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Lightweight Composite Building Materials with Hemp (Cannabis Sativa L.) Additives

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The scope of our research was to evaluate the potential of the content of fibre and shives in the biomass of industrial hemp cultivars grown under different nitrogen fertiliser rates to use them for increasing the energy efficiency as a thermal insulation and acoustic material. The aim of the research was to find out the production technology, properties of the thermal conductivity for lightweight concrete made from hemp shives and sapropel or gypsum as a binder to be used for thermal and sound insulation material. The hemp cultivar 'Bialobrzeskie' was used for lightweight composite materials and lightweight composite materials were obtained with hemp shive additives with heat transfer coefficient 0.046÷0.15 W mK^{-1} and sound insulation index R`=35 dB. The obtained composite materials can be used as sound and heat insulation materials for building envelope in residential buildings, office buildings and factories.

1. Introduction

Nowadays industrial hemp has become a very important crop for biomass production. Environmental concerns and recent shortages of wood fiber have renewed the interest in hemp as a raw material for a wide range of industrial products including textiles, paper, and composite materials (wood products, building materials, etc.). Hemp is fast-growing, and it is suitable for Europe's as well as Latvia`s agro-climatic conditions. The interest in the possibilities of growing hemp in the Baltic States is increasing year by year (Ivanovs et al., 2015;. Jankauskiene and Gruzdeviene , 2009). The application of hemp shives so far has been studied in application of lime (Walker et al., 2014; Walker and Pavia, 2014) and cement, having a relatively high acquisition costs, as well as gypsum and foam gypsum that has equal fire protection properties (Pulkis et al., 2016), but the raw material production has lower costs. Latvian gypsum resources are large, and so far gypsum as a bonding material has been used with hemp shives in composite construction materials as thermal insulation and sound absorption material (Brencis et al., 2015). Not only gypsum and foam gypsum but also sapropel can be used as a binder for hemp shives (Pleiksnis and Teirumnieka, 2014) since there are extensive resources of sapropel available in the Baltic region and the costs for its acquisition are low.
Sapropel is organic lake sediment that is formed from the remains of aquatic animals and plants, containing mineral particles (sand, clay, calcium carbonate and other compounds). Both materials – hemp shives and sapropel – are organic, renewable and locally available.
The solution is to find out more productive hemp cultivar shives for applications from the resources available in Latvia to use them for increasing the energy efficiency as a thermal insulation and acoustic material. The aim of the research is to find out the production technology, properties of the thermal conductivity for lightweight concrete made from hemp shives and sapropel or gypsum as a binder to be used for thermal and sound insulation material. Laboratory experiments show that this ecological material, which complies with modern requirements of thermal insulation and acoustic material, can be obtained from renewable raw materials - hemp shives with gypsum, sapropel binder.

2. Materials and methods

2.1 Hemp growing

Industrial hemp was grown in the Research and Study farm "Peterlauki" (56°53'N, 23°71'E) of Latvia University of Agriculture. The soil was sod calcareous, pHKCl 6.7, containing available for plants P (52 mg kg^{-1}) and K (128 mg kg^{-1}); the organic matter content was 21÷25 g kg^{-1} of soil. The field trials were carried out in 2012÷2014. Eleven cultivars of industrial hemp (Cannabis sativa L.) were used: 'Bialobrzeskie', 'Futura 75', 'Fedora 17', 'Santhica 27', 'Beniko', 'Ferimon', 'Felina32', 'Epsilon 68', 'Tygra', 'Wojko' and 'Uso 31'; they were treated with 8 different fertiliser norms (kg ha^{-1}): 1) N0P0K0, 2) P80K120 (F – background), 3) F+N30, 4) F+N60, 5) F+N90, 6) F+N120, 7) F+N150, and 8) F+N180. The total seeding rate of hemp was 50 kg ha^{-1}.
Hemp was sown in 10 m^2 plots, triplicated, in the middle of May, using a Wintersteiger plot sowing machine. Hemp was harvested using a small mower 'MF-70' when first matured seeds appeared. The yield of absolutely dry hemp biomass was calculated according to the data of fresh biomass yield during the harvesting time each research year.
The main task of our research was to evaluate the potential of the content of fibre and shives in the biomass of industrial hemp cultivars grown under different nitrogen fertiliser rates. The hemp cultivar 'Bialobrzeskie' is more widespread in Latvia, therefore, in our experiments we used its shives for creating composite materials.

2.2 Production technology of foam gypsum samples with hemp shives

The foam gypsum samples were produced using the three stadia method, mixing water, gypsum, a surface active substance (SAS) STAMEX F-15 FFFP 5%, and adding hemp reinforcement. As a foam maker the surface active substance was used in fire extinguishers. Foam gypsum binder – $\beta\ CaSO_4 \cdot 0.5H_2O$ was used in the experiments. The concentration of hemp shives used in foam gypsum is the amount of shives in grams per 1 kg dry gypsum binder (c, g kg^{-1}). The hemp shives concentration was varied within 3÷5 % kg^{-1}, but the gypsum binder mass was constant. Shives were prepared by chopping them in pieces and sifting in order to obtain the length of 2.5÷5.0 mm. The foam gypsum samples for testing in an acoustic tube were processed using round shape moldings with a 100 mm ∅ and the length of 250 mm. In order to obtain the heat transfer coefficient, the samples with the dimensions of 300×300×40 mm were made.

2.3 Production technology of sapropel with hemp shives samples

The organic sapropel was obtained from the lake Ubagova (Latvia). It was obtained from a depth of 6÷8 m. Water content in sapropel was 92.6 %. Sapropel hemp shives composite was obtained by mixing the following three main components in the cyclic mixers: hemp shives, sapropel and water in certain proportions. By varying the various components of the raw material an optimal composition of the composite was obtained (Table1). The resulting mixture compositions were placed in template (280 x 280 x 50 mm) and compressed. The samples were initially dried in LUA construction laboratory under ambient conditions of +19 ± 2°C temperature for 3÷4 days, depending on the amount of the binder. After this period the samples were removed from the moldings and continued to dry in the laboratory for 4÷5 weeks until a constant weight of the samples was achieved.

Table 1: Sapropel with hemp shives

Sample	Ratio hemp/sapropel (with water)	Hemp shives, g	Sapropel, g	Additional water, g	Water in material g	Sapropel without water g	Moisture %
1.	1:1	750	750	750	1444.5	55.5	74,90
2.	1:3	750	2250	0	2083.5	166.5	72,56
3.	1:5	750	3750	0	3472.5	277.5	76,33
4.	1:7	750	5250	0	4861.5	388.5	82,54

2.4 Heat transfer measurements

The heat conductivity of the foam gypsum samples was determined by heat flux method using the company's LASERCOMP measurement instruments FOX200 and FOX600. These instruments were designed according to ASTM C518-91 "Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus.

2.5 Sound insulation measurements

The sound insulation measurements were carried out using impedance tube (Sinus) by four microphone method. The sound transmission losses were determined at 1/3 octave and the reduced sound insulation index was determined according to ISO 717-1:2013 “Acoustics - Rating of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation”. The foam gypsum with hemp shives reinforcement (further in the text - FGH) samples with gypsum board (further in the text - FGHG) and without gypsum board covering were used for sound insulation measurement. The same covering was used for sapropel and hemp composite (further in the text – SH) and samples made from sapropel and hemp shives with gypsum board covering (further in the text – SHG). The samples with gypsum board covering were used to simulate a realistic wall with 250 mm thickness.

3. Results and discussion

The yield of hemp dry matter obtained in the field trials under agro-climatic conditions of Latvia on average comprised 15.06 (13.32–17.78) t ha^{-1} depending on the cultivar. The cultivation year and the selected cultivar considerably affected the yield of hemp biomass.

The use of hemp is economically important for production of fiber and shives. Studies show that their content depends on the choice of cultivars, fertiliser, seed norm, and growing conditions. Depending on the growing method, the shives content in sod calcareous soil varied from 54.4% to 70.2%, and fiber content varied from 29.8% to 45.6% of hemp dry matter yield.

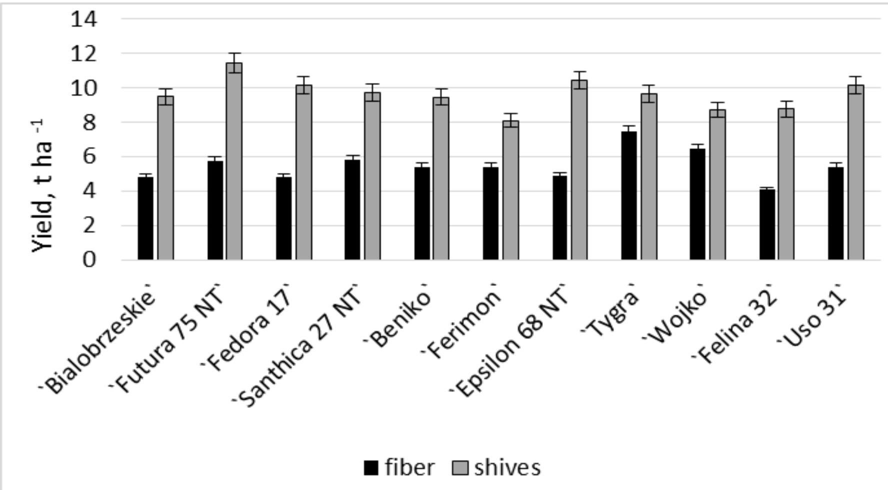

Figure. 1. The yield of fibers and shives obtained from hemp cultivars.

In Figure 1 the average yield of fibre from hemp cultivars is shown which was 4.88 t ha^{-1}. During the research years, the highest yields were obtained from the cultivars ‘Tygra’ (6.12 t ha^{-1}), ‘Bialobrzeskie’ (5.67 t ha^{-1}), and ‘Santhica 27’ (5.52 t ha^{-1}). The nitrogen mineral fertiliser had a positive effect on the yield of both dry matter and fibre of hemp. At a minimal rate of the nitrogen fertiliser F+N30 kg ha^{-1}, the average yield of fibre for the cultivar 'Futura75' was 4.25 t ha^{-1}. In contrast to the unfertilised variants N0P0K0, the average increase in the fibre yield constituted 0.87 t ha^{-1} or 25.7%. The increase in the fertiliser rate to F+N150 kg ha^{-1} ensured the fibre yield of 6.15 t ha^{-1}, which constituted 2.72 t ha^{-1} or 80.5 %. Further increase in fertiliser rates only slightly reduced the yield of fibre and shives.

By varying the concentration of hemp shives a composite material with different density in the range of 200÷450 kg m^{-3} was obtained. Increasing the concentration of hemp shives the volume density of the composite material decreases and it correlates with the previous research (Brencis et al., 2015). In the previous studies of foam gypsum composite material reinforced with hemp shives sound absorption coefficient and physical mechanical properties were determined (Brencis et al., 2011) to use the material in decorative ceiling panels. When using the hemp lightweight composite material as the intermediate frame fills for the thermal insulation (Gross and Walker, 2014), sound insulation is more significant than absorption. The sound insulation material properties such as homogeneity, dense structure with high internal attenuation coefficient are the decisive ones, in contrast to sound absorption, where critical properties are tortuosity, porosity (Gle et al., 2012) and volume density (Kinnane et al., 2016; Gle etal., 2011). For the samples obtained in this research sound insulation in 1/3 octave range and reduced noise insulation index (R`) over the all frequency range from 100÷3150 Hz were determined. In Figure 2 the results show that a significant sound insulating ability is used for the samples with gypsum board covering. This is explained by the fact that it is essential to improve the design density. Both frequency curves for materials covered with gypsum board observed resonance attenuation around 500 Hz, the maximum sound insulation (60dB) at 1250 Hz and the upper limit of attenuation at 2000 Hz. Above these limits the upper frequencies were observed with low insulation index, which is not characteristic of a good soundproofing material and it indicates low construction tightness. The foam gypsum with hemp shives and sapropel with hemp shives sound insulation without protective gypsum maximum is at 1250 Hz (32 dB) and in low frequencies – under 500 Hz- sound insulation has only 10 dB.

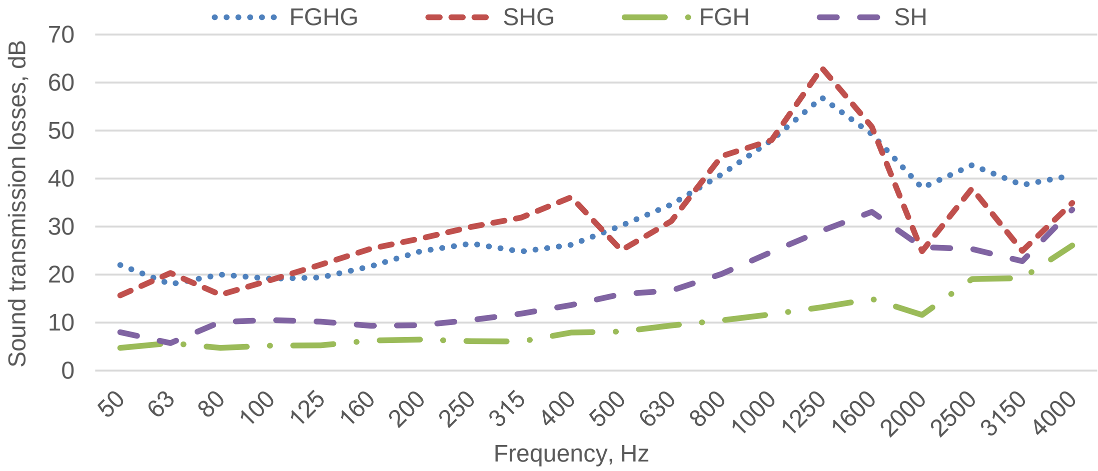

Figure 2: Sound transmission losses

In Table 2 weighed sound insulation index (R`) indicates that the lightweight composite materials with gypsum board cover plates have sound insulation of up to 35 dB, which is applicable to the facade sound insulation of different types of buildings (residential buildings, office buildings and manufacturing buildings) according to the Latvian Construction Standard LBN 016-15 "Building Acoustics". Wall construction with 250 mm thick light composite with hemp shives additives was used in demarcated external structures, but it is necessary to protect the material from moisture and wind. Creating additional structures for moisture and wind protection total wall thickness will increase and sound insulation will increase simultaneously.

Table 2 Reduced sound transmission index R`(C;C_{tr})

Material	R`, dB	(C;C_{tr}), dB	Volume density, kg m^{-3}
Sapropel with hemp shives (SH)	21	(-1;-4)	180
Sapropel with hemp shives and GB (SHG)	32	(-3;-2)	200
Foam gypsum with hemp shives (FGH)	12	(0;-2)	260
Foam gypsum with hemp shives (FGH)	14	(-1;-2)	430
Foam gypsum with hemp shives and GB (FGHG)	32	(-1;-3)	280
Foam gypsum with hemp shives and GB (FGHG)	35	(-1;-4)	450

Light composite material from hemp shives is applicable not only to the building exterior wall sound insulation but also thermal insulation. Figure 3 shows thermal conductivity coefficient of foam gypsum with hemp shives additive. It is in the range of 0.060 ÷ 0.15 W mK^{-1} and depends on the density and temperature at which the measurement was done. Thermal conductivity coefficient was established at different temperatures The overall trend of the thermal conductivity coefficient is to increase when the density increases. Thermal conductivity changes depending on the temperature have not been observed for the samples with the density of 210 kg m^{-3} and 260 kg m^{-3}, but at the density of 430 kg m^{-3} thermal conductivity coefficient increases with higher measured temperature.

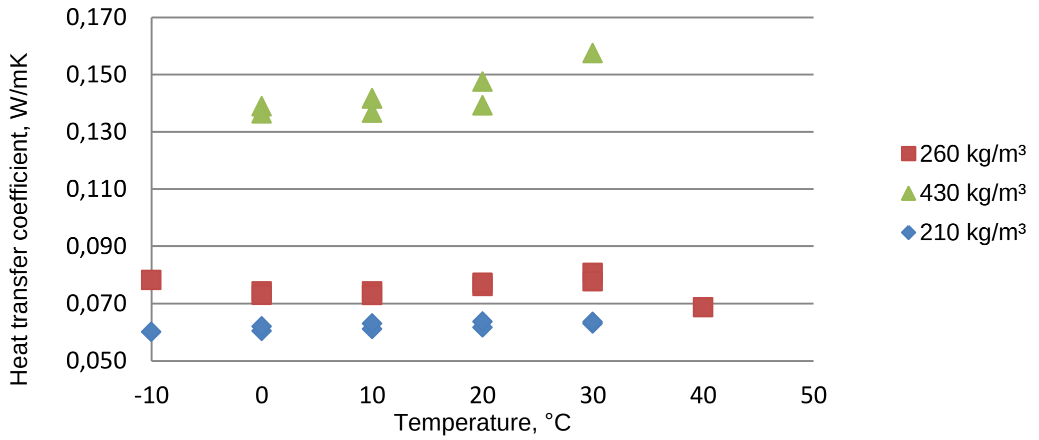

Figure 3: Foam gypsum with hemp shives additives Heat transfer coefficient depending on temperature.

Figure 4 shows sapropel and hemp shives composite material thermal conductivity coefficient determined at the density of 180 kg m^{-3}. In the temperature range of -10 ÷ 50°C thermal conductivity is 0.046 ÷ 0.065 W $mK^{-1}$and it is comparable with researches in Lithuania (Balcunas et al., 2016). The observed results in the temperature range of 0 ÷ 10° C have dispersion of results, which could be explained by the occurrence of moisture in the material during the measurement process varying the temperatures. Such circumstances are possible in external structures, therefore additional experiments and research are needed to avoid moisture development and accumulation in the material.
The structure, made of foam gypsum and hemp shives composite covered with gypsum board and a total thickness of 250 mm, provides thermal conductivity U=0.23 W mK^{-2} at density of 210 kg m^{-3} and is sufficient in all types of buildings. Thermal conductivity has been calculated at the temperature of 0°C, what is an average heat period temperature according to Latvia's regulations. Hemp shives and sapropel composite material provide a thermal conductivity coefficient of 0.046 ÷ 0.065 W mK^{-1} and thermal conductivity U=0.19 W mK^{-2}, which is applicable to the external walls of all types of buildings.

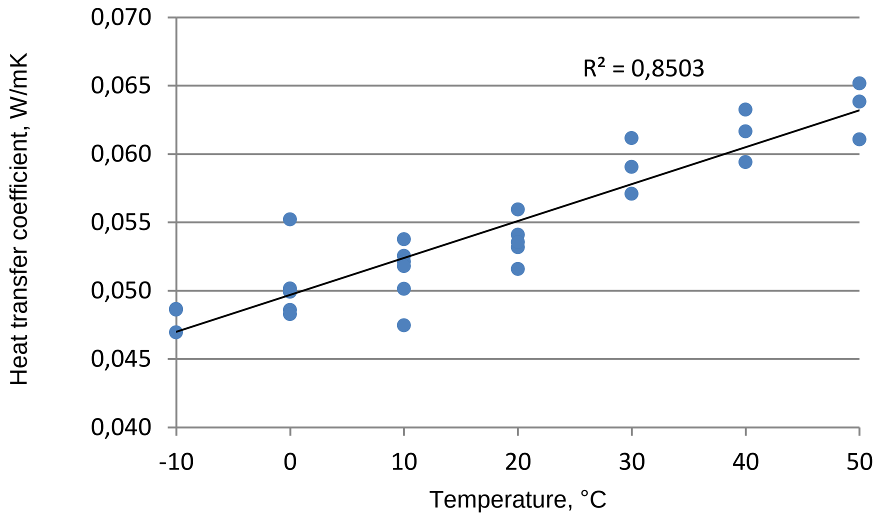

Figure 4: Sapropel with hemp shives additives Heat transfer coefficient depending on temperature

4. Conclusions

Under agroclimatic conditions of Latvia, the yield of the dry matter of industrial hemp cultivars on average is 15.06 t ha^{-1}, with hemp shives constituting approximately 9.4 t ha^{-1}.

According to our research hemp shives can be successfully used in building material composites and the cultivar 'Bialobrzeskie' is useful for it, considering the fertiliser, seed norm, growing conditions and their availability in Latvia.

According to the obtained results lightweight composite materials with hemp additives are possible to use for exterior walls. Structure with 250 mm composite material has thermal conductivity U=0.19÷0.23 W mK^{-2} and sound insulation index R`=30÷35 dB, which is sufficient for residential, office and industrial buildings.

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