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Development of Thermal Insulating Materials on Natural Base for Thermal Insulation Systems

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Abstract

With regard to the requirements of EU directive 2010/31/EU [1] is necessary in the construction and reconstruction of existing buildings to implement effective measures for reducing their energy consumption. From 1. 1. 2021 should get virtually all new buildings, buildings with almost zero energy. These facts mean that the construction of new and reconstruction of existing structures growing consumption of thermal insulation materials. From the perspective of sustainable development from the perspective of environmental (CO_2 emissions) are thermally insulating materials based on natural organic fibers promising alternative to synthetic thermal insulation of mineral fibers and foam-plastic substances. The main disadvantages of the thermal insulation materials based on natural, which very often precludes their use in thermal insulation systems structures are: high water absorption and poor response to fire. The paper deals with the possibility of modifying of thermal insulation materials based on technical hemp with a view to reducing water absorption and hygroscopicity.

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Keywords: insulating materials; natural fibers; technical hemp; water absorption; sorption moisture; thermal conductivity.

1. Introduction

Materials based on natural fibres from renewable raw material resources are now becoming increasingly popular. Due to its low mass density and cell structure, they show very good sound and thermal insulation properties, often better and more advantageous than synthetic fibres.

A great advantage of the insulation based on natural fibres is not only a low value of thermal conductivity but also the natural character of input fibres. Another advantage is that it is a renewable material which does not place any significant strain on the environment. For example, when compared with mineral wool, the insulation based on natural fibres has comparable and sometimes even better thermal technical characteristics (e.g. heat capacity or the afore-mentioned thermal conductivity) [2].

Despite these positive features, however, the construction market is still dominated by synthetic insulating materials. This is caused by some negative characteristics of materials based on natural fibres.

First of all, it is a high wettability and absorbability. These properties are due to an open pore structure of insulating materials as well as natural fibres themselves. Another consideration is the need to protect natural materials against biological attacks (e.g. against fungi and parasites); a major disadvantage is their flammability. Without modification, the materials based on natural fibres typically show reaction of fire within F class [3], [4].

Nevertheless, the negative properties of materials based on natural fibres can be largely modified by chemical treatment of fibres [5], [6], [7], [8], [9]. The paper deals with the results of research oriented toward modification of wettability and

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absorbability in natural insulation materials based on fibres of industrial hemp, especially from the perspective of potential use of these modified insulation materials for external thermal insulation contact systems (ETICS).

If the given insulation material is to be used for the construction of external thermal insulation contact systems, its short-term absorbability upon partial immersion should be less than 1 $kg.m^{-2}$ (according to ETAG 004) [10]. Generally, this requirement is also typical for insulating materials based on mineral wool (according to EN 13162) [11].

Further, material wettability has a negative impact on the final value of thermal conductivity of the insulating material under conditions of practical moisture; reduction in wettability should therefore improve thermal insulation properties of insulation material and its function in building constructions [12].

Test samples and methodology of experiments conducted

To investigate the modification of properties in thermal insulations based on natural fibres, we selected samples of hemp insulations which were produced by thermal bonding through the use of polyester bicomponent fibres (proportion of bicomponent fibres was 15%).

Given the fact that it should be difficult to prepare representative samples of insulating materials from modified fibres under laboratory conditions, we performed an additional treatment of insulators manufactured from pure fibres without any modification. In order to effectively apply chemical preparations to untreated insulations in the entire volume of test samples, insulators with lower mass densities (ranging from 30 to 40 $kg.m^{-3}$) were chosen. Experimental work was carried out on samples of slab-shaped insulating materials in sizes of 200×200 mm and 300×300 mm.

Fig. 1. Test samples

Then we selected different products (preparations) to make up impregnation substances, applicable to hemp insulation mats. Suitable impregnation products were selected based on research carried out in the market (construction and textile market), and also based on the results of previous studies and scientific papers published in professional journals.

For hydrophobic treatment of samples, the following products were chosen:

- Hexadecyltrimethoxysilan (HDTMS);
- Tris (2-methoxyethoxy) (vinyl) silan (TMEVS);
- Water-glass;
- Lukofob 39 – hydrophobic agent used for hydrophobization of silicate materials (product contains potassium methyl siliconate – more than 50% by weight; distilled water was used as a solvent for preparing the solution);
- Draxil 153 – hydrophobic agent for wood based on solvents (product based on siloxanes);
- Tagal – impregnation agent for textile (product contains isopropyl alcohol – from 10% to 20% by weight, gasoline (petroleum) fraction – from 50% to 90% by weight, and isopropyl acetate – from 1% to 5% by weight).

Individual products were applied by dipping or spraying. Further treatment was carried out using a sol-gel method [5], [8], [9], [13], by creating a silica sol from an aqueous solution of sodium water- glass with addition of HCl. The ratio of sodium water-glass, distilled water and HCl was 1:8:1. Two samples were prepared in this manner whereas one of them was additionally treated with hydrolysed HDTMS (4% by weight). We also tested a treatment using only the solution of sodium water-glass where the ratio of sodium water-glass and distilled water was 1:8.

Table 1. Recipes of hydrophobic coatings

Sample	Substance	Concentration [%]	Solvent	Amount of solution [%]	Application
REF	Without treatment	-	-	-	-
H6	HDTMS (85%)	6	Water	25	Spray
T6	TMEVS (98%)	6	Ethanol	25	Spray
LUK	Lukofob 39	4.76	Water	25	Spray
DR	Draxil 153	100	-	25	Spray
TG	Tagal	100	-	2,05	Spray

Table 2. Recipes of treatments using the sol-gel method and HDTMS silane

Sample	Substance	Sol			Solvent HDTMS			Amount of solution [%]	Application
		Water glass [unit]	Water [unit]	HCl [unit]	Concentration [%]	Amount of HDTMS [%]	Amount of ethanol [%]		
VS	Water-glass	1	8	-	-	-	-	256	S
VSH	Water-glass + HCl	1	8	1	-	-	-	217	S
VSHH	Water-glass + HCl + HDTMS	1	8	1	4	4	81	226	S+ spray HDTMS

Note: S – soaking

Fig. 2. Application of hydrophobic substance – soaking

Fig. 3. Application of hydrophobic substance – spray

Treated sample pieces were dried – first in the laboratory environment and then in an oven as needed.

The sample pieces were subject to the following laboratory testing:

- determination of length and width (according to EN 822) [14];
- determination of thickness (according to EN 823) [15];
- determination of mass density (according to EN 1602) [16];
- determination of short-term absorbability (according to EN 1609) [17];
- determination of hygroscopic sorption moisture (according to EN ISO 12571) [18];
- determination of thermal conductivity (according to EN 12667 [19] and ISO 8301 [20]).

2. Results of experiments

Mass density was determined in accordance with EN 1602 on samples having the size of 300×300 mm. These were samples with hydrophobic coating. The results are given in the following Table 3.

Table 3. Measured values of linear dimensions and calculated values of density in dried-up sample pieces

Sample	*m* [kg]	*l* [mm]	*b* [mm]	*d* [mm]	*ρ* [kg/m^3]
REF	292.72	290	299	87.8	38
H6	311.28	294	303	89.1	39
T6	317.35	305	301	91.5	38
LUK	308.67	300	302	86.1	40
DR	204.14	304	299	76.2	29
TG	201.06	305	300	76.0	29
VS	200.20	303	301	57.0	38
VSH	198.66	304	301	69.4	31
VSHH	208.75	303	303	74.1	31

Note: m – weight, l, b, d – dimensions of sample, ρ – bulk density

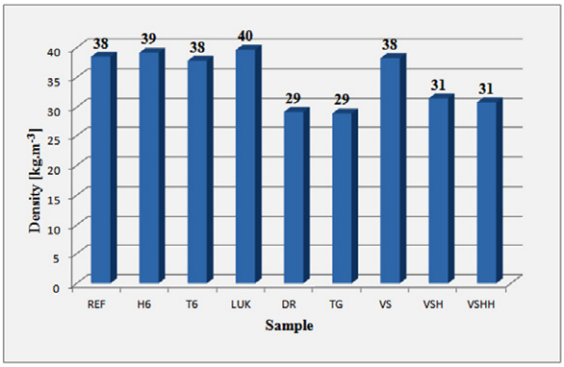

Fig. 4. Overview of density in dry state of testing samples

Subsequently, we determined the equilibrium sorption moisture $u_{23,80}$ [%] in accordance with EN ISO 12571; sample pieces with hydrophobic treatment were exposed to effects of ambient environment (temperature: +23 °C, relative air humidity: 80%). These values are crucial to determining the characteristic values of heat conductivity factor. The results are presented in the following table:

Table 4. Resulting values in determining the equilibrium sorption moisture at the temperature of +23 °C and relative air humidity of 80%

Sample	$u_{23,80}$ [%]
REF	14.6
H6	14.2
T6	14.4
LUK	14.8
DR	11.8
TG	11.6
VS	17.9
VSH	20.7
VSHH	21.4

Further, we determined the thermal conductivity factor λ [W.m^{-1}.K^{-1}] at steady state according to EN 12667 and ISO 8301. First of all, we determined thermal conductivity factors on dried-up sample pieces and, subsequently, on samples stored in an environment with the temperature of 23 °C and relative air humidity of 80%. Determination of the thermal conductivity was performed at a mean temperature of +10 °C and temperature gradient of 10 K. The measured values are listed in the following Table 5.

Fig. 5. Testing apparatus for determination of thermal conductivity

Table 5. Measured values of the thermal conductivity factor λ_{dry} in dried-up samples and $\lambda_{23,80}$ in samples stored at ambient temperature of +23 °C and relative air humidity of 80%

Sample	λ_{dry} (dry state) [W.m^{-1}.K^{-1}]	$\lambda_{23,80}$ (with sorption moisture) [W.m^{-1}.K^{-1}]
REF	0.04363	0.06257
H6	0.04430	0.05898
T6	0.04632	0.06179
LUK	0.04873	0.06450
DR	0.04751	0.06219
TG	0.05053	0.06746
VS	0.04527	0.06815
VSH	0.04793	0.06737
VSHH	0.04951	0.07114

Then we determined the short-term absorbability upon partial immersion W_p [kg.m^{-2}] according to EN 1609. The measurement results are shown in the following Table 6.

Table 6. Resulting values of the short-term absorbability test

Sample	A_p [m^2]	W_p [kg/m^2]
REF	0.0858	2.17
H6	0.0870	0.57
T6	0.0903	0.83
LUK	0.1105	1.61
DR	0.0903	0.72
TG	0.0897	0.36
VS	0.0921	1.71
VSH	0.0909	1.78
VSHH	0.0915	1.69

Note: A_p – surface area

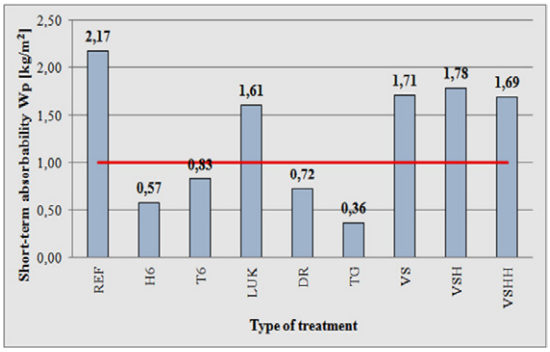

Fig. 6. Determination of short-term absorbability

Fig. 7. Test sample TG after short-term absorbability test

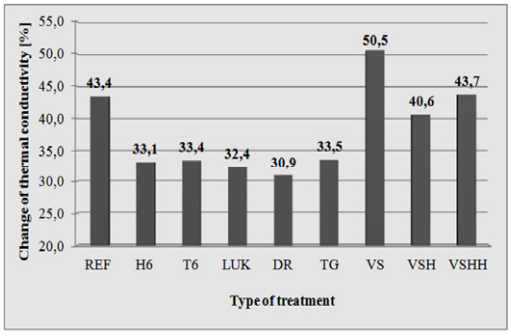

Fig. 8. Percentage Changes of thermal conductivity (λ_{dry}, $\lambda_{23,80}$)

3. Conclusion

Based on the experiments performed, it was found that the hydrophobic treatments significantly affected absorbability of thermal-insulating mats based on hemp fibres. Compared to the untreated REF sample, all treated samples showed lower values of short-term absorbability.

Using the hydrophobic agents, we tried to achieve short-term absorbability values less than 1 kg.m^{-2}. The best values were observed in H6, T6, DR and TG samples. The lowest value of short-term absorbability was found in the TG sample (W_p = 0.36 kg.m^{-2}). In samples treated by the sol-gel method, no significant reduction in absorbability was achieved. In comparing with results of utilization of sol-gel method for cotton fibers hydrofobization (described by Zhenqxiong [5]), it will be necessary, in case of hemp insulations, method of sol-gel coating application. It will be topic of next research activities.

Pursuant to the measured values of equilibrium sorption moisture at the temperature of +23 °C and relative air humidity of 80%, it can be concluded that hydrophobic treatments did not caused any significant improvement in the wettability of thermal insulating mats based on natural fibres. A slight reduction in wettability occurred only in TG samples (agent Tagal) and DR samples (agent Draxil 153). In these samples, the mass moisture content reached to 11.8% and 11.6%.

From the viewpoint of thermal insulation properties achieved, it can be said that the application of hydrophobic agents reduced the rate of degradation regarding the thermal insulation properties of insulators (except for the samples treated with the sol-gel method). The increase in the value of thermal conductivity when exposed to moisture (as opposed to the dried-up state) decreased (in case of samples: H6, T6, LUK, DR and TG) from 43% to 31 – 34%.

Acknowledgements

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