Proceedings of the Estonian Academy of Sciences,
2018, **67**, 2, 183–192
https://doi.org/10.3176/proc.2018.2.10
Available online at www.eap.ee/proceedings

MATERIALS SCIENCE

Mechanical and physical properties of industrial hemp-based insulation materials

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Received 19 October 2017, accepted 14 March 2018, available online 3 May 2018

Abstract. In recent years, research in the field of insulation materials in buildings has been focusing increasingly more upon ecological properties of these materials. Hemp is an annual bast fibre plant, which delivers fibres, shives, and seeds. Bast fibres are used as a raw material for thermal insulations while shives have been mainly used in animal bedding and construction. The aim of this research was to evaluate the mechanical and physical properties of the industrial hemp fibre- and bast-based insulation materials and compare them with wood-based materials. For producing hemp fibreboards, the hemp shives were ground with separative milling by a semi-industrial disintegrator to the average particle size of 0.136 mm. Urea–formaldehyde (UF) resin was used as the adhesive for hemp particleboards and fibreboards made by the dry method. Fibreboards made by the wet method were bonded without using any binders. Some fibreboards made by the dry method were covered with kraft paper on both sides using UF resin and PVA glue. Properties of particleboards and fibreboards were tested with the determination of density, swelling, resistance to axial withdrawal of screws, tensile strength perpendicular to the plane of the board, bending strength, and air permeability. The results showed that fibreboards made by the dry method were stronger and tougher than fibreboards made by the wet method. The only shortcoming of the former was their low water resistance as samples dissolved in water. Hemp particleboards were lighter and less dense than wood particleboards. However, the mechanical properties of the hemp particleboards were inferior to those of wood particleboards. In addition, the levels of water absorption and swelling of the hemp particleboards were higher than those of the wood particleboards.

Key words: hemp, particleboard, fibreboard, density, tensile strength, bending strength, swelling, water absorption, air permeability.

1. INTRODUCTION

The use of natural, sustainable, renewable, and environmentally friendly materials is gaining interest because of the increasing environmental awareness. For the sustainable construction of buildings, new sustainable materials have to be developed. In the last few years, there has been growing interest in the use of renewable sources such as natural plants for composite materials in the building industry [1,2]. Natural plants are comparatively cheap, recyclable, widely available, renewable, and have a good level of physical and mechanical properties [3]. Therefore, over the years there have been several studies on using various natural fibres for making building materials such as particleboards, medium density fibreboards (MDF), hardboards, and oriented strand boards (OSB). Natural bast fibres, such as hemp and flax have good tensile properties and could be suitable as reinforcements in particle- and fibreboard panels [4–8].

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Industrial hemp is a universal plant, which is quite easy and environmentally friendly to grow. Industrial hemp has been grown in Europe for hundreds of years and it is an important crop in many European countries such as the United Kingdom, Germany, and Spain. Most important applications for the strong fibre are canvas for sails, sacks, water hoses, and fabrics as well as ropes [9].

Hemp (*Cannabis sativa*) is an annual bast fibre plant, which is a source fibre, shives, and seeds. Its stems consist of surface layers, a bark layer with 20–50 bast fibre bundles, and a woody core with a central lumen. Bast fibres are used as a raw material for thermal insulations, cigarette paper, and biocomposites. Also shives produced from the woody inner core of the stems have been used as a thermal insulation, but mainly these have been used in animal bedding and construction. Hemp seeds have a high nutritional value and hemp oil has an excellent and unique fatty acid profile. They are both used for human food and animal feed [9,10].

Hemp is grown for fibre, oil, and drug production purposes. Fibre hemp is an annual herb plant growing up to 5 m high and with a diameter from 4 to 20 mm. Fibre hemp is mainly a dioecious plant, although occasionally monoecious plants are also found [11]. Industrial hemp can be cultivated on very different types of soils and it is considered to be one of the sturdiest and most adaptable crops. Industrial hemp is a universal plant, which is easy and environmentally friendly to grow. Usually, fibre hemp is ready to harvest in four months. The harvesting of industrial hemp takes place either in autumn when the straw is still green or in spring when the dry-line method can be used.

After harvesting, the bast fibres must be separated from the rest of the plant so that hemp fibres can be used. This separation has usually been achieved by dew retting or water retting following mechanical extraction processes. In the production chain, the processing steps depend on the structure of the hemp fibre thermal insulation produced [11,12]. Hemp insulation materials also have many great properties and are user-friendly during installation. Several studies show that hemp shives can be used for particleboard production [13–17]. Previous studies have shown that building materials made of hemp shives have good antiseptic, acoustic absorption, thermal insulation, and hydric regulation properties, they prevent condensation and are light [18–20].

The aim of this research was to develop new hemp shiveboards and fibreboards; to evaluate their mechanical and physical properties such as water absorption, air permeability, tensile and bending strength, and resistance to axial withdrawal of screws; and to compare these properties with those of wood-based materials.

2. MATERIALS AND METHODS

2.1. Materials

The raw material for making hemp boards was acquired in the form of shives from Hempson OÜ in Saaremaa, Estonia. Wood particles were acquired from AS Repo Vabrikud, Estonia. For making fibreboard, the hemp shives and wood particles were ground with separative milling by a semi-industrial disintegrator DSL-115. The average particle size for fibreboards was 0.136 mm. The passage amounts through sieves (mesh sizes 2.8, 1.4, 0.71, 0.355, 0.18, 0.09, 0.45, 0.02, 0.01, and 0.005 mm) are shown in Fig. 1. For a binder, an Achema KF-FE urea–formaldehyde resin (67% dry matter content) and Casco 2535 hardener were used. Physical and chemical properties of Achema KF-FE are presented in Table 1 and the product information of the hardener, Casco 2535, is shown in Table 2. For covering fibreboards with kraft paper, PENOSIL Premium WoodFix EN 204/D3 humidity-resistant wood adhesive (1-component PVAc–adhesive dispersion) was used. The resin, hardener, and kraft paper were purchased at a retail store.

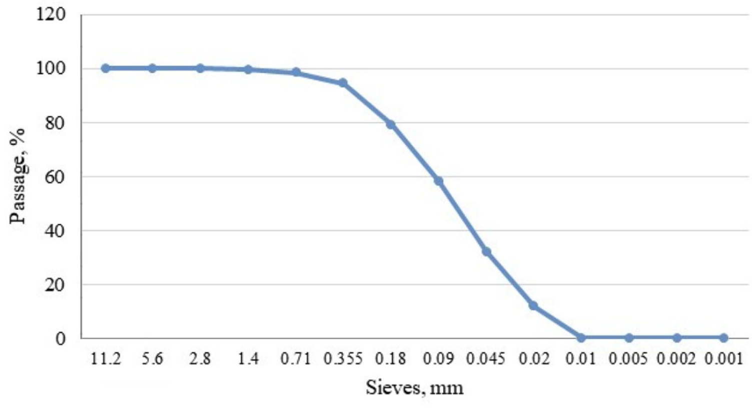

Fig. 1. Hemp fibre size analysis.

Table 1. Physical and chemical properties of urea–formaldehyde resin Achema KF-FE

Appearance	Whitish liquid
Mass fraction of non-volatile substances	67 ± 1%
Relative viscosity	75–140 s
pH	7.5–8.7
Consolidation time at 100 °C	40–60 s
Adhesive bond strength	10 N/mm^2
Coagulation ratio	(1 : 2)–(1 : 8)

Table 2. Physical and chemical properties of hardener Casco 2535

Physical state	Liquid
Colour	Grey
Odour	Faint
pH	3.5–5.5
Initial boiling point	100 °C
Density	1.45 g/cm^3
Solubility	Miscible in water
Viscosity at 25 °C	2000–10000 mPa·s

2.2. Hemp fibreboard production by the dry method

For producing hemp fibreboards, ground hemp chaffs were used as the raw material and urea–formaldehyde resin was used as the adhesive. For one board 340 g of hemp flour was taken; the amount of urea–formaldehyde resin (Achema KF-FE) was 11 wt% of the hemp flour dry matter. The hardener (Casco 2535) was added to the urea–formaldehyde resin in the amount of 10 wt% of the resin. Next, the hemp flour was mixed in a mechanical mixer with the adhesive for 3 min. Then a mat-forming frame was placed on the pressing plate and filled with the mixture of hemp flour and adhesive. First, the mixture was prepressed by hand. Then thickness calibrators were placed on the edges of the pressing plate to fix the thickness of the board. The formed mat was covered with the pressing plate and placed into a hot pre-heated press. Hot-pressing was done for 5 min at 110 °C at a pressure of 1.2 MPa.

2.3. Hemp fibreboard production by the wet method

For producing softboard, ground hemp chaffs were used as the raw material. For board forming a handsheet former LA-1, commonly used in paper industry laboratories, was applied. For one board 150 g of pulp with the dry matter content of 91% was taken. The concentration of pulp was 17062.5 g/m^3. First, the pulp was mixed with water in a blender and then it was poured into the drainer cylinder of the sheet former. After that, the mixed pulp was diluted up to the water : pulp ratio 8 : 1 in the drainer cylinder. The diluted pulp was mixed manually for 5 s to homogenize the concentration. After that the water was instantly drained. The formed mat was then placed between perforated plates and pressed in a hydraulic press at room temperature at a pressure of 0.32 MPa for 5 min. The pressed softboards were then dried in an oven at 103 °C for 24 h.

2.4. Covering fibreboards with kraft paper

Kraft paper pieces with dimensions 20 mm × 20 mm were cut out. Next, glue was prepared with the urea–formaldehyde resin (Achema KF-FE) and the hardener (Casco 2535) was added to the urea–formaldehyde resin in the amount of 10 wt% of the resin. Then, 120 g/m^2 of the glue was taken and paper pieces were glued on both sides of the fibreboard. The covered fibreboards were placed under a hot press for 5 min at an average temperature of 110 °C. In the case of glueing with Penosil EN 204/D3 (PVA), the fibreboards were placed under a cold press for 5 min. In both cases, the minimum pressure of the hydraulic press, 0.32 MPa, was applied.

2.5. Production of hemp and wood particleboards

For making hemp and wood particleboards, 340 g of wood chips or hemp shives (7% moisture content) was taken for one board and placed into a mixer with adhesive. The amount of the urea–formaldehyde resin (Achema KF-FE) was 11 wt% of the wood chips or hemp shives dry matter. The hardener (Casco 2535) was added to the urea–formaldehyde resin in the amount of 10 wt% of the resin. After the adhesive was added, the mixing was continued for 3 min, and then stopped. After mixing, a mat-forming frame was placed on the pressing plate and filled with the mixture of wood chips and adhesive. The mixture was thickened with a hand press. On the edges of the pressing plate, thickness calibrators were placed to fix the thickness of the board. The formed mat was covered with the pressing plate and placed into a hot press for 5 min at 110 °C at a pressure of 1.2 MPa.

2.6. Determination of density

Density was determined in accordance with EVS-EN 323 [21] as the ratio of the mass and the volume of the given sample. For this experiment, four 50 mm × 50 mm test specimens were used. The dimensions of the specimens were measured with a calliper (d = 0.01 mm) to an accuracy of 0.5%. After that, the volumes of the specimens were calculated from these dimensions. Each specimen was weighed with a technical scale (Mettler

Toledo, $d = 0.01$ g) to an accuracy of 0.5% and its mass in kilograms was recorded. Finally, the density in kilograms per cubic metre was calculated.

2.7. Determination of swelling and water absorption

The swelling of fibreboards was determined according to EVS-EN 317 [22]. Swelling in thickness was determined by measuring the increase in the thickness of the specimen after its complete immersion in water. Water absorption was measured by measuring the mass gain after complete immersion in water. For the water absorption and swelling experiment, four test specimens with dimensions 50 mm × 50 mm were used. For determining swelling, the thickness of the samples was measured before immersion in water with a calliper ($d = 0.01$ mm). For determining water absorption, the mass of the samples was measured before immersion in water to an accuracy of 0.01 g. Then the specimens were placed in water vertically keeping the upper edge 20 mm under water. The samples were kept in water under load at room temperature (23 °C) for 24 h. After that, the samples thicknesses and masses were measured again and swelling and water absorption were calculated.

2.8. Determination of resistance to axial withdrawal of screws

Resistance to axial withdrawal of screws was determined according to EVS-EN 320 [23]. Face withdrawal of screws was determined by measuring the force required to withdraw a defined screw from the specimen. Five specimens were taken from each sample board. The specimens were rectangular with dimensions 65 mm × 50 mm. Then the screws were inserted with a screwdriver perpendicular to the surface of the test piece, located at the midpoints of one face. For this test, a 4.2 mm × 45 mm steel screw was used. The screws were inserted into the test pieces in such a way that 15 ± 0.5 mm of the complete thread was embedded in the specimen. For testing face screw holding on the specimen with a thickness less than 15 mm, the screw was inserted so that the length of the incomplete thread protruded on the opposite side of the specimen. The specimens were mounted in a testing machine Instron 5866. For the testing of face screw withdrawal on boards less than 15 mm in thickness, a metal jig was used. For that, the screw was inserted into the boring in the centre of the metal jig and the specimen was well restrained by the metal jig. Axial load was applied to the underside of the screw head at a constant rate of movement of 10 ± 1 mm/min until the maximum load was achieved. The maximum load was recorded to the nearest 10 N sustained by the specimen during the withdrawal test on the face.

2.9. Determination of tensile strength

Tensile strength was determined according to EVS-EN 319 [24]. The aim of this test was to determine the resistance to tension perpendicular to the surface of the specimen by submitting it to a uniformly distributed tensile force until rupture occurs. Tensile strength perpendicular to the plane of the board was determined by the maximum load in relation to the surface area of the test piece. For this experiment, five specimens were used. Square test specimens with a side length of 50 ± 1 mm were used. Before conducting the experiment, wooden blocks (65 mm × 50 mm) compatible with the fixing device were glued to specimens using PVA glue. The specimens with glue on blocks were put under a load and left to cure for at least 24 h. In this test, a testing machine Instron 5866 was used. A load was applied at a constant rate of the crosshead movement throughout the test. The rate of loading was adjusted so that the maximum load was reached within 60 ± 30 s. The test was performed in a tensile tester at a speed of 20 mm/min, where the maximum load sustained by the test piece with a precision of 1% was recorded. The results from any test piece that exhibited partial or total glue-line failure or failure in the testing block were rejected.

2.10. Determination of bending strength

Bending strength was determined according to EVS-EN 310 [25]. The modulus of elasticity in bending and the bending strength were determined by applying a load to the centre of a specimen supported at two points. For this test five specimens of each sample board were used. Samples were rectangular with the dimensions of 50 mm × 150 mm. Also for this experiment, a testing machine Instron 5866 was used. First, the test specimen was placed flat on the supports, with its longitudinal axis at right angles to those of the supports with the centre point under the load. The load was applied at a constant rate of the crosshead movement throughout the test. The rate of loading was adjusted so that the maximum load was reached within 60 ± 30 s. The deflection in the middle of the specimen was measured to an accuracy of 0.1 mm and this value was plotted against the corresponding loads measured to an accuracy of 1% of the measured value. The maximum load was recorded to an accuracy of 1% of the measured value.

2.11. Determination of air permeability

Air permeability was determined according to EVS-EN 12114 [26]. Air permeability is the airflow rate at reference conditions as a function of the pressure difference. For this experiment, three specimens with dimensions of 100 mm × 100 mm of each sample board were used. First, the test specimen was placed into a rig and tightened with screws by drilling. Then the maximum pressure difference was selected according to the future use of the specimen tested. The minimum pressure difference should be at least equal to the smallest pressure difference measurable with the required accuracy of 5% as it was in this case. Altogether, the procedure was dependent on the air tightness of the test rig itself. The test rig was considered airtight because its residual airflow rate was less than 5% of the smallest flow rate to be measured.

During the experiment, three pressure pulses were applied with a differential pressure transmitter 699 (Huba Control). Each pulse was maintained for at least 3 s. Every time a maximum pressure of 550 Pa was applied and the data were recorded. After the maximum pressure was applied, the pressure was always lowered to zero before continuing with the next pulse. If the result was zero, the tested material was airtight and no following measurements were needed. However, if the result was not zero during these three pressure pulses at the maximum pressure, another experiment was made. Before this additional experiment, the pressure steps were distributed in a geometric series from the minimum to the maximum pressure differences in such a way that there were at least seven measured points. The full range was divided into N ($N \geq 6$) pressure steps.

3. RESULTS AND DISCUSSION

3.1. Density

The fibreboards made by the dry method were denser than the fibreboards made by the wet method (Fig. 2). According to the EWPAA product properties, the standard density of MDF with a thickness of 13–22 mm is 725 kg/cm^3 [27]. In this experimental work, the average density of fibreboard made by the dry method was 544 kg/cm^3. Therefore, the wood-based MDF was denser than the hemp fibreboard with 25% difference. Its cause may be the applied volume of pressure load during hot pressing [27]. According to the Pavatex product properties, the softboard density is 230 kg/cm^3 [28]. In the current experiment, the average density of the fibreboard made by the wet method was 185 kg/cm^3. Therefore, the wood-based softboard was about 20% denser than the hemp fibreboard. The differences may have occurred because of the different particle size and bonding abilities [29,30]. Density measurements showed that the density of the wood particleboard was by 17% higher than of the hemp particleboard (see Fig. 2). As the hemp particles had lower density and a porous structure, there were voids between the glue layer and hemp particles, which might have resulted in a lower overall density of the boards.

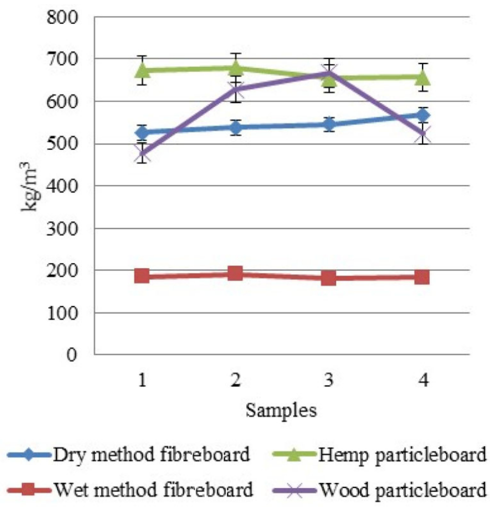

Fig. 2. Density of hemp and wood boards.

3.2. Swelling

The average swelling of the hemp fibreboard made by the wet method was 8.97% and its average water absorption was 480.11% (Fig. 3). Unfortunately, samples made by the dry method dissolved in water and no

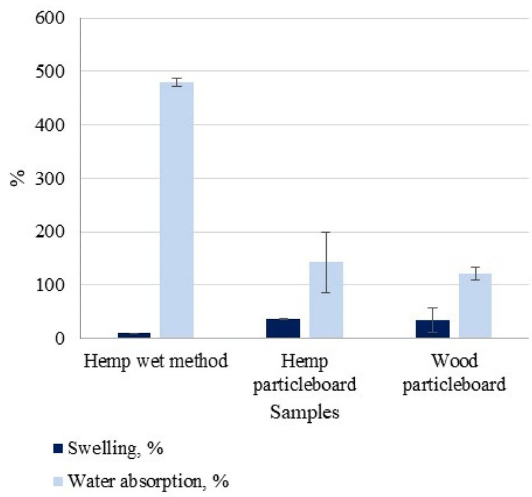

Fig. 3. Swelling and water absorption of hemp and wood boards.

measurable entity was left. According to the requirements given in EVS-EN 622-4, the swelling in thickness of wood-based fibreboard made by the wet method is 10% for boards with >19 mm thickness [31]. In this experimental work, the average swelling for the hemp fibreboard made by the wet method was about 9%. The difference is 10% because of the wood and hemp fibre morphology differences [29,31]. According to EVS-EN 622-5, the swelling is 12% for the dry method fibreboards with a thickness of 12–19 mm [32]. In addition, the EWPAA product properties show that the wood-based MDF swelling is approximately 8–12% [27]. Unfortunately, in the current experimental work, no data were recorded on swelling properties of the hemp fibreboard made by the dry method due to dissolved specimens. The swelling of the hemp particleboard was 6% higher than for the wood particleboard and the water absorption of the hemp particleboard was about 18% higher than for the wood particleboard. This can be explained by the lower density and more porous structure of hemp particles, which are more susceptible to water absorption.

3.3. Resistance to the axial withdrawal of screws

Results and data of the resistance to axial withdrawal of screws are givn in Fig. 4, which shows that the specimens covered with paper using PVA glue were the most resistant ones and the specimens made by the wet method were the least resistant to the axial withdrawal of screws. The material made by the wet method was even so weak that three out of five specimens broke during the test (Fig. 5). According to EVS-EN 622-4, the resistance to axial withdrawal of screws from wood-based fibreboards made by the dry method is 30 N/mm [31]. The EWPAA produced MDF (thickness 13–22 mm) resistance to axial withdrawal of screws is 47 N/mm. According to the current experiment, the average resistance to screw withdrawal from hemp fibreboards was 12 N/mm. Therefore, the wood-based fibreboard is more resistant to the axial withdrawal of screws than the hemp board. The difference is 60–74% [27,32]. According to the EcoBoards product properties, the resistance to axial withdrawal of wood-based softboards is 58 N/mm [33]. In our case, the average result of the hemp fibreboard made by the wet method was 2 N/mm. The difference is about 96%. This huge difference may have occurred because wood contains more lignin than hemp and therefore wood-based fibreboards are bonded better and more strongly [29,30]. Another reason may be the breaking of specimens during the test: only two more or less adequate results were obtained. Comparison of the results of hemp particleboards and wood particleboards indicates that wood particleboards have 30% higher resistance to axial withdrawal of screws than hemp particleboards, which can be explained by the lower density of hemp.

3.4. Tensile strength

Results of the measurement of tensile strength perpendicular to the plane of the board are illustrated in Fig. 6. The average tensile strength of fibreboard made by dry method was 0.0147 MPa and of that made by the wet method, 0.0068 MPa. Unfortunately, three out of five specimens made by the wet method broke loose from the wooden blocks before the experiment; therefore, there may not be enough data for adequate results. Nevertheless, from the available data and Fig. 6 it can be concluded that the fibreboards made by the dry

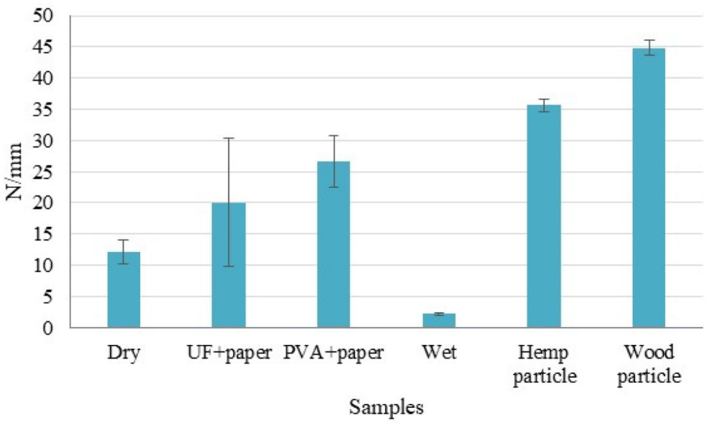

Fig. 4. Resistance to axial screw withdrawal for hemp and wood boards (UF+paper – hemp fibreboard covered with kraft paper glued with urea–formaldehyde resin; PVA+paper – hemp fibreboard covered with kraft paper glued with polyvinyl acetate resin).

Fig. 5. Sample made by the wet method broke during the test.

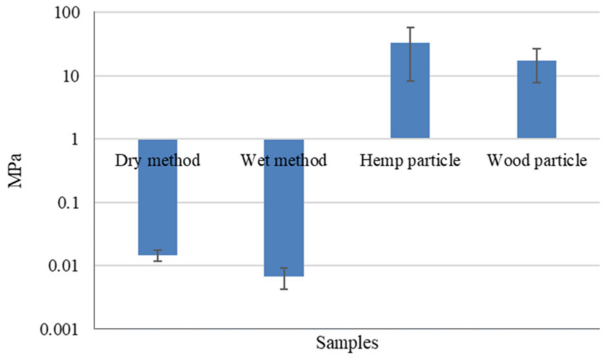

Fig. 6. Tensile strength perpendicular to the plane of hemp and wood boards.

method were stronger. According to EN 622-5, the tensile strength of wood-based fibreboard of 12–19 mm thickness is 0.55 MPa [32]. Moreover, the tensile strength of the EWPAA produced MDF with a thickness of 13–22 mm is 0.75 MPa. In this experimental work, the average tensile strength of hemp fibreboard made by the dry method was 0.015 MPa. The differences are about 96–98% [27,32]. However, tensile strengths by Kirilovs et al. [8] of hemp fibreboards made using urea–formaldehyde resins are similar to ours. In their research, the best results were obtained with the phenol–formaldehyde resin [8]. According to Pavatex data on softboards, the tensile strength of wood-based boards is 0.015 MPa [28]. In the current experiment, the tensile strength of hemp fibreboard made by the wet method was 0.007 MPa. The difference is about 54%, which can also be due to the fact that wood contains more lignin than hemp and therefore wood-based fibreboards are bonded better and more strongly [29,30]. Hemp particleboards showed 30% higher tensile strength perpendicular to the plane of the board than wood particleboards. This shows that hemp particles were more evenly mixed with glue than wood particles.

3.5. Bending strength

The average bending strength of different boards is shown in Fig. 7. The strongest material was hemp particleboard with the average bending strength of 7 MPa, which was 12% higher than the wood particleboard bending strength. This finding correlates with previous results by Kirilovs et al. [8]. The average bending modulus of elasticity of wood particleboard was 670.75 MPa and its bending strength was 6.26 MPa. The average bending modulus of elasticity of hemp particleboard was 437.80 MPa, which is 53% lower than the wood particleboard bending modulus of elasticity.

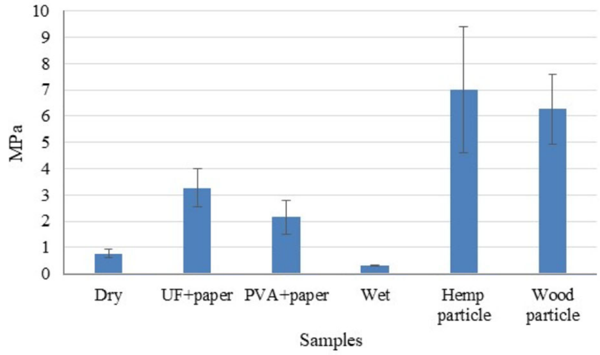

Fig. 7. Bending strength (UF+paper – hemp fibreboard covered with kraft paper glued with urea–formaldehyde resin; PVA+paper – hemp fibreboard covered with kraft paper glued with polyvinyl acetate resin).

Comparison of the bending strengths of fibreboards shows that the fibreboard made by the dry method and covered with paper using UF resin was the strongest while the fibreboard made by the wet method was the weakest. The same conclusions can be drawn on the modulus of elasticity (see Fig. 8). According to EVS-EN 622-4, the bending strength requirements for wood-based softboards with a thickness over 19 mm are 0.8 MPa [31]. In this experimental work, the average bending strength of the softboard was 0.31 MPa. Therefore, hemp softboard was weaker. The difference is 61.25%; caused again by the higher lignin content and better bonding of the fibres of wood [30]. According to EVS-EN 622-3, the bending strength for wood-based fibreboard with a thickness over 10 mm made by a dry method is 8 MPa [34]. In the current experimental work, the average bending strength of hemp fibreboards made by the dry method was about 1 MPa. From previous research, it can be concluded that hemp fibreboard is weaker [33]. The difference is about 87%.

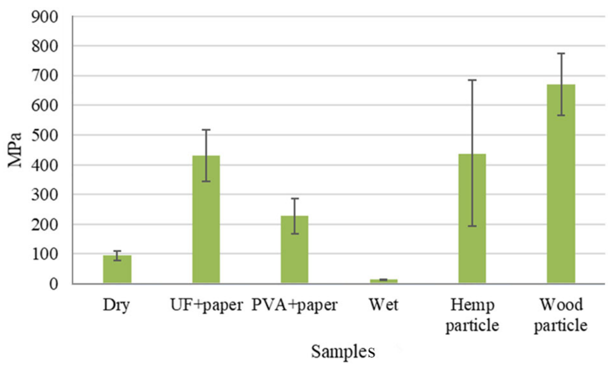

Fig. 8. Modulus of elasticity (UF+paper – hemp fibreboard covered with kraft paper glued with urea–formaldehyde resin; PVA+paper – hemp fibreboard covered with kraft paper glued with polyvinyl acetate resin).

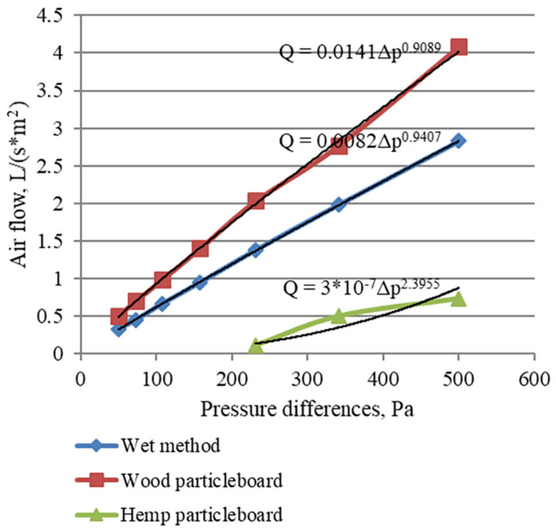

Fig. 9. Air permeability of hemp and wood boards.

3.6. Air permeability

All the fibreboard samples made by the dry method were airtight; therefore the presented results only concern fibreboards made by the wet method. Figure 9 illustrates the air permeability of hemp and wood particleboards. Our results showed that hemp fibreboard was less airtight than hemp particleboard, although it was more airtight than a board made from wood particles. The reasons why fibreboards made by the dry method are more airtight than particleboards may be that fibreboards are denser and less porous than particleboards. Hemp particleboards showed better resistance to air leakage than wood particleboards. The average air permeability of wood particleboards was 1.78 L/(s·m^2) and that of hemp particleboard was 0.19 L/(s·m^2). The lower air permeability of hemp particleboard may be explained with a better glue distribution in the board, which made the board more airtight.

4. CONCLUSIONS

Our results showed that the fibreboards made by the dry method were denser than the fibreboards made by the wet method. The wood particleboards were denser than the hemp particleboards. When it comes to swelling and water absorption results then, unfortunately, samples made by the dry method dissolved in water and no measurable entity was left. As compared to wood particleboards, hemp particleboards had higher swelling and water absorption. In the resistance to axial screw withdrawal, the specimens covered with kraft paper using PVA glue were the most resistant ones and the specimens made by the wet method were the least resistant. The material made by the wet method was even so weak that three out of five specimens broke during the test. As to the average bending strength of different boards, the strongest material was hemp particleboard and the weakest was fibreboard made by the wet method. The results of air permeability tests showed that all the fibreboard samples made by the dry method were airtight. From the air permeability tests, it can be concluded that hemp fibreboard was less airtight than hemp particleboard, although they were more airtight than the board made of wood particles. Based on this research it can be said that hemp particleboards are suitable as a building material. However, more research on hemp fibreboards is needed to improve their properties for the use as building materials.

ACKNOWLEDGEMENT

The publication costs of this article were covered by the Estonian Academy of Sciences.

REFERENCES

1. Pacheco-Torgal, F. and Jalali, S. Cementitious building materials reinforced with vegetable fibres: a review. *Constr. Build. Mater*., 2011, **25**, 575–581.
2. Preikss, I., Skujans, J., Adamovics, A., and Iljins, U. Evaluation of hemp (Cannabis sativa L.) quality parameters for building materials from foam gypsum products. *Chem. Eng. Trans*., 2013, **32**, 1639–1644.
3. Faruk, O., Bledzki, A. K., Fink, H., and Sain, M. Biocomposites reinforced with natural fibres: 2000–2010. *Prog. Polym. Sci*., 2012, **37**, 1552–1596.
4. Youngquist, J. A., English, B. E., Scharmer, R. C., Chow, P., and Shook, S. R. Literature review on use of nonwood plant fibers for building materials and panels. General Technical Report, FPL-GTR-80. U. S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, U. S., 1994.
5. Sampathrajan, A., Vijayaraghavan, N. C., and Swaminathan, K. R. Mechanical and thermal properties of boards made from farm residues. *Biores. Technol*., 1992, **40**, 249–251.
6. Bektas, I., Guler, C., Kalaycioglu, H., Mengeloglu, F., and Nacar, M. Manufacture of particleboards using sunflower stalks (*Helianthus annuus* I.) and poplar wood (*Populus alba* L.). *J. Compos. Mater*., 2005, **39**, 467–473.
7. Cöpür, Y., Guler, C., Akgul, M., and Tascioglu, C. Some chemical properties of hazelnut husk and its suitability for particleboard production. *Build. Environ*., 2007, **42**, 2568–2572.
8. Krilovs, E., Gusovius, H-J., Kukle, S., and Emsiņš, J. Performance of fibreboards made from wetpreserved

hemp. *Material Science. Textile and Clothing Technology*, 2013, **8**, 65–69.
9. Carus, M., Karst, S., Kauffmann, A., Hobson, J., and Bertucelli, S. *The European Hemp Industry: Cultivation, Processing and Applications for Fibres, Shivs and Seeds*. European Industrial Hemp Association, 2013.
10. Kymäläinen, H-R. and Sjöberg, A-M. Flax and hemp fibres as raw materials for thermal insulations. *Build. Environ.*, 2008, **43**, 1261–1269.
11. Nykter, M. Microbial Quality of Hemp (Cannabis sativa L.) and Flax (Linum usitatissimum L.) from Plants to Thermal Insulation. PhD thesis. University of Helsinki, Department of Agrotechnology, 2006.
12. Kymäläinen, H-R., Koivula, M., and Kuisma, R. Quality requirements of flax, linseed and hemp fibre for insulation materials. University of Helsinki, Department of Agricultural Engineering and Household Technology, 2002.
13. Hague, J. Substitution of particles and fibers from agricultural crops into wood-based panels. Ministry of Agriculture, Fisheries and Food Research and Development NF0301 Final Project Report. BioComposites Center, University of Wales Bangor, 1998.
14. Theis, M. and Grohe, B. Biodegradable lightweight construction based on tannin/hexamine bonded hemp shaves. *Holz Roh Werkst.*, 2002, **60**, 291–296.
15. Balducci, F., Harper, C., Meinlschmidt, P., Dix, B., and Sanasi, A. Development of innovative particleboard panels. *Drvna Industrija*, 2008, **59**, 131–136.
16. Nikvash, N., Kraft, R., Kharazipour, A., and Euring, M. Comparative properties of bagasse, canola and hemp particleboards. *Eur. J. Wood Wood Prod.*, 2010, **68**, 323–327.
17. Lühr, C., Pecenka, R., Gusovius, H-J., Wallot, G., Rinberg, R., and Tech, S. Development of an axial fractionator for hemp shive cleaning and industrial applications of shives. *J. Agr. Sci.*, 2013, **5**, 9–16.
18. Collet, F., Bart, M., Serres, L., and Miriel, J. Porous structure and water vapour sorption of hemp-based materials. *Constr. Build. Mater.*, 2008, **22**, 1271–1280.
19. Fourmentin, M., Faure, P., Pelupessy, P., Sarou-Kanian, V., Peter, U., Lesueur, D., et al. NMR and MRI observation of water absorption/uptake in hemp shives used for hemp concrete. *Constr. Build. Mater.*, 2016, **124**, 405–413.
20. Stevulova, N., Kidalova, L., Cigasova, J., Junak, J., Sicakova, A., and Terpakova, E. Lightweight composites containing hemp hurds. *Procedia Eng.*, 2013, **65**, 69–74.
21. Eesti Standardikeskus. EVS-EN 323:2002. Wood-based panels - Determination of density.
22. Eesti Standardikeskus. EVS-EN 317:2000. Particleboards and fibreboards - Determination of swelling in thickness after immersion in water.
23. Eesti Standardikeskus. EVS-EN 320:2011. Particleboards and fibreboards - Determination of resistance to axial withdrawal of screws.
24. Eesti Standardikeskus. EVS-EN 319:2000. Particleboards and fibreboards - Determination of tensile strength perpendicular to the plane of the board.
25. Eesti Standardikeskus. EVS-EN 310:2002. Wood-based panels - Determination of modulus of elasticity in bending and bending strength.
26. Eesti Standardikeskus. EVS-EN 12114:2000. Thermal performance of buildings - Air permeability of building components and building elements - Laboratory test method.
27. Engineered Wood Products Association of Australasia. http://www.ewp.asn.au/ (accessed 2018-03-26).
28. Acara Concepts. http://www.acaraconcepts.com/wp-content/themes/acaraconcepts/pdfs/Brochure-Pavatex-Products&Application.pdf (accessed 2018-03-29).
29. Pickering, K. L. (ed.) *Properties and Performance of Natural-Fibre Composites*. Woodhead Publishing Limited, Cambridge, England, 2008.
30. Acara Concepts. http://www.acaraconcepts.com/wood-fibre-insulation/ (accessed 2018-03-26).
31. Eesti Standardikeskus. EVS-EN 622-4:2010. Fiberboards - Specifications - Part 4: Requirements for softboards.
32. Eesti Standardikeskus. EVS-EN 622-5:2010. Fibreboards - Specifications - Part 5: Requirements for dry process boards (MDF).
33. Eesti Standardikeskus. EcoBoards. http://www.eco-boards.eu/sample-page/ecoboard-softboard/ (accessed 2018-03-27).
34. Eesti Standardikeskus. EVS-EN 622-3:2004. Fibreboards - Specifications - Part 3: Requirements for medium boards.

Tööstuslikust kanepist isolatsioonimaterjalide mehaanilised ja füüsikalised omadused

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Viimastel aastatel on ehitusvaldkond muutunud väga keskkonnateadlikuks mitte ainult energia säästmise mõttes, vaid rohkem on hakatud kasutama ka loodussõbralikke materjale. See on ka põhjuseks, miks naturaalsete toormaterjalide, näiteks kanepi ja lina vastu on tänapäeval huvi suurenenud. Kanepist toodetud isolatsioonimaterjalidel on palju suurepäraseid omadusi ja need on paigaldamisel väga kasutamissõbralikud.

Käesoleva töö eesmärgiks oli uurida isolatsioonimaterjale, mis on valmistatud tööstuslikust kiukanepist. Kanepiisolatsiooniplaatide valmistamise toormaterjaliks oli kanepiluu, mida saadi Saaremaa ettevõttest Hempson OÜ. Kiudplaadi valmistamiseks oli vaja kanepiluu eelnevalt jahvatada. Jahvatatud kanepikiu keskmiseks suuruseks oli 0,136 mm. Lisaks valmistati antud töös ka kanepilaastplaadid ja võrreldi nende omadusi puitlaastplaadiga. Laastplaatide ja kuivmeetodiga kiudplaatide valmistamiseks kasutati sideainena ureaformaldehüüdvaiku (Achema KF-FE) segatuna

kõvendiga (Casco 2535). Märgmeetodiga kiudplaatide valmistamisel sideainet ei kasutatud. Mõned kuivmeetodil tehtud kiudplaadid kaeti mõlemalt poolt jõupaberiga, et tõsta nende mehaanilisi omadusi. Selleks kasutati kas ureaformaldehüüdvaiku või veekindlat PVA-liimi (Penosil EN 2014/D3). Valmistatud laast- ja kiudplaatidega tehti erinevaid katseid, nagu tiheduse, pundumise, tõmbetugevuse, paindetugevuse ning õhuläbilaskvuse määramine.

Katsete tulemustest võib järeldada, et kuivmeetodil valmistatud kiudplaadid on tugevamad ja vastupidavamad kui märgmeetodil valmistatud. Kuivmeetodil valmistatud plaatide ainus puudujääk oli halb veekindlus, mis tuli välja pundumiskatsest, kus kuivmeetodil valmistatud katsekeha lagunes vees ära. Kanepilaastplaadid olid väiksema tiheduse ja väiksemate tugevusomadustega kui puitlaastplaadid. Katsetulemuste põhjal võib öelda, et kanepilaastplaadid sobivad kasutamiseks ehitusmaterjalina.