ACOUSTIC PROPERTIES OF BINDERLESS PANEL MADE FROM PRETREATED HEMP (CANNABIS SATIVA L.) SHIVES

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ABSTRACT

In Latvia industrial hemp cultivation is rapidly growing. A study of binderless panel made from hemp (Cannabis sativa L.*) shives after hydrothermal pretreatment and steam explosion treatment is reported. The acoustic properties of the panels were determined by means of the sound absorption coefficient (α_w) determined according to standards ISO 10534-2:2001 and 11645:2000. The average sound absorption coefficient (α_w) of the panels reached between 0.10 ÷ 0.15 and varies in all frequency ranges (250 – 4000 Hz) between 0.05 ÷ 0.90 depending on the raw material treatment and hot-pressing conditions. According to the standard EN ISO 11645:2000, the obtained sound absorption coefficients of binderless panels conform to Class E absorbent, which is the lowest rate.*

Key words: hemp *(Cannabis sativa* L.*)* shives, hydrothermal pretreatment, steam explosion treatment, binderless panel, acoustic properties.

INTRODUCTION

Today renewable resources of biomass (wood and agricultural residues, shrubs, etc.) are a real alternative to oil as a raw material for the production of chemicals and motor fuel. However, biomass pretreatment is needed to obtain such products.

The biomass pretreatment process most commonly means hydrolysis of biomass components such as hemicelluloses, lignin and cellulose. The pretreatment process is one of the most important stages further in the biomass processes, where the mechanical and chemical structure of the biomass cell wall is changed, as well as making it easier to convert to other valuable products (boards, bioethanol, levoglucosane, etc.) in further processing (Yang et al., 2012). The increasing demand for platform chemicals derived by the chemical industry increases the demand for furfural, which is exclusively obtained from biomass containing hemicelluloses. It is used for the production of a wide range of important non-petroleum derived chemicals such as furan, tetrahydrofuran and furfuryl alcohol (Lange et al., 2012). One of the biomass examples is the hemp plant consisting of long (bast) fibres and woody part of the stem with short fibres called shives. The main utilization of hemp as a crop is for its bast fibres until now (Shahzad, 2012). However, the high content of hemicelluloses of the shives (Table 1) shows its great potential for furfural production. Also, this valuable raw material is concentrated in one place at the fibre production manufacturer's site. The hemp species have been approved and are a rapidly expanding crop in Latvia with a yield from 150 ha in 2009 to 1200 ha in 2013. The hemp shives make up to 75% of the oven dry stalk. The high content of such chemical components of the hemp shives as cellulose and lignin, like a relatively low content of minerals (Table 1), confirm that the crop also has a potential for production of binderless panels.

Table 1

Chemical Components of Shives of Hemp Species "Bialobrzeskie"

Chemical component	Percentage
Cellulose	43.7 ± 0.4
Hemicelluloses	31.8 ± 0.7
Lignin	22.0 ± 0.6
Minerals (ash)	1.6 ± 0.1

To utilize leftover lignocellulose after obtaining furfural, binderless panels could be made by using no additional adhesives at all during the panels' production process. The panels made from shives after catalyzed pretreatment may have improved water resistance because the hemicelluloses are the most water absorbing component (Garrote et al., 2001) and after the pretreatment its content is significantly diminished. Furthermore, steam explosion (SE) treatment transforms the lignin structure in the plant matrix and promotes the binderless composite moulding in the following hot-pressing process (Okuda et al., 2006; Shao et al., 2009; Tupciauskas et al., 2011).

Materials obtained from secondary feedstock, such as glass, rubber (Pastor 2014), industrial residues

(Garcia-Valles et al., 2008), tyres (Maderuelo-Sanz et al., 2012) etc. can be developed to produce acoustic absorbents.

Analysing typical absorption materials and their ability to muffle the sound in different frequency ranges has a situation where the panel absorbents are highly adept in the low frequency range. The Helmholtz resonator absorber in the average frequency range with a very pronounced absorption in narrow frequency range and porous absorbers are efficient in the high frequency range (Fig 1. Fahy, 2005).

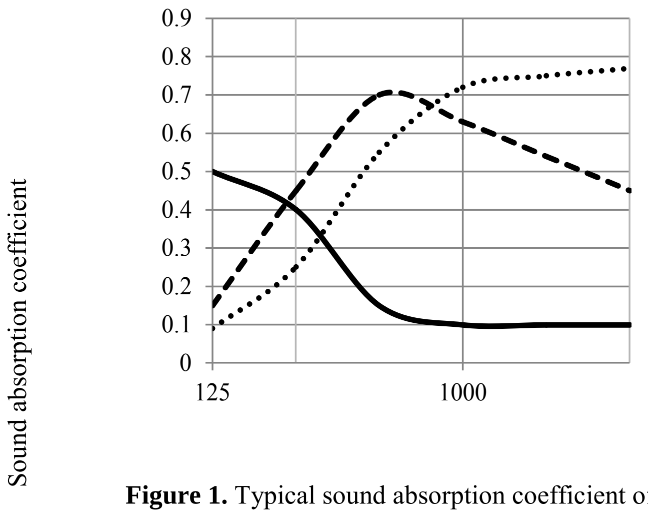

Figure 1. Typical sound absorption coefficient of materials in various frequency ranges: porous absorber, Helmholtz resonator, panel absorber.

A wide range of biomaterials has been used for production of acoustic panels, for example, kenaf, sunflower, maize, Jerusalem artichoke, miscanthus (Balduci et al., 2008) coir (Fouladi, 2010; Fouladi, 2011) etc. On average, the highest values of the absorption coefficient of these materials can be reached in the region above 2000 Hz. They are not applicable as separate panels for finishing or shielding operations, since they are loose, porous or soft materials. Previous studies about hemp shives acoustic absorption ability depending on the fractional composition and binder content (Gle, 2011; Gle, 2012) showed that satisfactory results can be obtained if about 26% of the binder was used for moulding of the panels. If a lower amount of binder was used, the absorption coefficients of the panels were close to those of raw material.

Binderless panels are thin (6÷8 mm) and are classified as a panel absorber in an efficient absorption low frequency range. Previous investigations concerning the ability of natural fiber to be employed as a sound absorber have been carried out (Putra et al., 2013). However, according to our knowledge acoustic absorption of binderless panels made of hemp shives has not been previously investigated. The objective of the study was to investigate acoustic properties of binderless panels as an absorption material.

MATERIALS AND METHODS

The study of binderless panels from pretreated hemp (Cannabis sativa l.) shives is a part of the biorefinery concept illustrated in Fig. 2.

Raw material

The shives of the hemp variety "Bialobrzeskie" (Poland, code 893) was chosen as a raw material. The chemical and elemental composition given in Table 1 was determined as described in Gandofi et al., 2013. The raw material was fractionated by a MUOTOTERA OY classifier using 5 screens according to SCAN-CM 40:01, 2013. For further processing the fraction 3–12 mm, which comprises 77% of the residues of hemp fibre production, was used to homogenize the raw material and to avoid the presence of undesirable compounds such as sand and long fibres.

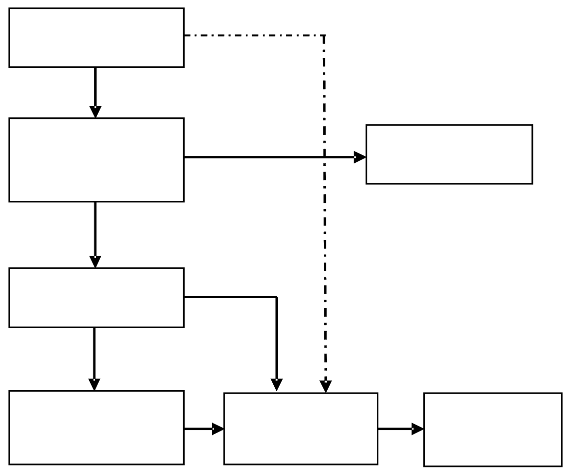

Figure 2. Complex utilization of hemp shives obtaining value added products.

Hydrothermal pretreatment

Lignocellulosic residue for the panels moulding was obtained by the hydrothermal pretreatment process of hemp shives, carried out in a specially constructed 13.7 L bench scale laboratory reactor equipped with a steam jacket in continuous steam flow (200 mL/min) conditions described elsewhere (Brazdausks et al., 2013; 2014). Temperatures of 160°C, 170°C and 180°C were chosen and the duration of the process was 90 min. Before the process, the raw material was mixed with a calculated amount of the catalyst $Al2(SO4)3$ – 5 wt% of the oven dry sample. Further in the paper the hemp shives samples after the hydrothermal pretreatment are defined as H160, H170 and H180.

Steam explosion (SE) treatment

A part of each pretreated lignocellulosic leftover was additionally steam-exploded in a 0.5 L batch reactor (Tupciauskas et al., 2011) to liberate lignin from the cell wall to the fibre surface since the lignin is the most important component relevant to binderless panel production (Okuda et al., 2006; Shao et al., 2009). The SE treatment conditions for all pretreated samples were the same: temperature 235°C and time 5 s. Further in the paper the hemp shives samples after the pretreatment and SE treatment are defined as H160SE, H170SE and H180SE.

Panel manufacture

After the pretreatment and SE treatment hemp shives were air dried (25±2°C) and hot-pressed at one stage press under 3 MPa pressure (p) by four regimes for each pretreatment temperature and SE treatment samples, varying the temperature (T), time (t) and moisture content (MC) as shown in Table 2. Further in the paper the panel samples indicating the manufacture regime given in Table 2 are defined as e.g. H160_2, H170SE_1, etc.
Precisely weighed lignocellulosic materials were pre-pressed under 2±1 MPa for 7±3 s using a frame. Untreated hemp shives were used as reference material (Ref in Table 2) pressing under 5 MPa pressure because of the material non pretreated structure. The set density of all samples was 1000 kg m^{-3} and the set panel dimensions 100×100×7 mm.

Table 2

Panel manufacturing conditions

No	T, °C	t, min	MC, %	p, MPa
1	150±2	15	10±2	3±0.2
2	160±2	15	10±2	3±0.2
3	160±2	15	5±2	3±0.2
4	170±2	10	5±2	3±0.2
Ref	200±2	15	7±2	5±0.2

Determination of panel acoustic absorption

Determination procedure for the panel's acoustic absorption properties was carried out for 3 parallel samples from each panel and obtained values were averaged, and the relative error of measurements was less than ±5%.
The measurements of the sound absorption coefficient (α_w) in frequency ranges 250; 500; 1000; 2000; 4000 Hz were performed for binderless panel samples in an impedance tube (Ø 40 mm) by applying two microphone transfer function method according to ISO 10534-2:2001 and ISO 11645:2000.

RESULTS AND DISCUSSION

Binder-less panels made from hemp shives after pretreatment and steam explosion (SE) have an average sound absorption coefficient (α_w) between 0.10 ÷ 0.15 and vary in all frequency range between 0.05 ÷ 0.90. The highest absorption coefficient was observed in the frequency range of 2000 ÷ 4000 Hz with the highest value at 4000 Hz (Table 3), which is logical due to the material's ability to absorb higher frequencies. The sound absorption coefficient at low-frequency region (250 ÷ 1000 Hz) is almost similar for all samples, and it is below 0.15.

Table 3

Average sound absorption coefficients of panel sample groups

Sample group	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	α_W
H160	0.05	0.05	0.10	0.55	0.90	0.10
H170	0.10	0.10	0.15	0.25	0.40	0.10
H180	0.05	0.10	0.15	0.20	0.25	0.15
H160SE	0.10	0.10	0.15	0.20	0.25	0.10
H170SE	0.10	0.10	0.20	0.30	0.40	0.15
H180SE	0.10	0.10	0.10	0.15	0.20	0.10
Ref	0.05	0.05	0.10	0.45	0.30	0.10

Sample Ref. results of the highest sound absorption value were achieved at 2000 Hz. The sample is made of hemp shives without pretreatment and then the surface formed roughness and open cavities which discharge sound material and muffles it, turning it into heat energy. The sample Ref. curve of sound absorption coefficient in the frequency range (Fig. 4) is characterized by Helmholtz resonator type absorbents (Fig. 1), but not the type of absorbent panels.
The results obtained showed that in the low frequency range (below 2000 Hz) there is no direct impact of the panels manufacture conditions on the acoustic absorption coefficients, but indirectly they are affected by changing physical properties of the pretreated and steam-exploded hemp shives (Fig. 3).
The highest sound absorption coefficients were reached in the frequency range of 4 kHz for panel samples made from pretreated shives at 160°C and 170°C and then steam-exploded one. (H160, H170, H170SE, Table 3).
Assessing the impact on raw material treatment, the panels obtained from pretreated and then steam-exploded materials did not have significant differences on average value of α_w; however, there were significant differences in some frequency ranges (samples H160 and H160SE, H170 and H170SE in Table 3). The α_w significantly increases in all frequency range almost for all obtained panel samples except of Reference sample (Fig. 3). Maximal value of α_w of sample made from raw shives (Ref) was achieved at 2000 Hz. After the pretreatment of shives at 160°C the maximal value of α_w increases from 0.45 to 0.90 at the highest frequency (samples Ref and H160, Table 3). Increasing the raw material pretreatment temperature up to 180°C, the α_w tends to decrease in the frequency range between 2000 ÷4000 Hz but in the frequency range between 500 ÷ 1000 Hz the α_w tends to increase, however, the average value did not improve (samples H160, H170, H180, Table 3).

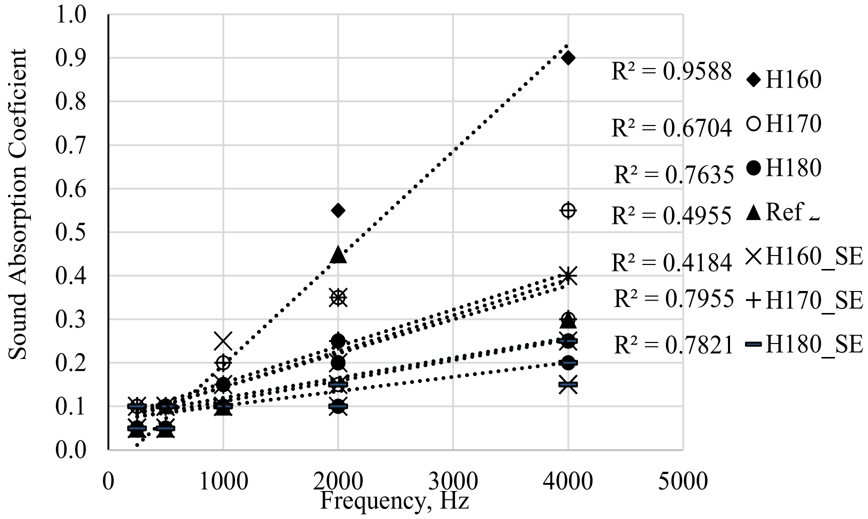

Figure 3. Panel sound absorption coefficient depending on hemp shives treatment.

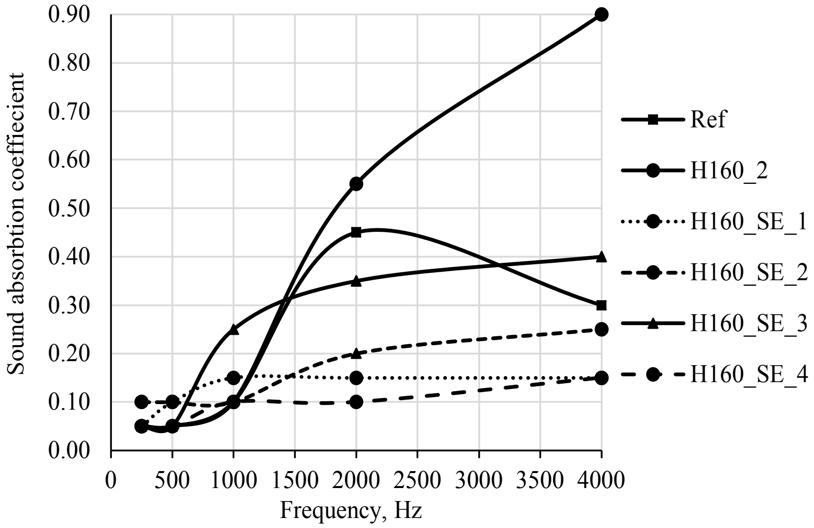

Figure 4. Panel sound absorption coefficient depending on the manufacture conditions from shives pretreated at 160°C.

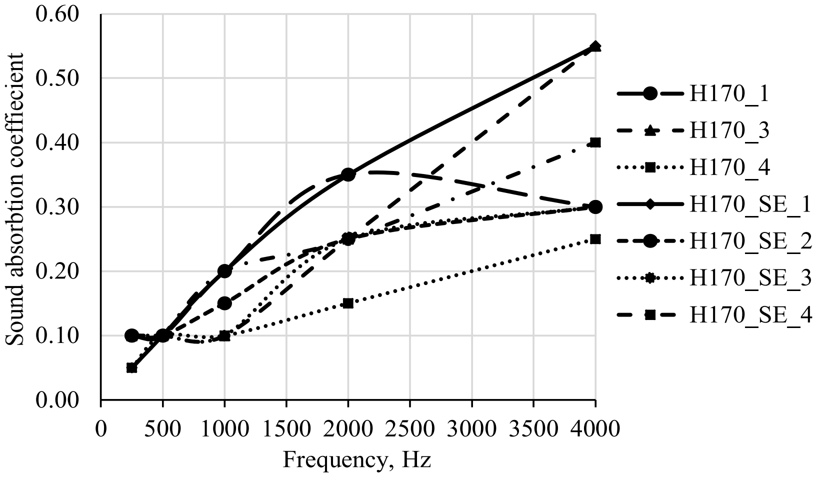

Figure 5. Panel sound absorption coefficient depending on manufacture conditions from shives pretreated at 170°C.

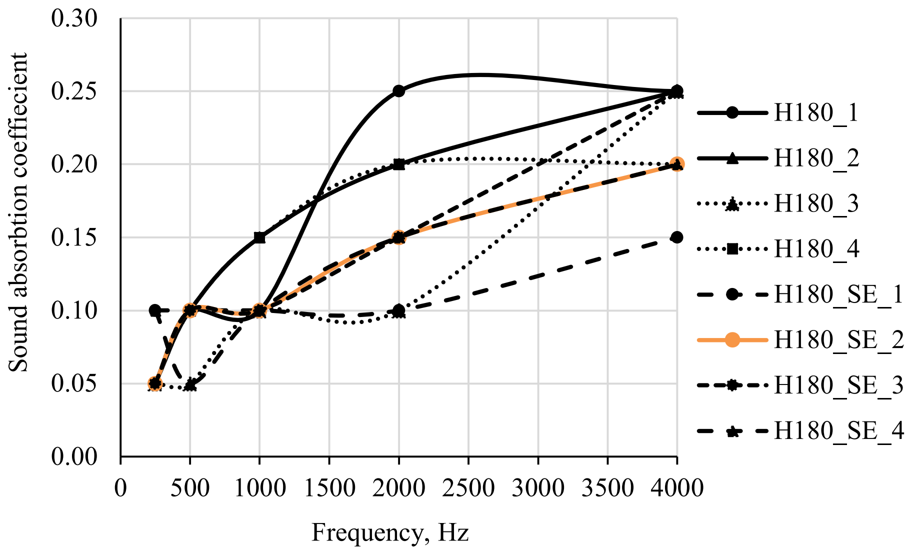

Figure 6. Panel sound absorption coefficient depending on manufacture conditions from shives pretreated at 180°C.

The samples made from SE shives have significantly decreased values of αw, especially in the frequency range of 2000 ÷ 4000 Hz. The observation mentioned before, particularly appear comparing the panel samples made of pretreated shives at 160°C (H160 and H160SE, Fig. 3). The impact of the panel manufacturing conditions on the measured α_w are shown in Figures 4 – 6. The best result of α_w in the frequency range of 1000 ÷ 4000 Hz, achieved was a panel sample made of the pretreated shives at 160°C and then steam exploded shives hot-pressed by regime No 3 (H160SE_3, Fig. 4). However, the same material hot-pressed by regime No 2 achieved higher values of α_w at a frequency range of 250 ÷ 500 Hz (H160SE_2, Fig. 4) showing the impact of the material moisture content during hot-pressing (No 2 and 3, Table 2).

Assessing the impact of pressing regimes of panel samples made of pretreated shives at 170°C the best values of α_w in the frequency range of 250 ÷ 2000 Hz, was achieved by regime No 1, but in the frequency range of 4000 Hz – by regime No 3 (H170_1 and H170_3, Fig. 5). From the panel sample group made of pretreated shives at 170°C and then steam-exploded shives, the best manufacturing regime is No 1 (H170SE_1, Fig. 5) competing in values of α_w with panels made of pretreated shives at the same temperature.

The best values of αw for the panels made of shives pretreated at 180°C achieved: were the samples hot-pressed by regimes No 1 and 2 that gradually increase from 0.05 to 0.25 demonstrating some differences at frequency range 1000 ÷ 2000 Hz (H180_1 and H180_2, Fig. 6). However the average αw of the samples is the same.

The best result of αw for the panels made of pretreated at 180°C and SE shives showed the sample hot-pressed by regime No 3 (H180SE_3, Fig. 6). Generally the analysed results show that lignocellulosic materials for binderless panels with potentially good sound absorption properties are obtained after pretreatment at 170°C and even after following the SE treatment. It is recommended to develop the panels with the goal of improving the α_w values assembling the panels in different systems or making a perforated surface.

Without the panel's manufacturing parameters, the sound absorption coefficient is influenced by the surface quality, which depends on the particle size of the raw material, and the modulus of elasticity, which ensures a material's ability to resist quick deformation. Such a property of the material has been observed also for elastic materials by other authors (Foret, Guigou-Carter, Chene, 2010), when in the range below 160 Hz the acoustic absorption coefficient is affected by their porosity. In the range of 160 ÷ 1000 Hz the dominant impact on the absorption coefficient has a bulk density of the raw material, but above the 1250 Hz level material thickness has a higher impact. While in the range of 1250 ÷ 5000 Hz the absorption coefficient is affected by porosity again. Such of the panels' properties as modulus of resistance, thickness and modulus of elasticity have an impact on the acoustic properties up to 35% most in the frequency range above 1250 Hz.

According to the standard EN ISO 11645 (2000), the obtained sound absorption coefficients of the manufactured binderless panels conform to Class E absorbent, which is the lowest rate. Sound absorption coefficient values by octaves show that the weighted sound absorption coefficients (α_w) can be improved by increasing the value of sound absorption at a low-frequency region. An improvement at this region can be achieved by the application of different systems of panels, where one of the elements used is a binderless panel with an additional perforation or by increasing the panel thickness (Schmidt 1969).

CONCLUSIONS

It is possible to obtain binderless panels from untreated hemp shives and from pretreated ones and also from steam-exploded ones. The weighted sound absorption coefficient (α_w) for the investigated binderless panels is 0.10 ÷ 0.15 and varies in all frequency ranges (250 ÷ 4000 Hz) between 0.05 ÷ 0.90 depending on the raw material treatment and hot-pressing conditions. According to the standard EN ISO 11645 (2000) the obtained sound absorption coefficients of the binder-less panels conform to Class E absorbent, which is the lowest rate.

Binder-less panels from pretreated hemp shives can be used as acoustic absorbent in the frequency region above 2 000 Hz.

Generally the analysed results show that lignocellulosic materials for binder-less panels with potentially good sound absorption properties are obtained after pretreatment at 170°C and even after following SE treatment.

The best sound absorption coefficients for the panels achieved by hot-pressing regimes No 1, 2 and 3 indicated the pressing temperature of 150°C and 160°C, time 15 min and moisture content of lignocellulosic material between 5 and 10%. However the moisture content was found to be too high threatening the delamination of the panels after opening the press.

It is recommended developing the panels with the goal of improving the α_w values assembling the panels in different systems or making a perforation.

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