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Utilization of Technical Hemp for Thermal Insulating Materials Production

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ABSTRACT

The demand for new ecologically friendly materials based on fast-renewable natural row sources is currently growing in the EU. Utilization of these materials is expected mainly in the area of low-energy and passive buildings where the thermal and moisture microclimate optimal for human system should be ensured, using minimum energy for heating. The article is focused on the utilization of agricultural products such as cannabis sativa, jute and flax to manufacture thermal insulating mats, on their features and their utilization in modern building structures. The final part of the article contains a general comparison of these thermal insulating materials and the main types of conventional building materials used in the EU.

INTRODUCTION

Constructions made from natural materials are becoming more and more popular. Why so many investors choose natural materials for their buildings? There are many reasons for this trend:

- natural materials are easily recoverable resources,
- properties of natural materials are close to needs of human organisms, in particular from the point of view of interior humidity micro-climate,
- natural materials are usually easy to access anywhere,
- use of natural resources for manufacture of construction materials considerably decreases energetic requirements of the production,
- easy recycling of natural organic materials after the end of their lifetime,
- lower cost of input materials.

Effective use of natural materials can contribute to modern buildings with thermal comfort and desirable humidity microclimate. The paper deals with the possibility of using farm crops like technical hemp, jute and linen for manufacture of thermo-insulating mats, their properties and their application in modern building constructions.

ALTERNATIVE RAW MATERIAL RESOURCES

Thermal insulating and soundproofing materials based on alternative natural resources are very promising at present time. One of the main advantages is their fast and easy recoverability as well as local accessibility. These material resources dispose with good ratio

of useful properties and price their production saves both energy and environment. These resources involve materials from the area of agriculture, forestry and stockbreeding, more and more frequent in the construction market in the EU.
One of the most progressive material resources in agriculture is technical hemp. The main advantage is that it can be grown virtually anywhere in Europe as annual farm crop.
Technical hemp has been used for ages; archeological findings of hemp in sepultures are as old as 800 B.C. Hemp is an annual dioecious plant originating from central Asia. It was valued in particular for its strength and durability. Technical, ecological and economical advantages were again discovered in modern times in different branches of industry, including construction industry.
Insulating materials based on technical hemp are made from hemp fiber with a certain amount of hemp chaffs. Technical hemp is a perfect alternative for wood; some properties (e.g. thermal insulating) even exceed those of wood. These organic fibrous natural materials have excellent thermo-insulating, mechanical and acoustic properties. Similarly to technical hemp can be used flax or jute. Properties of flax and jute are very close to technical hemp properties.

Fig. 1. Photo of hemp chaffs

Fig. 2. Photo of hemp fibers

MANUFACTURE OF THERMO-INSULATING MATERIALS BASED ON NATURAL FIBERS

Research of new thermo insulating material based on natural fibers from farm sector and study of their end-use properties has been going on for several years on the Faculty of Civil Engineering of the Technical University in Brno as a part of a research project.
Within this research, a study on the possibilities of using fibers of technical hemp, flax and jute for manufacture of insulating mats or boards for insulation of floating floors, separating walls, roofs or facades has been carried out.

Test samples were made from technical hemp, flax and jute as a part of pilot run on a special production line processing fibrous materials and producing insulation mats. Organic fibers with different contents of chaff were the input material. Table 1 gives labeling and content of individual test samples – proportion of incoming components..
Thermo-insulating properties of construction materials are generally influenced by many factors, which have to be taken into account during production and application in building industry. In the phase of production itself, it is necessary to observe mainly:

- density,
- thickness of fibers,
- the amount of binder used.

Hand in hand with these parameters, both thermo-mechanical and mechanical properties of final product change as well as its cost. The optimal composition generally aims at maximal level of end-use properties and acceptable cost. test samples with different compositions were made, so that the above mentioned requirements were met and thermo-insulating, acoustic and mechanical properties could be evaluated with respect to different volume weight, type and thickness of fibers and amount of bicomponent binder.

Table 1. Indication and composition of testing samples

Sample	**Material source**	**Composition [%]**		
		Fibers	Bicomponent	Chaff
1	Jute	68	20	12
2	Flax	68	20	12
3	Technical hemp	48	20	32
4	Technical hemp	64	20	16
5	Technical hemp	48	20	32
6	Technical hemp	48	20	32
7	Technical hemp	48	20	32
8	Technical hemp	64	20	16
9	Technical hemp	49	10	41

Three kinds of hem fibers with different amounts of chaff were used for manufacturing samples from technical hemp. Polyester fibers, so-called bi-components, were used as binder. These fibers have two polyester layers : an inner part – a polyester core with melting point at 250 °C (this part of fiber have function as reinforcement) - and a jacket, made from low-melting polyester, melting at 120 °C (this part of fiber have function as binder).
The production of heat-insulating carpets from technical hemp is implemented in practice according to the following procedure:

- pulping of packages of technical hemp,
- modification of hemp fibre (application of substances against burning, biological pests, etc.),
- drying of the fibre,
- pulping of packages with bi-component fibres,
- pneumatic mixing of hemp and bi-component fibres,
- adding the pulped remainders from production,
- homogenization of mixture,
- creation of boards of insulating carpets,
- caking of boards under increased pressure and temperature (creation of boards of the required thickness and density),
- cooling of the carpet,
- cutting boards in the required format,
- packing and storage.

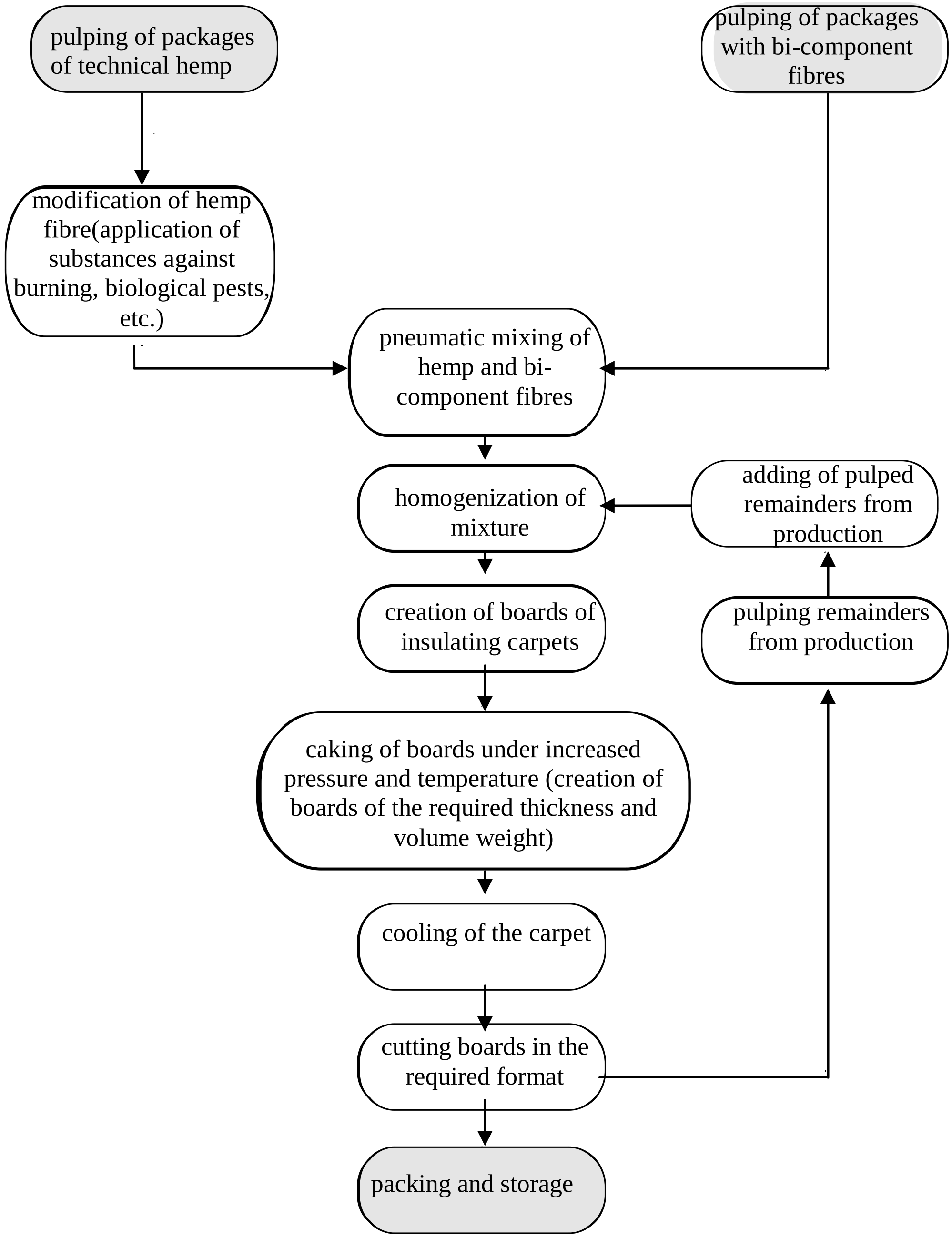

Fig. 3. Block diagram of the production of insulating mats from technical hemp

DETERMINATION OF PROPERTIES OF TEST SAMPLES

Overview of measured values

Test samples of plate shape of dimensions 300 x 300 mm and 200 x 200 mm (thickness of samples was between 10 – 80 mm, see below) were prepared from insulating boards 500 by 1000 mm made. These were used for determination of thermo-insulating, physical and mechanical properties. To test acoustic properties, instead, tests samples with cylinder shape and diameter 30 mm and 100 mm were made (thickness of samples was between 10 – 80 mm, see below).

Fig. 4. Photography of testing samples (sample 8)

A series of laboratory measurements was carried out to determine basic properties important for thermo-insulating materials for roofs, facades, floating floor and separating walls. Following properties were determined:

- Thickness (according to EN 1602),
- Density (according to EN 1602),
- Sound absorption coefficient (according to ISO 10534 and EN 11654) in acoustic interferometer,
- Thermal conductivity (according to 707012, EN 12667),
- Water vapour transmission properties (according to EN 12086),
- Tension at 10% deformation (according to EN 826),
- Dynamic stiffness (according to ISO 9052-1),
- Tensile strength (according to EN 1607).

The results are shown in Table 2 and in the following graphs.

Table 2 Physical and mechanical properties of samples

Sample	Thickness	Density	Sound absorption coefficient	Thermal conductivity	Factor of diffuse resistance	Dynamic stiffness	Tension at 10% deformation	Tensile strength
	[mm]	[kg.m^{-3}]	[-]	[W.m^{-1}.K^{-1}]	[-]	[MPa.m^{-1}]	[kPa]	[kPa]
1	81,2	26,1	0,40	0,0482	2,1	3,1	1,0	6,25
2	77,4	32,1	0,40	0,0442	2,9	3,6	0,4	7,75
3	77,9	30,2	0,45	0,0500	2,8	3,0	0,6	15,56
4	79,6	29,6	0,40	0,0488	2,2	3,1	0,8	16,23
5	67,0	56,8	0,55	0,0419	3,8	4,0	6,7	21,75
6	30,3	33,1	0,25	0,0441	3,8	7,2	0,5	23,47
7	9,4	111,6	0,15	0,0482	5,3	20,8	36,9	25,00
8	40,2	82,1	0,35	0,0405	4,0	7,4	11,2	15,00
9	40,1	94,4	0,40	0,0399	4,2	8,62	21,0	18,8

On the basis of the measured values, the following dependencies were established:

- dependence of thermal conductivity on density,
- dependence of thermal conductivity on type and thickness of the fibers,
- dependence of mechanical properties on density,
- dependence of mechanical properties on type and thickness of fibers.

Dependence of thermal conductivity on density

The basic indicator of the thermo-insulating properties of materials is their density.. Unfortunately, the relationship that exists between them cannot be approximated by a simple linear function and it is not valid for all types of insulating materials.

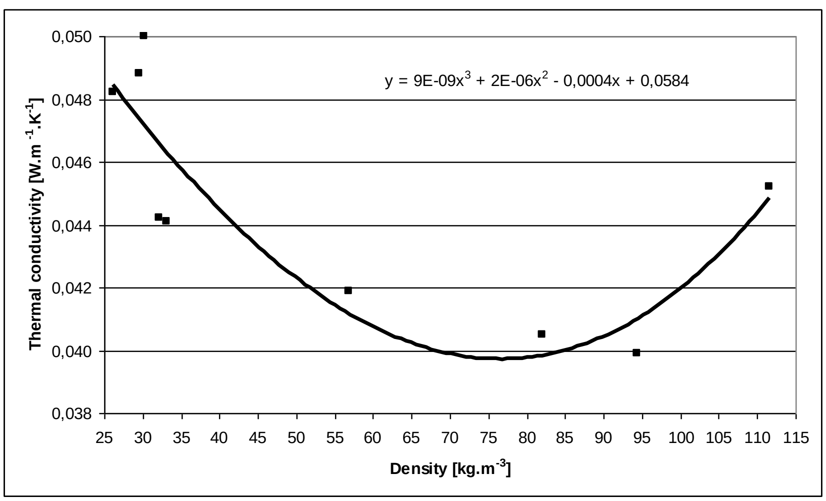

Fig. 5. Dependence of thermal conductivity on density (samples 3 – 9 based on technical hemp)

Generally, insulating material with low volume weight shows high air permeability; moreover, heat can propagate in the field of infrared, since the structure of fibers is relatively loose. Increasing of density gradually decreases the value of thermal conductivity as a result of the decrease of radiation and streaming. Then, at a certain value of thermal conductivity coefficient - different for each material - the trend is inverted and the value of thermal conductivity coefficient begins to grow with increasing thermal conductivity. This is caused by the increasing transmission of heat in the solid phase by conduction.

As it is shown in graph 1, by interpolating the data, it appears that the lowest value of thermal conductivity for the material investigated should be found at a density of approximately 77 $kg.m^{-3}$. Optimal value of volume weight as regards thermal insulating properties should lie between 50 and 100 $kg.m^{-3}$ (according to dependence in graph 1; thermal conductivity < 0,042 $W.m^{-1}.K^{-1}$).

Dependence of thermal conductivity coefficient on the type and thickness of fibers

Thickness of fibers is another important indicator of thermal insulating materials. Smaller thickness of mineral fibres brings better thermal insulating properties [1]. However, the situation is different for organic fibers since they are naturally porous.
A representative number (30) of linen, hemp and jute fibers were microscopically analyzed . Three measurements were taken on each of the fibers; results were statistically evaluated: average thickness and thickness distribution were determined

Table 3 Overview of the measured average thickness of fibers of hemp, flax and jute

Fiber type	Average thickness of clean fiber d_m [μm]
Flax	111,1
Jute	94,2
Technical hemp	155,2

The thickness was measured on clean fibers. However, it must be born in mind that insulating materials were made from fibers mixed with chaffs - coarse parts with thicknesses above 1 000 μm (percentage of chaffs are stated in Table 1).
The relationships found between density, thickness of fibers and insulating properties revealed that the influence of density is stronger compared to the influence of fiber thickness and therefore it is possible to determine the given relationship only for samples with comparable density. Thus, the relationship between thermal conductivity coefficient and fiber thickness was determined for samples with volume weight around 30 $kg.m^{-3}$ (see in graph 2).

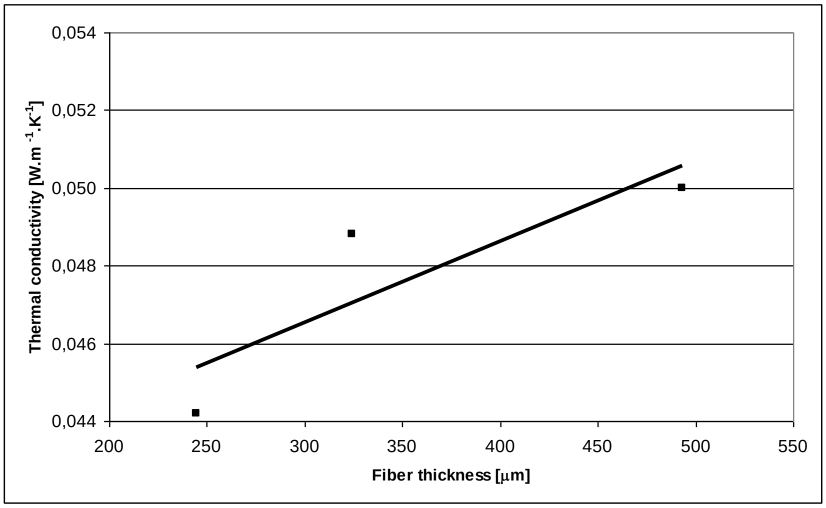

Fig. 6. Relationship of thermal conductivity coefficient and recalculated fiber thickness (including chaff)

Asgraph 2 shows, thermal conductivity of fibers affect by thickness. Hence, increasing thickness of organic fibers from farm crops degrades thermo-insulating properties of material with constant value of density (according to results in table 2 above).

4.4 Dependence of mechanical properties on the density

Mechanical properties of fibrous thermo-insulating materials depend on their volume weight and amount of binder used. In the given case, relationship of stress at 10% deformation and relationship for tensile strength were individually determined. Results are given in diagrams 3 and 4.

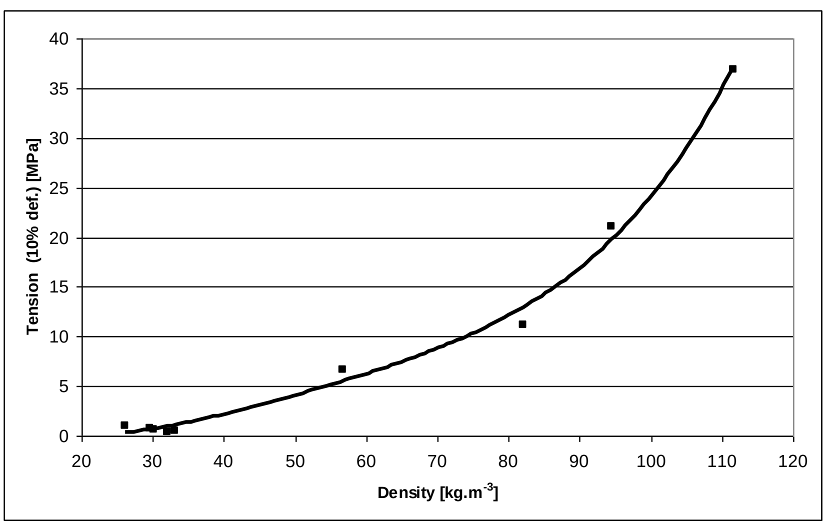

Fig. 7. Dependence of tension at 10% deformation on density

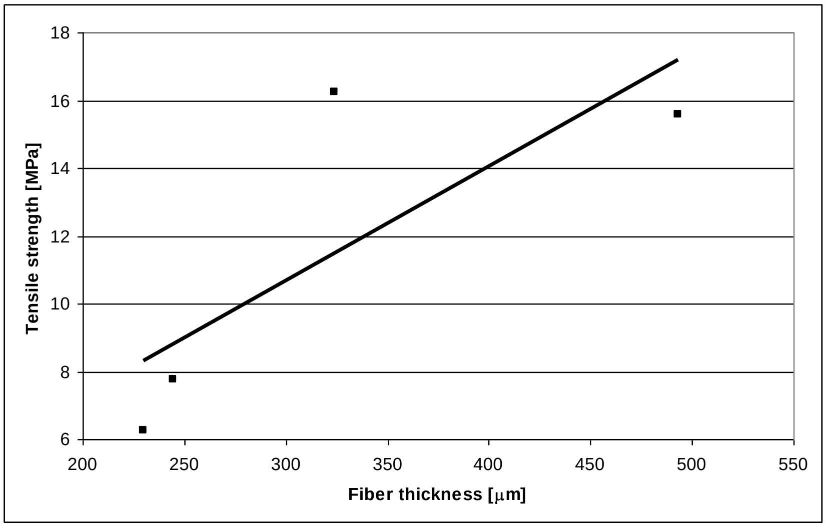

Fig. 8. Dependence of tensile strength on density

Stress at 10% deformation showed very strong relationship between volume weight and 10% deformation; correlation coefficient was as high as 0.99. Correlation for tensile strength was lower 0.54.

Dependence of mechanical properties on the type and thickness of fibers

Also in this case, it was not possible to determine the relationship between mechanical properties and type and thickness of fibers because the influence of the density of samples was very strong. Again, relationship between mechanical properties and fiber thickness was determined for samples with identical density around 30 kg.m^{-3}, while values of fiber thickness were recalculated to include the chaffs particles.

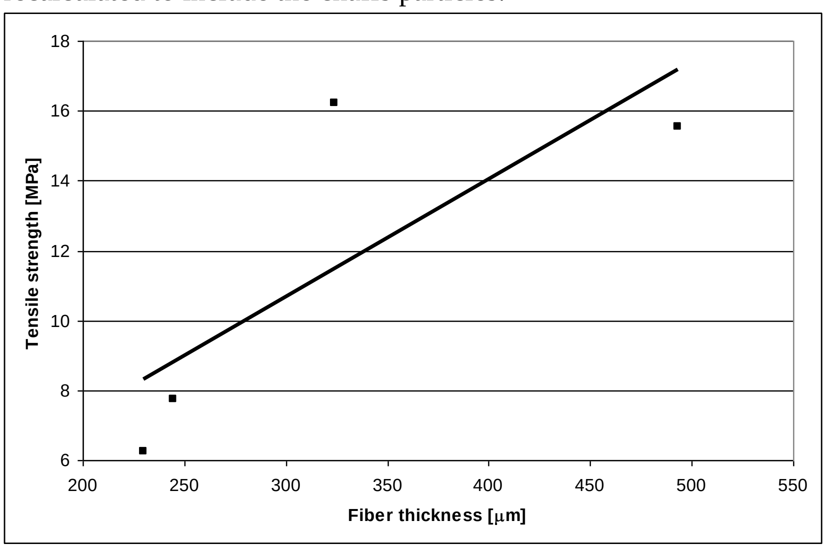

Fig. 9. Dependence of tensile strength on recalculated fiber thickness (including chaff)

Graph 5 shows that a linear dependency can be actually found. With higher fiber thickness rise the tensile strength of insulation material up.

CONCLUSIONS

Test samples of insulating materials based on technical hemp, jute and flax were tested to determine mechanical, physical, acoustic and thermo-insulating properties.
Based on the measurements of thermal conductivity coefficient λ dependency on volume weight ρ_v, the following relationship (1) was determined:

$$\lambda = 9.10^{-09} \cdot \rho_v^3 + 2.10^{-06} \cdot \rho_v^2 - 4.10^{-4} \cdot \rho_v + 0,0584 \qquad (1)$$

As a consequence, the lowest and therefore optimal value of heat conductivity coefficient should be found at the density of 77 $kg.m^{-3}$, which is within the range of optimal values of density for thermal insulating properties (50 to 100 $kg.m^{-3}$).

It is possible to determine further properties of insulation material based on the technical hemp used during this research and compacted to a density of 77 $kg.m^{-3}$ by means of above mentioned relationship:

Table 4 Selected optimal values

Thermal conductivity	Density	Tensile strenght	Tension at 10% deformation
[$W.m^{-1}.K^{-1}$]	[$kg.m^{-3}$]	[kPa]	[kPa]
0,0399	77	18.97	11

It can be said that, given a constant value of density, the increase in thickness of organic fibers by adding farm crops degrades the thermo-insulating properties of the material .

The research also determined the acoustic properties of thermo-insulating materials made of natural fibers. Very interesting values of dynamic stiffenss were found: almost all the samples gave a value between 3 and 9 $MPa.m^{-1}$: such values rank these insulating materials into the group of dynamically soft materials (according to the Czech national tandard CSN 730532), suitable for acoustic insulation in the structure of floating floors.

With respect to the development of science and technology, it can be said that thermal insulation made from technical hemp are likely to become a suitable alternative to commonly used boards made from different materials (mineral wool, polystyrene or polyurethane). Measurements proved that properties of insulating board from organics fibers are fully comparable to common insulating boards made from other materials.

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