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Study of Hydrothermal Behavior of Thermal Insulating Materials Based On Natural Fibers

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Abstract**—**Thermal insulation materials based on natural fibers represent a very promising area of materials based on natural easy renewable row sources. These materials may be in terms of the properties of most competing synthetic insulations, but show somewhat higher moisture sensitivity and thermal insulation properties are strongly influenced by the density and orientation of fibers. The paper described the problem of hygrothermal behavior of thermal insulation materials based on natural plant and animal fibers. This is especially the dependence of the thermal properties of these materials on the type of fiber, bulk density, temperature, moisture and the fiber orientation.

Keywords**—**Thermal insulating materials, hemp fibers, sheep wool fibers, thermal conductivity, moisture.

I. Introduction

ONE of the main global topics of current time is reduction of energetic requirements of existing and new buildings, which is important for limitation of global warming and from the point of view of sustainable development in building industry. These facts are implemented in legal requirements in major part of developed countries. Within European Union, it is for example Direction of European Parliament and Council 2010/31/EU, which is implemented in legal requirements of individual member countries.

Thermal-insulation based on natural fibers are progressive materials based on secondary raw materials or easily renewable raw material resources. If these materials are industrially produced, most of their parameters are comparable or better than parameters of synthetic thermo-insulating materials. Current market offers various thermo-insulating materials based on natural fibers, which are mostly industrially produced by means of thermal binding. Fibers in these materials are oriented square to the direction of flow of heat (insulation mats) or in the direction of heat flow (insulation lamellas).

As regards sources of input materials, bast fibers originating from agriculture can be used (for example hemp, flax, kenaf, jute), fibers from cattle-breeding (like sheep wool), fibers from textile industry or waste recycled textile (mix of fibers with prevailing proportion of cotton) [1]-[3].

However, thermo-insulating behavior of natural fiber based materials slightly differs from synthetic materials, which is caused by low thermal conductivity and higher moisture content sensitivity of natural fibers. One of the problems of natural fibers is their variability of length and thickness, often quite considerable, which is based on the type of the fiber, its cleanliness and degree of treatment (like degree of pulping or tearing-up of bast fibers from agriculture). Another problem of this type of material is orientation, thickness and volume weight of given material related to its thermo-insulating properties [4]-[7].

Research works carried out at the Brno University of Technology were focused on the study of thermally-technical behavior and transfer of heat within the structure of selected thermo-insulating materials based on natural fibers.

II. Test Samples Composition

Based on the literature search and availability of individual samples of insulation materials, 6 types of insulation materials were selected differing in kind, thickness, orientation of fibers and volume weight. All samples were made with the method of thermal bonding. For the specimen No. 3, the method of perpendicular orientation of fibers was selected. Test specimens had following composition:

1. Specimen No. 1: Insulation material based on technical hemp with lower volume weight (composition: 85% natural fibers; 15% bonding fibers),
2. Specimen No. 2: Insulation material based on technical hemp with higher volume weight (composition: 85% natural fibers; 15% bonding fibers),
3. Specimen No. 3: Insulation material based on technical hemp with perpendicular orientation of fibers (composition: 85% natural fibers; 15% bonding fibers),
4. Specimen No. 4: Insulation material based on sheep wool with fiber thickness 23 μm (composition: 85% natural fibers; 15% bonding fibers),
5. Specimen No. 5: Insulation material based on sheep wool with fiber thickness 33 μm (composition: 85% natural fibers; 15% bonding fibers),
6. Specimen No. 6: Insulation material based sheep wool with fiber thickness 23 μm and 33 μm (composition: 85% natural fibers; 15% bonding fibers).

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III. Test Methods and Samples Preparation

Samples were in the form of mats, from which test specimens of required dimensions were prepared. Following values were determined on all test specimens:

- length and width in accordance with EN 822 [8],
- thickness in accordance with EN 823 [9],
- volume weight in accordance with EN 1602 [10],
- thermal conductivity in accordance with EN 12667, ISO 8301 depending on volume weight [11], [12],
- thermal conductivity in accordance with EN 12667, ISO 8301 depending on moisture content [11], [12].

First, length and width in accordance with EN 822 under laboratory conditions at the temperature 23±2) °C and relative humidity (50±5)% were determined. Then, thickness was determined at nominal pressure (50±1) Pa in accordance with EN 823 and volume weight in accordance with EN 1602. Test results are stated in following table:

TABLE I
Overview of Physical Properties of Test Samples

Sample	Length [mm]	Width [mm]	Thickness [mm]	Density [kg.m^{-3}]
1	289	275	88.1	29
2	306	296	103.6	34
3	300	300	34.5	19
4	312	303	85.6	24
5	298	297	96.8	21
6	303	298	85.8	21

Then, thermal conductivity coefficient was determined. Measurements were carried out in accordance with EN 12667 and ISO 8301 at medium temperature +10°C and thermal gradient 10K. Measured were test specimens depending on volume weight; individual specimens were compressed to 90%, 80%, 70%, 60% and 50% of their original volume.

TABLE II
Overview Thermal Technical Properties of Test Samples (1)

Pressing	Sample 1		Sample 2		Sample 3	
	Density [kg.m^{-3}]	Thermal conductivity [W.m^{-1}.K^{-1}]	Density [kg.m^{-3}]	Thermal conductivity [W.m^{-1}.K^{-1}]	Density [kg.m^{-3}]	Thermal conductivity [W.m^{-1}.K^{-1}]
0%	29,20	0,05258	34,38	0,05352	19,09	0,04522
10%	32,45	0,05199	38,20	0,04935	24,88	0,04541
20%	36,51	0,04899	42,97	0,04733	33,50	0,04690
30%	41,72	0,04584	48,55	0,04553	34,79	0,04886
40%	48,67	0,04383	56,47	0,04348	38,53	0,04897
50%	58,41	0,04141	67,52	0,04129	40,88	0,05066

TABLE III
Overview Thermal Technical Properties of Test Samples (2)

Pressing	Sample 4		Sample 5		Sample 6	
	Density [kg.m^{-3}]	Thermal conductivity [W.m^{-1}.K^{-1}]	Density [kg.m^{-3}]	Thermal conductivity [W.m^{-1}.K^{-1}]	Density [kg.m^{-3}]	Thermal conductivity [W.m^{-1}.K^{-1}]
0%	23.52	0.04051	20.49	0.04479	20.55	0.04572
10%	25.98	0.03813	22.84	0.04202	22.83	0.04190
20%	29.37	0.03675	25.64	0.03871	25.60	0.04101
30%	33.43	0.03552	29.24	0.03708	29.29	0.03828
40%	38.98	0.03421	34.21	0.03471	34.31	0.03745
50%	45.66	0.03267	41.16	0.03379	40.97	0.03489

Then, thermal conductivity was determined with various moisture content of test specimens. All measurements were carried out at medium temperature +10°C and thermal gradient 10 K. Test results are stated in following tables:

TABLE IV
Overview Influence of Thermal Conductivity of Test Samples on Moisture Content

Sample	Thermal conductivity [W.m^{-1}.K^{-1}]		
	Moisture: 0%	Moisture: 8 %	Moisture: 20 %
1	0.0518	0.0526	0.0555
2	0.0524	0.0535	0.0568
3	0.0449	0.0452	0.0511
4	0.0379	0.0405	0.0485
5	0.0406	0.0448	0.0528
6	0.0418	0.0457	0.0541

IV. Evaluation of Test Results

Based on the measurements it was found that increasing volume weight of test specimens by compressing thermal considerably reduced thermal conductivity in most cases.

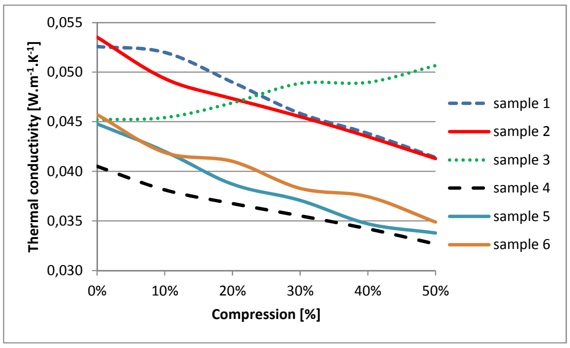

Fig. 1 Influence of compression on thermal conductivity value of test samples

However, the specimen with perpendicular hemp fiber (oriented in the direction of thermal flow) showed worsened thermo insulating properties. Dependence of thermal conductivity on volume weight (compression) was of similar character also with specimens made from hemp and sheep wool. Hence, it can be concluded that no influence of kind and thickness of fiber was proved.

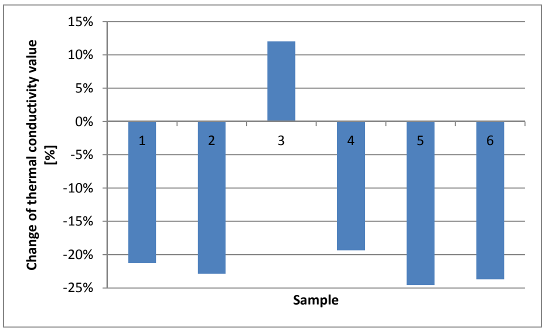

Fig. 2 Overview of change of thermal conductivity of test samples (comparison of 0% and 50% compression).

Fig. 3 Apparatus Holometrix 2300 for determination of thermal conductivity

As regards dependence of thermal conductivity on moisture content, strong influence of moisture content on thermo insulating properties of test specimens was proved in all cases. If compared, test specimens from sheep wool are considerably more sensitive to moisture than hemp insulation. No influence of orientation of fibers (different behavior of specimen No. 3 with perpendicular orientation of fibers) was proved.

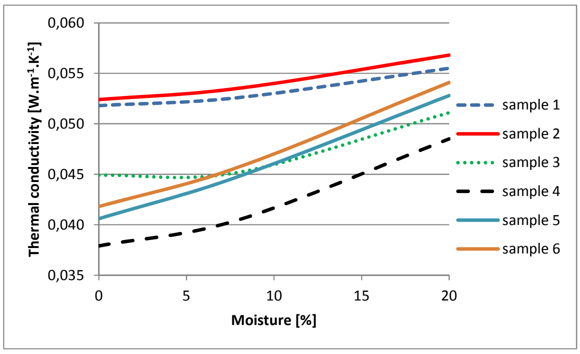

Fig. 4 Influence of compression on thermal conductivity value of test samples

V. CONCLUSION

Study of hydrothermal behavior of insulation material based on natural fibers was carried out.

It was found that thermal conductivity of these materials is strongly dependent on compression and moisture. As regards dependence of thermal conductivity of individual insulation materials on volume weight, it was found that specimens with fibers oriented in the direction of the mat (perpendicular to the direction of heat flow) showed decrease of thermal conductivity after increasing volume weight. However, the specimen with fiber oriented perpendicular to the mat (in the direction of thermal flow) showed worsened thermo insulating properties and increasing of thermal conductivity after compression. Hence, it was found that the determining parameter is orientation of fibers, which is more important than kind and thickness of fibers. As regards dependence of thermal conductivity on moisture content, moisture content caused considerable degradation of thermo insulating properties of all test specimens. In this case, the decisive factor is the kind and thickness of fibers. Test specimens based on sheep wool are very sensitive to moisture content. Dependence of thermal conductivity of individual test specimens on moisture content was coherent with functional dependencies stated in EN ISO 10456 [13].

Fig. 5 Photography of test samples No. 1

Fig. 6 Photography of test samples No. 2

Fig. 7 Photography of test samples No. 1

Fig. 8 Photography of test samples No. 4

Fig. 9 Photography of test samples No. 5

Fig. 10 Photography of test samples No. 6

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