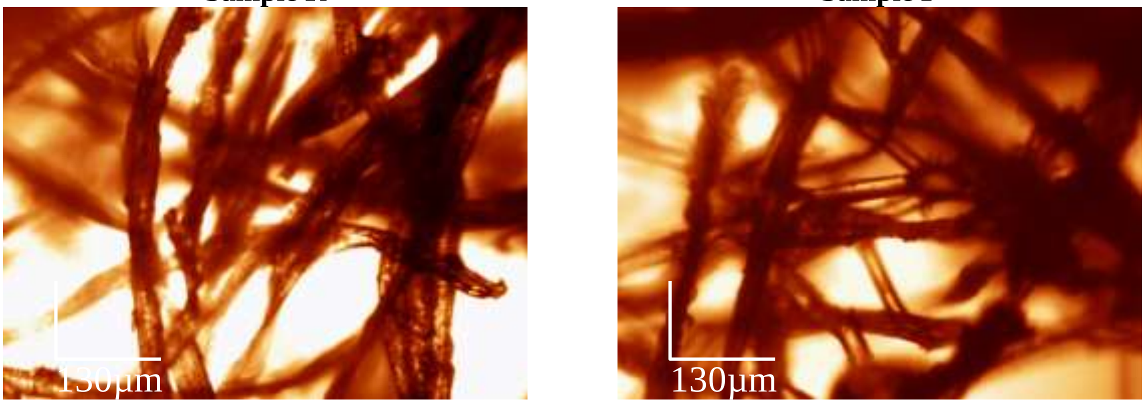

Photo 1. An optical microscope image (x10) obtained for selected area of the sample.

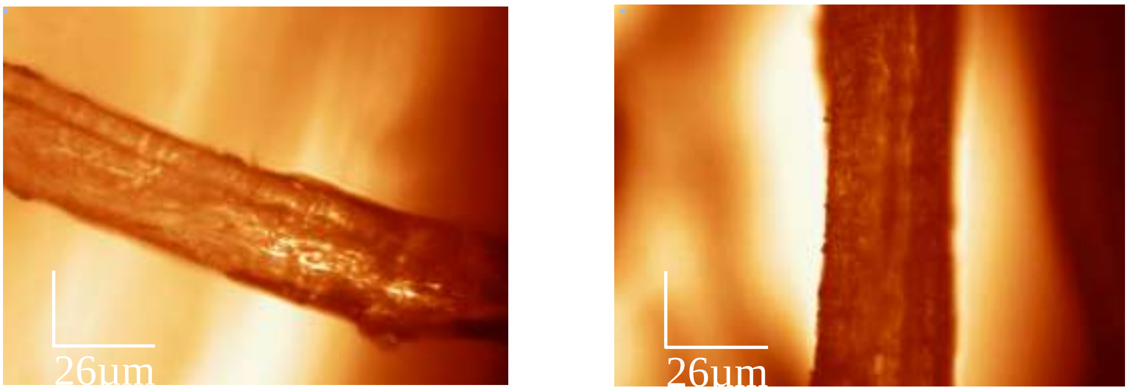

Photo 2. An optical microscope image (x50) obtained for selected area of the sample.

2.2. Physical and Mechanical Properties of the Samples

2.2.1. Sample Preparation

Specimens were cut to a certain size (mainly of 600 x 600 mm, or 300 300 mm) from the middle of a material block to ensure they did not include any ages of the material block. The specimens were conditioned at room temperature (23 ± 2) ^{0}C and (50 ± 5) % relative humidity (the weight of each specimen has reached a steady state - variation of its weight were less than ± 0,1 %). The weight, length, width, thickness of specimen were recorded before every measurements.

2.2.2. Dimensional Stability Test

Dimensional stability test were performed according to EN 1604 under 23 ^{0}C and relative humidity 90% for 48h storage time. The samples size were of 300 x 300 mm. In table 4 and 5 results of dimensional stability test were presented.

Table 4. Dimensional stability results for wood wool, Sample F.

	Dimensional stability [%]		
Sample F	length, $\Delta\varepsilon_l$	width, $\Delta\varepsilon_w$	thickness, $\Delta\varepsilon_t$
F_1	0,1	0,2	0,0
F_2	0,1	0,3	0,1
F_3	0,1	0,1	0,1
Mean value	0,1	0,2	0,1

Table 5. Dimensional stability results for wood wool, Sample R

	Dimensional stability [%]		
Sample R	length, $\Delta\varepsilon_l$	width, $\Delta\varepsilon_w$	thickness, $\Delta\varepsilon_t$
R_1	0,1	0,2	0,0
R_2	0,1	0,0	0,1
R_3	0,2	0,1	0,0
Mean value	0,2	0,1	0,1

2.2.3. Water Vapour Transmission

To determine properties of water vapour transmission method of EN 12086 Standard was applied, widely used for characteristic of buildings materials. The measurements were done at (23 ± 1) ^{0}C. Results of water vapour resistance factor μ were presented in table 6.

Table 6. Results of water vapour resistance factor μ for wood wool samples.

Size	Sample F	Sample R
600 x 600	0,5	2,1
300 x 300	0,6	2,0

3. Moisture Sorption Sample

3.1. Conditioning Chamber

The conditioning chamber (the same function as exsiccator) was a glass box with size (700 x 700) mm and high 500 mm. The cover of the chamber was sealed by a gasket. Inside of the conditioning chamber was a metal lattice where samples were placed. The lattice lied on the small polystyrene blocks (10 cm high) to allow free circulation of the air in whole chamber. Under the lattice (on the bottom of the chamber, between small polystyrene blocks) a beaker with certain saturated solution was placed to provide certain humidity in the chamber. For ensure that humidity is the same in every place in the conditioning chamber a cooler was placed over the sample, which worked through all conditioning time. Humidity was controlled by LB-705 (LAB-EL) thermohygrometer (uncertainty: temperature ± 0,1^{0}C, humidity ± 2,0%).

For purpose of this investigation three conditioning chamber were prepared, where there samples (each one for one sample) could be conditioned (photo 1).

The conditioning chambers were placed into the conditioning room, where constant temperature (23 ± 2 ^{0}C) was kept and controlled.

Photo 3. The conditioning chambers with wood wool samples.

3.2. Humidity in the Conditioning Chamber

To obtain certain humidity in the chamber different saturated solutions of salt were used. In certain temperature range saturated solution of the salt are able to provide certain humidity of the air. For this investigation the temperature range from 20 ^{0}C to 25 ^{0}C was chosen and three certain humidity were taken into account: 54 %, 75 %, 81 %. For these reason saturated solution of the salt were taken:

- Magnesium nitrate – humidity of the air under the saturated solution: 54%
- Sodium chloride – humidity of the air under the saturated solution: 75%
- Ammonium sulfate – humidity of the air under the saturated solution: 81%

3.3. Preparation of the Moisture Sorption Sample

Specimens with certain size (600 x 600 mm, or 300 x 300 mm), dried to constant weight, were placed into a one of conditioning chamber with certain humidity. The time of sample condition was control by periodic weighing until constant weight of the sample. In the fig. 1 the time of moisture increase in wood wool samples is shown. Generally samples were kept in the conditioning chamber more than 16 days.

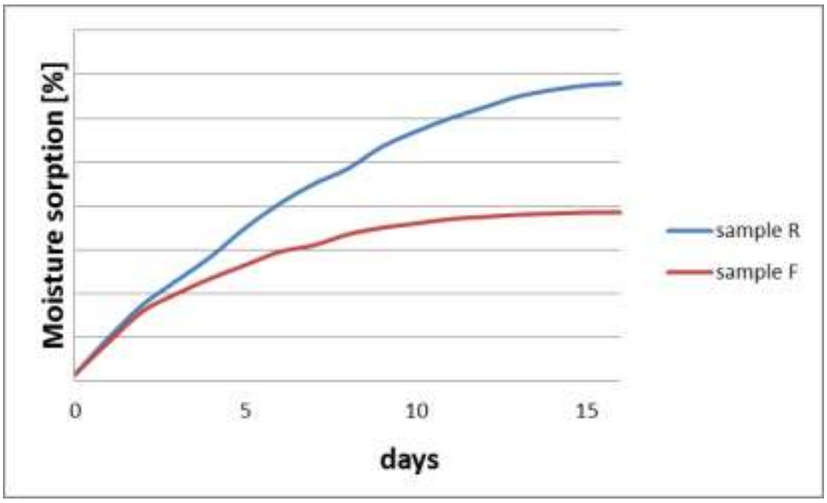

Fig. 1. The time of moisture increase in wood wool samples.

Number of adsorbed moisture on the solid surface depends on partial vapor pressure of water vapor in the ambient air, therefore depends on number of water vapor particles which can contact with the solid surface. Based on results of increase of sample moisture the isotherm of sorption was prepared (shown at Fig.2).

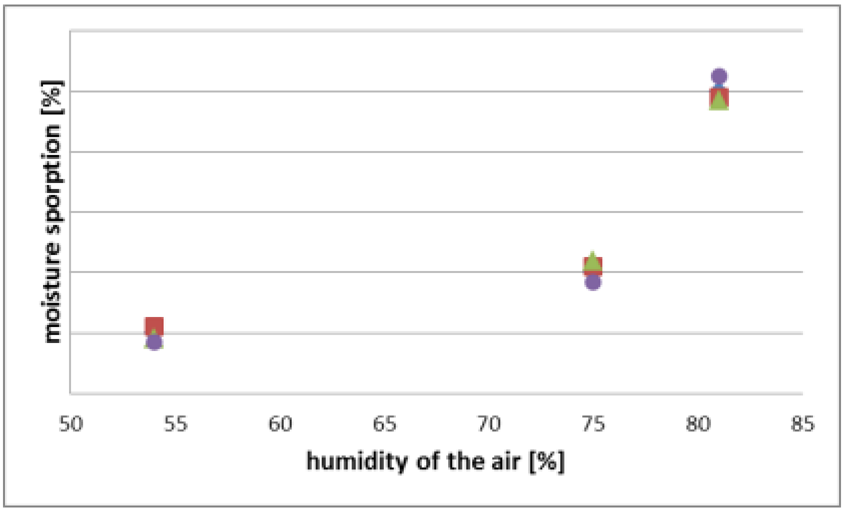

Fig. 2. Correlation of sorption for wood wool samples.

Measurements of the thermal conductivity of the moisture wood wool samples could last even 48 hours, so samples were wrapping the thin polyethylene foil (thermal resistance was negligible) to avoid vapour transfer with ambient air of the laboratory.

4. Results of Thermal Conductivity of Moisture Sorption Samples

The heat flow meter apparatuses (FOX 314 and FOX 600 by LaserComp) were used to obtain results of thermal conductivity of the samples. Apparatuses are dedicated to measure the steady-state heat transfer through flat sample. Measurement were performed according to EN 12667. The test uncertainty was 2,3 % for FOX 600 apparatus, 2,4 % for FOX 300 apparatus at the confidential level of 95%.

To avoid migration/transport of vapour through the sample the difference between two plates of the apparatus was 10K (hot plate was 15^{0}C, cold plate was 5 ^{0}C), mean temperature 10 ^{0}C (EN 12664). Before and after tests the sample was weighted.

All investigated samples were conditioned in three different conditions of relative humidity: 54%, 75% and 81%. Then the sample was weighted and wrapped the polyethylene foil. The moisture content of wood wool sample was expressed as a ratio of the mass of water per unit mass of dry sample (Hartley, 2001).

The results of thermal conductivity for wood wool samples with differ content of moisture sorption were presented in table 7.

Table 7. Thermal conductivity coefficient, λ, [W/(m·K)] of wood wool samples with differ moisture sorption content.

Sample (dimension)	Thermal conductivity coefficient of sample with moisture sorption content [W/(m·K)]:		
	54 %	75 %	81 %
F (600 x 600) Density 50 [kg/m^3]	0.03818 0.03810 0.03784	0.03835 0.03830 0.03820	0.03868 0.03877 0.03880
F (300 x 300) Density 60 [kg/m^3]	0.04071 0.04020 0.03931	0.04242 0.04121 0.04081	0.04600 0.04551 0.04411
R (600 x 600) Density 110 [kg/m^3]	0.03812 0.03825 0.03989	0.04142 0.04167 0.04229	0.04308 0.04403 0.04473
R (300 x 300) Density 90 [kg/m^3]	0.03760 0.03745 0.03710	0.03801 0.03790 0.03742	0.03890 0.03840 0.03810

In figures 3-6 change of thermal conductivity coefficient were presented for wood wool samples (F and R) vs. humidity of the air.

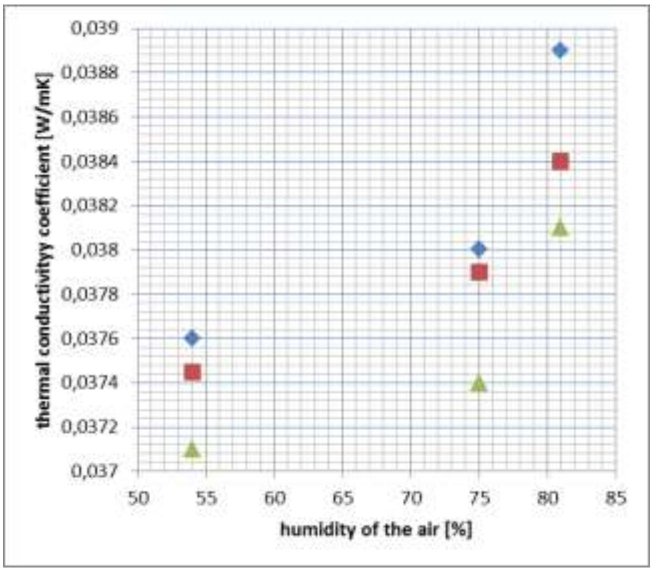

Fig. 3 Thermal conductivity coefficient of sample R vs. humidity of the air (54%, 75% and 81 %). Size of samples (300 x 300 x 40) mm and density 90 kg/m^3.

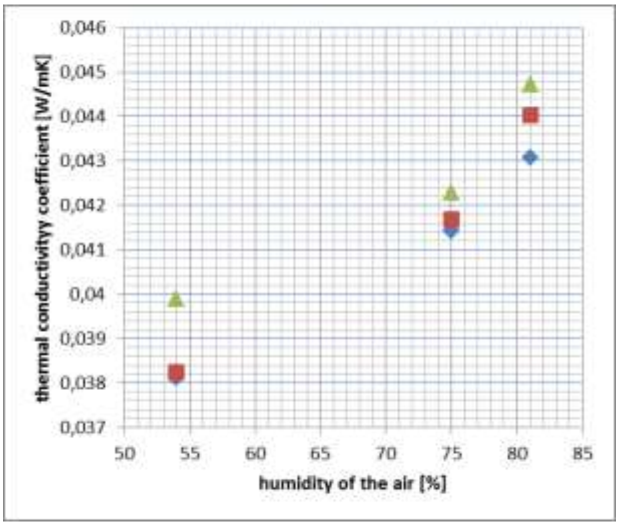

Fig. 4 Thermal conductivity coefficient of sample R vs. humidity of the air (54%, 75% and 81 %). Size of samples (600 x 600 x 140) mm and density 110 kg/m^3.

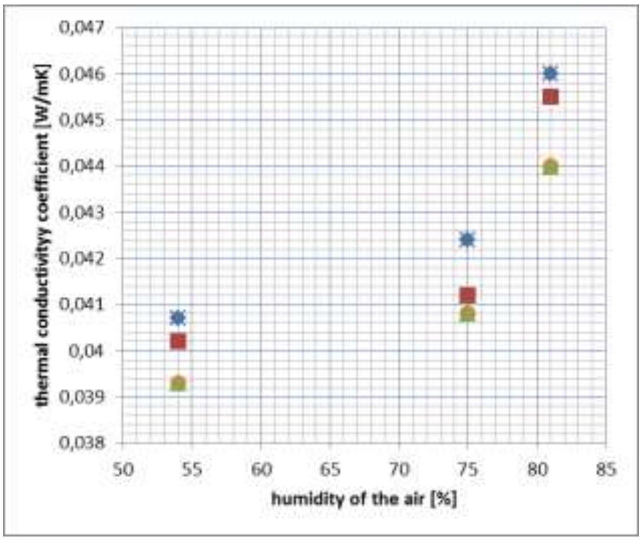

Fig. 5 Thermal conductivity coefficient of sample F vs. humidity of the air (54%, 75% and 81 %). Size of samples (300 x 300 x 60) mm and density 60 kg/m^3.

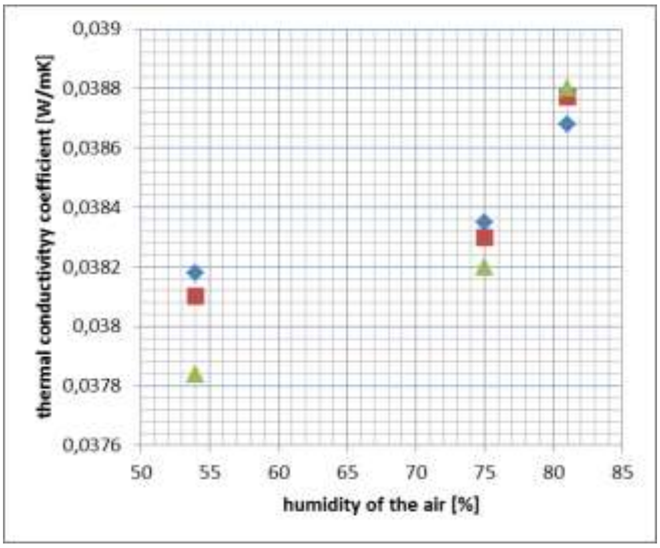

Fig. 6 Thermal conductivity coefficient of sample R vs. humidity of the air (54%, 75% and 81 %). Size of samples (600 x 600 x 150) mm and density 50 kg/m^3.

5. Conclusions

The values of thermal conductivity coefficient of investigated wood wool samples were increasing during adsorption of vapour from the air. Correlation between thermal conductivity coefficient and moisture sorption of samples were presented on figures 3-6. The highest observed change of thermal conductivity coefficient correlated with moisture sorption was estimated on 15% for F samples when humidity of air increased from 54% to 81%. For such increase of humidity of the air, moisture of the sample increased about 7%. Lower increase of thermal conductivity coefficient (around 2%) was observed in lower range of humidity of the air. Such increase was caused a lower value of adsorption of vapour form the air, what was observed on fig. 2 (correlation of sorption for wood wool samples).

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EN 12667 Thermal performance of building materials and products. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods. Products of high and medium thermal resistance
EN 1604 Thermal insulating products for building applications. Determination of dimensional stability under specified temperature and humidity conditions