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UTILIZATION OF ALTERNATIVE RAW MATERIAL SOURCES FROM AGRICULTURE FOR THE PRODUCTION OF INSULATING MATERIALS

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Abstract. Thermal insulating materials based on natural fibres currently represent a progressive direction in the area of thermal insulations, particularly from the viewpoint of sustainable development in the area of the production of building materials and construction because it concerns materials based on an easy-renewable and locally available raw material base. In existing constructions, these materials may well replace other thermal insulating materials (e.g. EPS or mineral wool), which are more demanding in terms of energy and raw materials (Zach and Hroudova 2010b).
The main use of these materials is primarily in so-called healthy constructions, i.e. in constructions where traditional construction technologies and natural construction materials are used which by their thermal moisture behavior is close to the demands of the human body. From the viewpoint of utility properties, insulating materials on the basis of natural fibres have very good thermal-insulating properties, good mechanical properties and low eco-toxicity (Zach and Hroudova 2010a; Uihlein, and Ehrenberger *at al.* 2010).
The article addresses the complex evaluation of the production of thermal insulating materials on the basis of natural fibres, mainly flax and hemp. According to implemented measurements it was find out, that insulating materials on the basis of natural flax and hemp fibres dispose of very good thermal insulating properties. Measured values of thermal conductivity of test specimens range between 0,0368 and 0,0419 $W.m^{-1}.K^{-1}$ (in dependence on bulk density and type of fibres). Next finding was that specimens with higher content of flax fibers have better thermal insulating properties comparing to samples with higher amount of hemp.

Keywords:.thermal insulating materials, thermal conductivity, natural fibres, technical hemp, flax, eco-toxicity, healthy constructions, renewable row materials.

1. Introduction

Thermal insulating materials based on natural fibers represent one of sustainable technologies of production of construction materials coming from recoverable material resources in agriculture (Zach and Hroudova 2010a; Kymäläinen 2008; Vėjelienė *at al.* 2010). The aim of the research was a complex study focused on influence of the kind of natural fiber on resulting thermal insulating properties of material. Based on literature search and results of previous researches, following input materials were selected:

- flax fiber (of different origin),
- retted hemp fiber,
- non-retted hemp fiber.

Developed materials can be used mainly in civil engineering in the area of external insulation of existing and new buildings. Dominant field of application is expected in following areas:

- insulation of inclined roofs,
- insulation of external claddings (integrated thermal-insulation),
- insulation of partition walls,
- insulation of roofs (hung ceilings),
- complex application for timber-frames. (Zach and Hroudova 2009; Rasmussen and Nicolajsen 2007; Lyons 2006).

The main expected advantages are accessibility of input materials, in particular from the long-term point of view, which is very important for sustainable development. Low ecological toxicity and low thermal demands of production of developed insulation materials are also advantageous as well as easy recyclability after the end of their life time in structure.

As for end use properties, the main gains are harmlessness for health and good thermo-insulating properties. Since the materials are based on natural fibers, good properties as regards air humidity absorption and desorption can be expected. Use of developed materials in interiors of structures without moisture stops on inner side is expected to enhance and stabilize interior humidity microclimate (Zach and Hroudova 2009; Zach and Hroudova 2010b).

2. Input materials and measurements

Two kinds of flax fibers from different localities and two kinds of hemp fibers were selected as input materials:

- fiber FLAX1: country of origin - France,
- fiber FLAX2: country of origin – Germany.

Two kinds of hemp fiber:

- fiber HEMP1: non-retted hemp,
- fiber HEMP2: retted hemp.

Both fibers originated in France. The aim was assessment of influence of the kind of natural fiber with constant volume weight on resulting thermal insulating properties of the developed material.

Polyester fibers, so-called bicomponents were used as binder. The fiber consists of two layers of polyester - inner polyester core with melting point 250°C coated with low-melting polyester with melting point 120°C.

Input material was mixed with 15% of polyester fibers and resulting mixture was layered on a belt at the temperature of 150°C, pressed into the form of boards with required thickness and volume weight and consequently, after cooling down, cut into smaller boards. Manufacture of testing specimens was realized as pilot run in a production line (Zach 2009).

Testing specimens used for laboratory measurements were 200 by 200 mm and 300 by 300 mm large. Detailed composition of individual test specimens is stated in table 1 below.

Table 1. Composition of test specimens

Sample n.	FLAX1	FLAX2	HEMP 1	HEMP 2
1	0%	50%	25%	25%
2	0%	50%	25%	25%
3	0%	50%	50%	0%
4	0%	50%	50%	0%
5	0%	50%	0%	50%
6	0%	0%	0%	100%
7	0%	0%	50%	50%
8	0%	0%	100%	0%
9	30%	0%	0%	70%
10	30%	0%	0%	70%
11	30%	0%	0%	70%
12	50%	0%	0%	50%
13	50%	0%	0%	50%
14	50%	0%	0%	50%
15	70%	0%	0%	30%
16	70%	0%	0%	30%
17	70%	0%	0%	30%

Note: composition of group of specimens 9, 10, 11, also 12, 13, 14 and next 15, 16, 17 was identical because of elimination of possible change of sample bulk density in repeatable production.

Ratio of natural and bicomponent fibers was always 85:15.

The research work included determination of physical and thermo insulating properties of test specimens. In particular:

- determination of thickness according to EN 823.
- determination of density according to EN 1602
- determination of thermal conductivity according to EN 12667

3. Results

Thickness d [mm] was determined in accordance with EN 823 on testing specimens with dimension 200 x 200 mm at nominal load 50 Pa (200g). Density ρ_v [kg.m^{-3}] was determined and evaluated in accordance with EN 1602 on test specimens with dimensions 200 x 200 mm. Volume weight after pressing testing specimens down to uniform thickness 50 mm was determined. Before tests, the specimens were dried at the temperature of 150°C until their weight was constant. Results of tests are stated in following table 2.

Table 2. Measured thicknesses and volume weights of testing specimens at nominal load 50 Pa in accordance with EN 823 and EN 1602 (dried state) and after pressing down to 50 mm

Sample n.	Nominal load 50 Pa		For thickness 50 mm	
	d [mm]	ρ_v [kg.m^{-3}]	d [mm]	ρ_v [kg.m^{-3}]
1	58,02	34,5	50	37,4
2	56,82	31,7	50	33,5
3	53,62	30,9	50	31,9
4	55,41	31,8	50	32,8
5	56,85	33,9	50	36,3
6	56,77	27,8	50	31,6
7	55,45	32,2	50	35,7
8	51,22	35,5	50	36,4
9	58,49	31,8	50	37,3
10	57,73	29,4	50	34,0
11	55,68	30,0	50	33,4
12	53,99	29,4	50	31,8
13	61,77	31,8	50	39,3
14	56,22	29,9	50	33,6
15	57,57	28,8	50	33,2
16	54,37	28,5	50	31,0
17	60,29	28,1	50	33,9

Thermal conductivity was determined at mean temperature +10°C and thermal gradient 10K (according to EN 12667). Testing specimens were dried at the temperature of 105°C until their weight was constant and the value of thermal conductivity coefficient was determined. Measurements were taken for nominal pressure at the load of 50Pa and after pressing down to thickness 50 mm (table 3 and fig 1).

Table 3. Measured values of thermal conductivity (in dry state)

Sample. n.	Nominal load 50 Pa		For thickness 50 mm	
	d [mm]	$\lambda_{10,dry}$ [W.m^{-1}.K^{-1}]	d [mm]	$\lambda_{10,dry}$ [W.m^{-1}.K^{-1}]
1	58,02	0,0389	50,00	0,0374
2	56,82	0,0400	50,00	0,0378
3	53,62	0,0380	50,00	0,0372
4	55,41	0,0396	50,00	0,0380
5	56,85	0,0409	50,00	0,0385
6	56,77	0,0417	50,00	0,0409
7	55,45	0,0410	50,00	0,0399
8	51,22	0,0418	50,00	0,0419
9	58,49	0,0382	50,00	0,0370
10	57,73	0,0417	50,00	0,0403
11	55,68	0,0402	50,00	0,0394
12	53,99	0,0393	50,00	0,0386
13	61,77	0,0378	50,00	0,0368
14	56,22	0,0391	50,00	0,0382
15	57,57	0,0384	50,00	0,0374
16	54,37	0,0379	50,00	0,0375
17	60,29	0,0386	50,00	0,0373

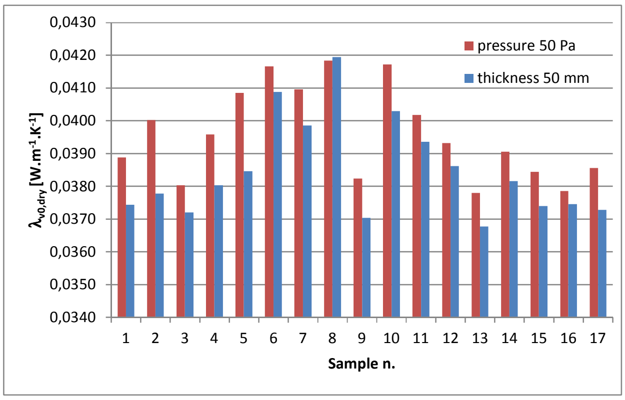

Fig 1. Overview of results of determination of thermal conductivity for samples under pressure of 50 Pa and thickness 50 mm (in dry state)

4. Evaluation of measurements

Dependence of measured values of thermal conductivity on density (both individual and summative for both thicknesses) was determined to evaluate individual experiments complexly (fig 2). Coefficient of correlation $\rho_{x,y}$ was determined for density (X) and thermal conductivity (Y).

$$\rho_{X,Y} = \frac{E(XY) - E(X)E(Y)}{\sqrt{E(X^2) - E^2(X)}\,\sqrt{E(Y^2) - E^2(Y)}} \quad (1)$$

In given case, following values of correlation coefficient were determined:

- For nominal load 50 Pa: $\rho_{x,y}$ = 0,22,
- For nominal pressing down to thickness 50 mm: $\rho_{x,y}$ = -0,12,
- For summative values: $\rho_{x,y}$ = -0,20,

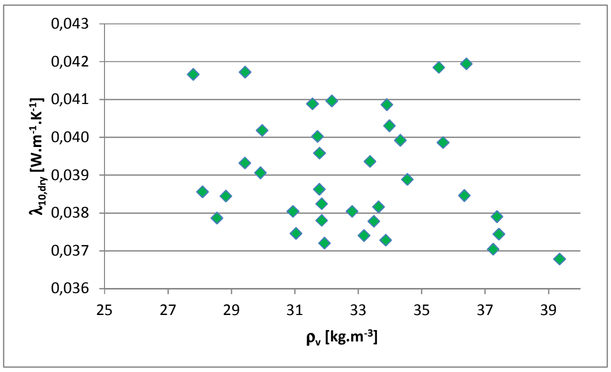

Fig 2. Dependence of thermal conductivity on density (summary)

Calculated values of correlation coefficient (from -0,20 till 0,22) imply that there is no strong dependency between density and thermal conductivity coefficient (determined for given set of measured values).

The next step was determination of dependency of thermal conductivity coefficient on the kind of fibers on the basis of measured values of individual types of material (table 4 and fig 3).

Table 4. Measured values of thermal conductivity of individual content of technical hemp at nominal load 50 Pa

Content of hemp	Composition / Sample n.	Nominal load 50 Pa	For thickness 50 mm
		λ [W.m^{-1}.K^{-1}]	λ [W.m^{-1}.K^{-1}]
30%	15, 16, 17	0,0383	0,0374
50%	1, 2, 3, 4, 5, 12, 13, 14	0,0392	0,0378
70%	9,10, 11	0,0400	0,0389
100%	6, 7, 8	0,0415	0,0409

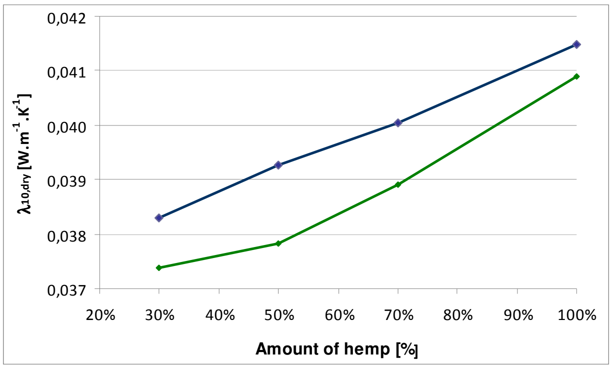

Fig 3. Dependency of thermal conductivity on the content of hemp at nominal load 50 Pa and pressing down to 50 mm

Strong dependency between content of hemp and value of thermal conductivity in both cases, values of correlation coefficients were the same:

- For nominal load 50 Pa: $\rho_{x,y}$ = 1,00,
- For pressing down to thickness 50 mm: $\rho_{x,y}$ = 0,97,
- For summative values: $\rho_{x,y}$ = 0,99.

Results of implemented measurements show that specimens with higher content of flax fibers have better thermal insulating properties comparing to samples with higher amount of hemp. From the point of view of thermal insulating properties, in case of flax fibre insulations, there was found no remarkable difference between samples from fibres flax 1 and flax 2. Same similarity in results with no remarkable differences, were found in case of insulations from hemp 1 and hemp 2.

5. Conclusion

Physical, mechanical and thermal/moisture technical properties were determined on testing specimens of insulation based on technical hemp and flax. The research was focused on influence of the kind of natural fiber on resulting thermo insulating material, while following raw materials were selected as the most common: flax fiber (two kinds), retted and non-retted hemp fiber.

Test specimens were subjected to determination of: thickness (in accordance with EN 823), volume weight (in accordance with EN 1602), thermal conductivity (at normal moisture content and at dried state, at different values of density) – in accordance with EN 12667. Values of measured thickness were from 51,22 to 61,77 mm (nominal load 50 Pa in accordance with EN 823).Values of density of testing specimens were following:

- for nominal load 50 Pa: 27,8–35,5 kg.m^{-3},
- for pressing down to thickness 50 mm: 31,0–39,3 kg.m^{-3}.

Study of dependency of thermal insulating properties revealed that values of thermal conductivity of testing specimens were:

- for nominal load 50 Pa: 0,0378–0,0418 W.m^{-1}.K^{-1},
- for pressing down to thickness 50 mm: 0,0368–0,0419 W.m^{-1}.K^{-1}.

Dependence of measured values of thermal conductivity on density was determined to evaluate individual experiments complexly. It was found that there is no dependency between bulk density and thermal conductivity of testing specimen (of different composition). On the other hand, there is very strong correlation between thermal conductivity and kind of fiber.

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