Acoustic and Thermal Insulating Materials Based On Natural Fibres Used in Floor Construction

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Abstract**—**The majority of contemporary insulation materials commonly used in the building industry is made from non-renewable raw materials; furthermore, their production often brings high energy costs. A long-term trend as far as sustainable development is concerned has been the reduction of energy and material demands of building material production. One of the solutions is the possibility of using easily renewable natural raw material sources which are considerably more ecological and their production is mostly less energy-consuming compared to the production of normal insulations (mineral wool, polystyrene). The paper describes the results of research focused on the development of thermal and acoustic insulation materials based on natural fibres intended for floor constructions. Given the characteristic open porosity of natural fibre materials, the hygrothermal behaviour of the developed materials was studied. Especially the influence of relative humidity and temperature on thermal insulation properties was observed.

Keywords**—**Green thermal and acoustic insulating materials, natural fibres, technical hemp, flax, floor construction.

I. INTRODUCTION

NATURAL organic fibres represent an ecological raw material source with a broad application in industry. Natural insulation materials have been widely used in building in the past, however, with the advances in science and industry, these materials have been gradually replaced with new synthetic materials whose feedstock are mostly non-renewable material sources such as petroleum or aggregate. The production of contemporary insulations is mostly energy-demanding and given current information about oil reserves, it is advisable to gradually develop materials from easily renewable raw material sources whose production is not demanding on energy and is not harmful to the environment. It has been an effort of many research teams to develop advanced materials based on natural fibres with good thermal insulation and acoustic properties. [1]-[3]

The design and use of high-quality thermal insulations has key importance in terms of reducing energy costs of building structures. This brings a decrease in gas, soot and dust emissions which has a direct positive influence on the environment. This issue is especially important with regards to the negative aspects of global warming and also given the conditions set by the Kyoto Protocol, next in terms of the directive of the European Parliament and Council of the European Union 2010/31/EU and the requirements of the Act No. 406/2000 Coll. – on Energy Management as amended (amended by 318/2012 Coll. from 3rd October 2012), and the "20-20-20" climate and energy package. [4], [5]

The paper describes the results of research in insulation materials based on hemp and flax fibres suitable especially for application in floors and horizontal constructions. First, the experiments determined the basic physical, mechanical, acoustic and thermal insulation properties of the developed fibrous materials and afterwards the examination of their hygrothermal behaviour was performed.

II. DESIGN OF TESTING MIXTURES

Six mixtures utilising two types of natural fibres were designed. The first three mixtures F1, F2 and F3 are mixtures made only with the stems of common flax, the other three mixtures designated H1, H2, H3 were made by producing a mixture with a specific ratio of hemp fibres, binder bicomponent fibres from polyester and shives produced in hemp processing. The hemp mixtures were produced in a production line enabling the processing of fibrous materials at an increased temperature and pressure; the flax mixtures were prepared using the following methods. Mixture F1 was prepared from stems cut and shortened by a pulling machine, which were later avivaged. Mixture F2 was obtained by pressing at the field from cut and shortened stems, mixture F3 was prepared by pressing crushed stems also at the field. The percentages of the individual components are in Table I.

TABLE I
COMPOSITION OF TEST MIXTURES [IN MASS %]

Mixture	**Natural fibres**		**Bicomponent fibres**	**Shives**
	- Flax -	**- Hemp -**		
F1	85	-	15	*)
F2	85	-	15	*)
F3	85	-	15	*)
H1	-	48	20	32
H2	-	49	10	41
H3	-	64	20	16

*) whole stems (fibers + shives)

Afterwards, the specimens sized 200 mm x 200 mm and 300 mm x 300 mm, conditioned in a laboratory at temperature 23°C and 50% relative humidity were subjected to the following laboratory tests. [6]

- Determination of thickness *d* and linear dimensions of specimens (according to EN 822, EN 823, EN 12085) [7]-[9];

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- Determination of density ρ (according to EN 1602) [10];
- Determination of thermal conductivity λ (according to CSN 72 7012-3, EN 12667, ISO 8301) [11], [12];
- Determination of water vapour resistance factor μ (according to EN 12086) [13];
- Determination of compressive strength at 10% strain σ_{10} (according to EN 826) [14];
- Determination of tensile strength perpendicular to faces σ_{mt} (according to EN 1607) [15];
- Determination of dynamic stiffness s_d (according to ISO 9052-1) [16].

III. EVALUATION OF LABORATORY MEASUREMENTS OF THE DEVELOPED INSULATIONS

The measurement of basic physical, mechanical, thermal and acoustic insulation properties was performed according to the above mentioned standard procedures on 3 specimens of each mixture. The evaluation of these experimental measurements is in Table II.

Fig. 1 Apparatus Holometrix 2300 for determination of thermal conductivity

TABLE II
RESULTS OF LABORATORY MEASUREMENTS OF DEVELOPED INSULATIONS

Mixture	**Thickness** [mm]	**Bulk density** [kg.m^{-3}]	**Water vapour resistance factor** [-]	**Thermal conductivity** [W.m^{-1}.K^{-1}]	**Compressive strength at 10% strain** [N.mm^{-2}]	**Tensile strength** [N.mm^{-2}]	**Dynamic stiffness** [MPa.m^{-1}]
F1	40.3	81.6	4.1	0.0477	6.9	8.4	10.8
F2	39.7	115.3	3.8	0.0404	14.1	14.6	7.4
F3	40.1	100.4	4.0	0.0452	13.2	10.8	6.7
H1	9.4	111.6	5.3	0.0482	36.9	25.1	20.8
H2	40.2	82.1	4.2	0.0405	11.2	15.3	7.4
H3	38.4	95.5	3.9	0.0399	21.0	18.8	8.5

Based on the performed measurements, bulk density of the mixtures was determined to range from 81.6 kg.m^{-3} to 115.3 kg.m^{-3}, while the specimen thickness was from 9.4 mm to 40.3 mm. Based on the experimentally obtained values of water vapour resistance factor, it can be stated that the materials are diffusion-open. The lowest water vapour resistance factor value was found with mixture F2, 3.8; conversely, the highest value was recorded with mixture H1, 5.3. In terms of thermal insulation properties, the best values of thermal conductivity were obtained with specimens conditioned in a laboratory (temperature 23°C, relative humidity 50%) made from mixtures F2 0.0404 W.m^{-1}.K^{-1}, H2 0.0405 W.m^{-1}.K^{-1} and H3 0.0399 W.m^{-1}.K^{-1}. Mixtures H1 and H3 displayed very good mechanical properties, where mixture H1 reached values of compressive strength at 10% strain of 36.9 N.mm^{-2}. This mixture also exhibited the greatest tensile strength perpendicular to faces, 25.1 N.mm^{-2}. Dynamic stiffness is key in terms of acoustic insulation properties of floors. Mixture F3 had the lowest value of dynamic stiffness, 6.7 MPa.m^{-1}.

The results obtained by the experiments indicate that the materials most suitable for insulation of floors and horizontal constructions are mixtures F2, F3, H2 and H3 (attention was paid mainly to a good ratio of acoustic, thermal insulation and mechanical properties). These mixtures were subsequently subjected to an examination of hygrothermal behaviour in order to determine the influence of temperature and relative humidity on the thermal insulation properties of the developed materials.

Fig. 2 Measurement of tensile strength

IV. EXAMINATION OF HYGROTHERMAL BEHAVIOUR OF TEST MIXTURES F2, F3, H2 AND H3

Given that these are natural materials with open porosity, it was necessary to examine the behaviour of the developed materials dependent on the relative humidity and temperature of the environment. [17] It is generally accepted that these conditions (relative humidity, environment temperature) have a significant influence on the characteristic properties of insulation materials.

Fig. 3 Measurement of dynamic stiffness

Specimens from mixtures F2, F3, H2 and H3 sized 300 x 300 mm were used in determining the dependency of thermal conductivity on:

- temperature,
- moisture content,
- relative humidity.

The determination of thermal conductivity was performed by means of the stationary plate method according to CSN 72 7012-3 and EN 12667 using Lambda 2300, Holometrix Micromet Inc., USA. The determination of thermal conductivity dependent on temperature was performed at medium temperatures 0°C, +10°C, +20°C, +30°C, +40°C and temperature gradient 10 K. The evaluation is in the following Table III and in Fig. 4.

TABLE III
OVERVIEW OF VALUES OF THERMAL CONDUCTIVITY DEPENDING ON TEMPERATURE

Mixture / Temperature	**0 °C**	**10 °C**	**20 °C**	**30 °C**	**40 °C**
F2	0.0397	0.0404	0.0415	0.0440	0.0463
F3	0.0431	0.0452	0.0469	0.0482	0.0497
H2	0.0392	0.0405	0.0428	0.0450	0.0465
H3	0.0390	0.0399	0.0413	0.0430	0.0449

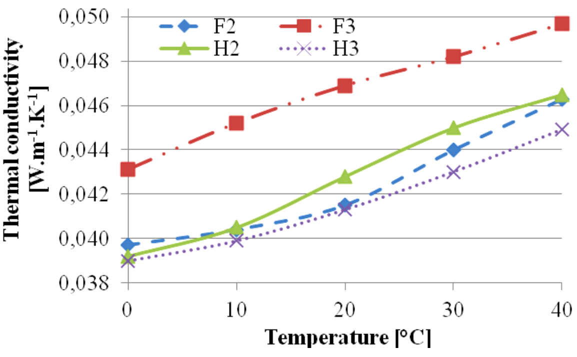

Fig. 4 Dependence of thermal conductivity on temperature

Based on the data from the experiments, it can be stated that mixture H3 displayed the lowest temperature sensitivity, with increase in thermal conductivity by 15.13 %. Conversely, the highest percentage increase of thermal conductivity values was found with mixture H2, 18.62 %.

The next step was the evaluation of the influence of relative humidity and material moisture on material thermal conductivity; see Table IV, Figs. 5 and. 6.

TABLE IV
OVERVIEW OF VALUES OF THERMAL CONDUCTIVITY DEPENDING ON RELATIVE HUMIDITY AND MOISTURE

Mixture / Relative humidity		**0 %**	**50 %**	**80 %**
F2	Moisture w [%]	0.0	5.18	10.13
	λ [W.m^{-1}.K^{-1}]	0.0395	0.0404	0.0469
F3	Moisture w [%]	0.0	6.78	12.24
	λ [W.m^{-1}.K^{-1}]	0.0427	0.0452	0.0499
H2	Moisture w [%]	0.0	5.41	10.42
	λ [W.m^{-1}.K^{-1}]	0.0393	0.0405	0.0452
H3	Moisture w [%]	0.0	5.85	11.41
	λ [W.m^{-1}.K^{-1}]	0.0389	0.0399	0.0456

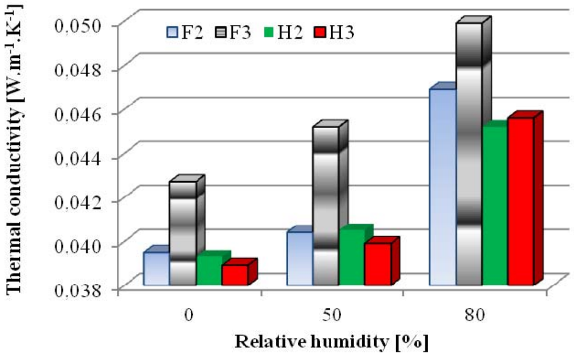

Fig. 5 Overview of thermal conductivities by other relative humidities

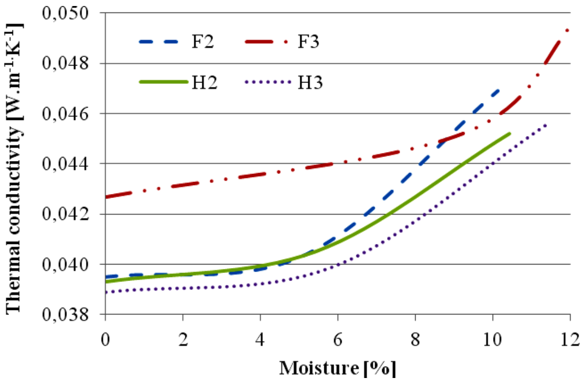

Fig. 6 Dependence of thermal conductivity on material moisture

The determination of dependence of thermal conductivity on relative humidity and material moisture has shown that mixture H3 had the lowest moisture sensitivity, 14.31%, as opposed to mixture F2 which had the highest moisture sensitivity 18.73%.

V. CONCLUSION

The obtained results of physical, mechanical, thermal-technical and acoustic properties of the developed insulation materials as well as the examination of their hygrothermal behaviour suggest that these materials are promising alternatives to insulation materials commonly used today on the European building market, such as expanded polystyrene and mineral wool. The results of the experiments indicate that the materials possess properties at least comparable to those of normal insulations. However, it must be noted that these natural material are more sensitive to relative humidity. For this reason it is necessary to apply these materials properly in practice, e.g. incorporate them systemically into the construction. As is visible from the results of the research and development of the natural insulation materials, most suitable application appears to be in floor insulation, insulation of non-load bearing walls and lightweight building envelopes. Based on the findings of the experiments, it can be stated that the mixture most suitable for insulation of horizontal constructions is mixture H3, i.e. hemp-based mixture which exhibited the following properties: bulk density 95.5 $kg.m^{-3}$, low thermal conductivity under laboratory conditions was 0.0399 $W.m^{-1}.K^{-1}$, low water vapour resistance factor 3.9, compressive strength at 10% strain 21.0 $N.mm^{-2}$, tensile strength perpendicular to faces 18.8 $N.mm^{-2}$, dynamic stiffness 8.5 $MPa.m^{-1}$.

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REFERENCES

[1] A. Korjenic, V. Petranek, J. Zach, J. Hroudova, “Development and performance evaluation of natural thermal-insulation materials composed of renewable resources”, *Energy and Buildings*, vol. 43, issue 9, 2011, pp. 2518-2523.
[2] A. Korjenic , T. Bednar, “Developing a model for fibrous building materials”, Energy and Buildings, vol. 43, issue 11, 2011, pp. 3189-3199.
[3] C. MacDougall, “Natural Building Materials in Mainstream Construction: Lessons from the U. K”, In *Journal of Green Building*, vol. 3, Issue: 3, 2008, pp. 3-14.
[4] Climate Action (online). Last revision 10th of September 2012, Online on: <http://ec.europa.eu/clima/policies/package/index_en.htm>.
[5] K. Kabele, “Review of the European Directive 2002/91 / EC on the energy performance of buildings”. In *TZB-info* (online), Online on: <http://www.tzb-info.cz/hodnoceni-energeticke-narocnosti-budov/6739-revize-evropske-smernice-2002-91-es-o-energeticke-narocnosti-budov>.
[6] S. Stastnik, J. Zach, “Testing of insulation materials”, 1. Issue. Brno University of Technology, Faculty of Civil Engineering, CERM, 2002.
[7] EN 822 Thermal insulating products for building applications - Determination of length and width, 2013, CEN.
[8] EN 823 Thermal insulating products for building applications - Determination of thickness, 2013, CEN.
[9] EN 12085 Thermal insulating products for building applications - Determination of linear dimensions of test specimens, 2013, CEN.
[10] EN 1602 Thermal insulating -- Products for building applications. Determination of the apparent density, 2013, CEN.
[11] EN12667 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, 2001, CEN.
[12] ISO 8301 Thermal insulation -- Determination of steady-state thermal resistance and related properties -- Heat flow meter apparatus, 2010, CEN.
[13] EN 12086 Thermal insulating products for building applications - Determination of water vapor transmission properties, 2013, CEN.
[14] EN 826:2013 Thermal insulating - Products for building applications - Determination of compression behavior, 2013, CEN.
[15] EN 1607 Thermal insulating products for building applications - Determination of tensile strength perpendicular to faces, 2013, CEN.
[16] ISO 9052-1 Acoustics - Determination of dynamic stiffness - Part 1: Materials used under floating floors in dwellings, 1993, CEN.
[17] J. Vejeliene, A. Gailius, S. Vejelis, et. al. “Evaluation of Structure Influence on Thermal Conductivity of Thermal Insulating Materials from Renewable Resources”, *Materials Science-Medziagotyra.* In National Conference on Materials Engineering, vol. 17, Issue 2, 2011, pp. 208-212.