WOOD RESEARCH doi.org/10.37763/wr.1336-4561/69.2.337347
e-ISSN 2729-8906
69(2): 2024 337-347 pp.

LIGNOCELLULOSIC LINERS BASED ON WOOD WOOL

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(RECEIVED MARCH 2023)

ABSTRACT

Basic physical and mechanical properties of lignocellulosic liners up to 1.5 mm thick with a compact and non-crumbling surface based on wood wool and thermoplastic water based glues were determined. PVAc and starch glue with a high proportion of water content were used. The dry mat was pressed gradually under high pressure up to 28 MPa and a temperature of around 190°C with the release of steam. Tests according to the CEPI (Confederation of European Paper Industries) standards were adopted. Procedures for tensile strength according to ISO 1924-2 (2008), Burst strength according to ISO 2758 (2014), puncture according to ASTM D781-68 (1973), water absorption according to ISO 5637 (1989) and porosity according to TAPPI Test method T460 were applied.

KEYWORDS: Lignocellulosic liners, spruce, wood wool, physical-mechanical properties, PVAc, starch, pressing diagram, tensile strength, Burst index, puncture test, water absorption, thickness swelling, porosity.

INTRODUCTION

Wood wool fulfills mainly additional functions in packaging, filling gaps, and filtering or animal bedding in practice, but despite the chemical incompatibility between wood and cement, wood-cement composites are now being investigated, mostly in the form of panels because of its excellent exterior properties (Na et al. 2014). Wood-wool cement panels are environmentally friendly sound absorbers or insulation with suitable mechanical properties.

Self bearing panels were created at bulk densities of 400 - 600 kg/m^3 (Jafari et al. 2023, Ārgalis et al. 2024, Zhou et al. 2024).

Currently, when the issue of wood recycling is highly up to date (Ihnat et al. 2020, Lübke et al. 2020), the recycling potential of thin-walled wood fractions is considered only marginally. Recycling wood waste in the form of wood wool in cement composite materials appears as a promising solution according to Berger at el. (2020). Tsapko et al. (2019) used low quality pine for wood wool production for soundproof composites. Ihnát et al. (2024) suggested valorization of wood waste in the form of wood shavings for LC liners.

Thin lignocellulosic (LC) liners made from shavings were presented as a less valuable alternative to veneers made of high-quality wood (Ihnat et al. 2024). LC liners represent wood-based semi-finished products for further use in the production of honeycomb boards, fluting, lightweight wood-based composites and are also interesting for the creative and model making industry. A significant advantage is their easy handling and formatting and full recycling. LC liners resemble thick liners made either on the basis of semi-chemical pulp or recycled paper (Adamopoulos 2006). The strength of LC liners is ensured by the addition of water based thermoplastic glues. The amount of 5-20% PVAc or starch glue is added in the form of a min 30% aqueous solution, which results in a better dispersion of the glue on the surface of the wood particles. The high viscosity of urea-formaldehyde adhesives makes their application difficult (Kowaluk and Fuczek 2009) and also the water content occurring in the adhesives is necessary for the rapid creation of steam at a temperature of around 190□-200□. Pressurizing over 25 MPa ensures a higher volumetric weight and smooth surface, the liner does not crumble during handling. Pressing is short-term because the hot softened liner no longer springs and its hardening takes place under a pressure of 13 MPa in a cold press (Lubke and Ihnát 2023).

The aim of this study is to prepare LC liners based on wood wool and determine their basic physical and mechanical properties. Since it is a thin and flexible material, the test methods applied were those as the ones used for testing paper liners.

MATERIAL AND METHODS

Preparation of test samples

Commercial wood wool made of spruce (*Picea excelsa* L.) was used for laboratory samples preparation. In the first step, the wood wool was cut on a knife chopper so that the length of the individual particles was no longer than 2-4 cm. Small particles and dust were removed through a sieve 2 mm x 2 mm. The wood wool was dried for 24 h at a temperature of 103°C to a moisture content of 3%. Average thickness of fractions was determined using a Lorenton and Wettre (SE) thickness gauge on 0.202 mm with standard deviation 0.034 mm. A representative sample of 60 particles was selected from the individual fractions. The width of the individual particles was around 2 mm, which was determined by the production equipment.

PVAc Duvilax glue diluted with water was used to prepare the adhesive mixture (33% a.d.). Starch adhesive mixture (33% a.d.) was prepared of ECO 2777 (Allied solutions, HU) with characteristics of used starch agents (medium charge density and medium molecular weight and low cross-linker level).

The liner sheets of weighing 100 g a.d. were formed by layering in the form of 355 mm x 275 mm (Tab. 1). The thickness of the layered mat after manual compaction was approximately 10 mm. Care was also taken to ensure that as little time as possible passed from the application of the adhesive mixture, through the mixing and layering of the pressed mat to the closing of the press.

Tab. 1: Samples of LC liners made of wood wool. Recipe for the preparation.

No	**Format size**	**Total sample weight a.d.**	**Glue content a.d.**	**Glue used**	**Pressing temperature**	**Press diagram** (Fig. 1)
1.	355 mm x 275 mm	100 g	10%	PVAc	190□	prepressing to 2 MPa for 1 min + increasing pressure on 28 MPa and **immediately release pressure** + cold press 13 MPa
2.				starch		

Press diagram

LC liners were pressed in a press with plates heated to 190□. Flat pressing uses multi-stage compression and pressure release associated with the release of steam, which could cause tension defects in the cross-section (Xu et al. 2003). Pressing took place without delimiting pads. Cooling was part of the pressing cycle. The pressing cycle is shown in Fig. 1. Conditioning of LC liners was carried out in a specialized room at a temperature of 23□ and 55% relative humidity for 7 days.

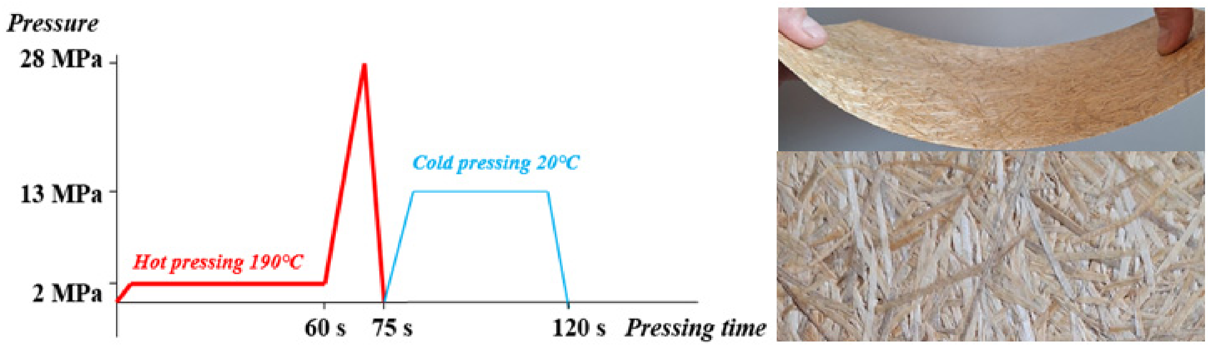


Fig. 1: Pressing diagram of the preparation of LC liners made of wood wool.

Test methods

LC liners are characterized by their small thickness and flexibility, thus it is not possible to use most of the usual procedures for testing of wood-based board materials, which show high stiffness and, on the contrary, low flexibility (Ihnat et al. 2024). Therefore, tests according to CEPI standards were chosen to determine the physical-mechanical properties. Procedures for tensile load according to ISO 1924-2, 2008, Burst strength according to ISO 2758 (2014), water absorption according to ISO 5637 (1989), puncture according to ASTM D781-68 (1973) and porosity according to TAPPI Test method T460 were applied.

Thickness measurement and determination of basis weight

A Lorentzen and Wettre (SE) digital device was used to measure the thickness. The thickness (mm) was measured and recorded at the marked points, where the properties (non-destructive porosity and destructive pressure and puncture) were later measured. The thickness of the 15 mm x 160 mm test strips intended for tensile strength was measured in the center for each sample separately. The other sheets were weighed as a whole, similar to the thickness measurement. The basis weight (g/m^2) was defined as the proportion of weight per square meter. Cutting of LC liners was performed by simple trimming.

Measurement of tensile strength, Burst strength and puncture

The tear strength measurement was performed on an INSTRON model 1011 device with a displacement of 10 mm/min and a distance between the clamps of 100 mm. The test samples were made to a size of 15 mm x 160 mm. The device records the force required to tear the test specimen (N) and the relative elongation of the specimen to tear (%). The tensile strength for the sample (jaw spacing 100 mm) based on 1 m length is then determined according to Eq. 1. Tensile index is expressed as the ratio of market strength and surface weight.

Tensile strength (N/m) = Force recorded (N) / Sample width (0,015 m) (1)

Tensile index (Nm/g) = Tensile strength (N/m) / Basis weight (g/m^2) (2)

A Lorentzen & Wettre Burst-O-Matic (SE) device was used to determine the Burst strength. The device is set according to ISO 2758: 2014 Paper. Determination of bursting strength. This international standard specifies a method for measuring the Burst strength (breakthrough) of paper subjected to increasing hydraulic pressure on a small circular area pressed by a membrane. It can be used for paper in the range of 70 kPa to 1,400 kPa. The device measures and directly records Burst strength (kPa), which is defined as the ratio of Burst strength and surface weight:

Burst index (kPa.m^2/g) = Burst strength (kPa) / Basis weight (g/m^2) (3)

The Lhomargy puncture tester was used to measure the puncture (J) according to ASTM D781-68 (1973): Standard test methods for puncture and stiffness of paperboard and corrugated and solid fiberboard. The device is originally designed to measure the energy required to punch through corrugated cardboard using a punching head in the shape of a bent triangular needle attached to a fixed arm that moves in an arc under load.

Measurement of Gurley porosity

Densometer Lorentzen & Wettre (SE) was used to measure porosity (s) set according to TAPPI Test method T460 om-02 Air resistance of paper (Gurley method). This method is used to measure the air resistance of an approximately 6.45 cm^2 circular area of paper using a pressure difference of 1.22 kPa. The recommended range of a liquid column instrument is from 5 to 1800 s per 100 ml cylinder volume.

Water absorption and thickness swelling determination

Water absorption was determined according to ISO 5637 (1989) Paper and board. Determination of water absorption after immersion in water. The weight of the sample measuring 100 x 100 mm was initially weighed (m_0) and immersed in water for 10 s. After 2 min, the sample was weighed (m_1). Water intake was determined according to Eq. 4. Also, thickness swelling was determined according to Eq. 5 after conditioning the samples at temperature of 23□ and 55% relative humidity until the weight stabilizes:

$$\text{Water absorption (\%)} = m_1 - m_0 / m_0 * 100 \quad (4)$$

$$\text{Thickness swelling (\%)} = h_1 - h_0 / h_0 * 100 \quad (5)$$

where: m_0 – weight of the sample after conditioning in an environment of 23°C and 55% RH (g), m_1 – weight of the sample after soaking for 10 s and draining excess water for 2 min (g), h_1 – thickness of the sample after water soaking (mm), h_0 – initial thickness of the sample (mm).

RESULTS AND DISCUSSION

LC liners valorize less valuable wood or waste wood, which is first transformed into a thin fraction. Wood shavings, or as in this case, wood wool, come into consideration. Similar thick paper liners can be produced from wood waste, but using chemical methods, for example, by partial removal of lignin (Balberčák et al. 2017, 2018). Unlike paper liners, the strength of LC liners is significantly dependent on the adhesive used and its content in the mat. Water-based thermoplastic adhesives have been applied so far (Ihnát et al. 2024). This is also due to the fact that water from the glue is used to turn it into steam and due to the pressing method, which also uses cooling (Lübke and Ihnát 2023).

Thickness and basis weight

The pressing method allowed to prepare samples with uneven thickness using a laboratory press. The thickness ranges approximately from 0.9 to 1.8 mm (Fig. 2), while the mean thickness was 1.311 mm (St dev = 0.177 mm) for PVAc and 1.384 mm (St dev = 0.180 mm) for starch adhesive used.

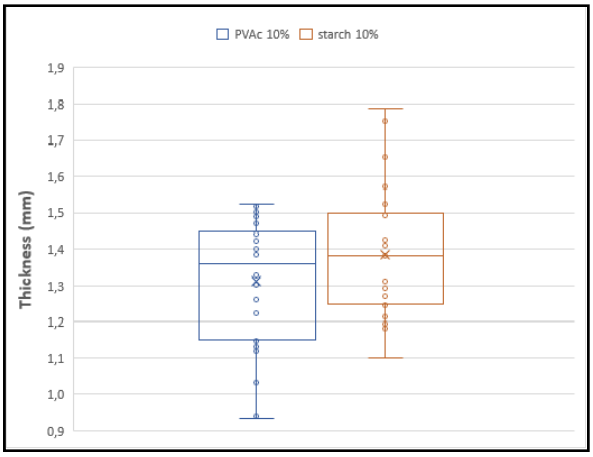


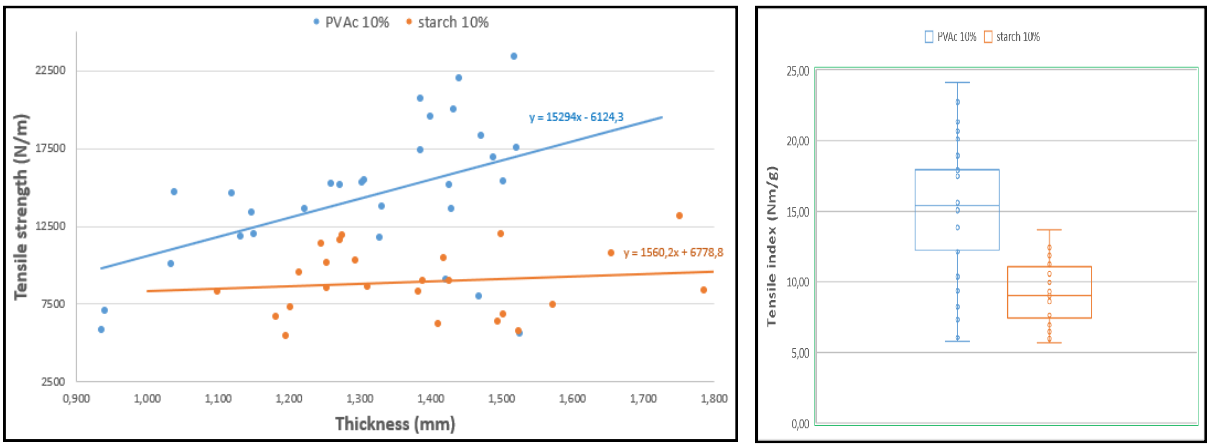
Fig. 2: Thickness of prepared LC liners based on wood wool.

A basis weight of 970 g/m^2 for 10% PVAc adhesive content, and 960 g/m^2 for the starch adhesive was achieved. For comparison the thickness of paperboards is usually in the range of 0.2-1.0 mm and their grammage varies from 120 – 700 g/m^2.

Ihnát et al. (2024) prepared LC liners based on wood shavings with PVAc glue with the mean thickness of 1.386 mm at the basic weight of 1021 g/m^2. Individual shaving particles with thickness in the range of 0.453-0.540 mm were used for their preparation. In this study, the average thickness of individual wood wool particles was determined to be 0.202 mm, which is half of the thickness of the shavings in our previous research. The use of wood wool seems to be more advantageous from this point of view, since there is a greater overlapping of the wood material in the cross-section. Siegel et al. (2023) stated that wood wool from a thickness of 0.2 mm reaches the mechanical properties of solid wood, the authors focused on birch and spruce wood. Generally, the thickness of wood particles depends on their fiber characteristics (Ihnat et al. 2021).

Tensile strength

Fig. 3 shows the dependence of tensile strength on the thickness of liners. A more significantly rising character of the regression line describes better strength properties of LC liners when using PVAc adhesive compared to starch adhesives. An almost linear course of the regression line when using the starch adhesive indicates that the amount of 10% starch a.d. is minimal in terms of strength of final liners (Fig. 3a).



a) *b)*

Fig. 3: a) Dependence of tensile strength on the thickness of LC liners and adhesive type, b) tensile index of LC liners based on wood wool.

Tensile index parameter was defined to compare thin materials with different thicknesses while taking into account the basic weight (Fig. 3b). The average values of the tensile indexes were 14.87 Nm/g (St dev = 4.67 Nm/g) for PVAc glue and 9.31 Nm/g (St dev = 2.23 Nm/g) for starch glue, at the 10% glue content. The measured tensile index is higher than in case of shaving liners (8.44 Nm/g) (Ihnát et al. 2024), but 8 to 13 times lower, depending on the glue used, than the values measured for tissue papers (Balberčák and Kuňa 2024).

Evaluation using the tensile index is suitable for thin materials where the basic weight (grammage) or volume unit is decisive. If the tensile strength calculation is related to the cross-section, then Eq. 1 is modified to Eq. 6. The tensile strengths calculated in this way (Tab. 2) reach values 10,95 MPa for PVAc glue and 6,55 MPa for starch glue (Tab. 2).

Tensile strength (MPa) = Force recorded (N) / Sample width x Sample thickness (mm) (6)

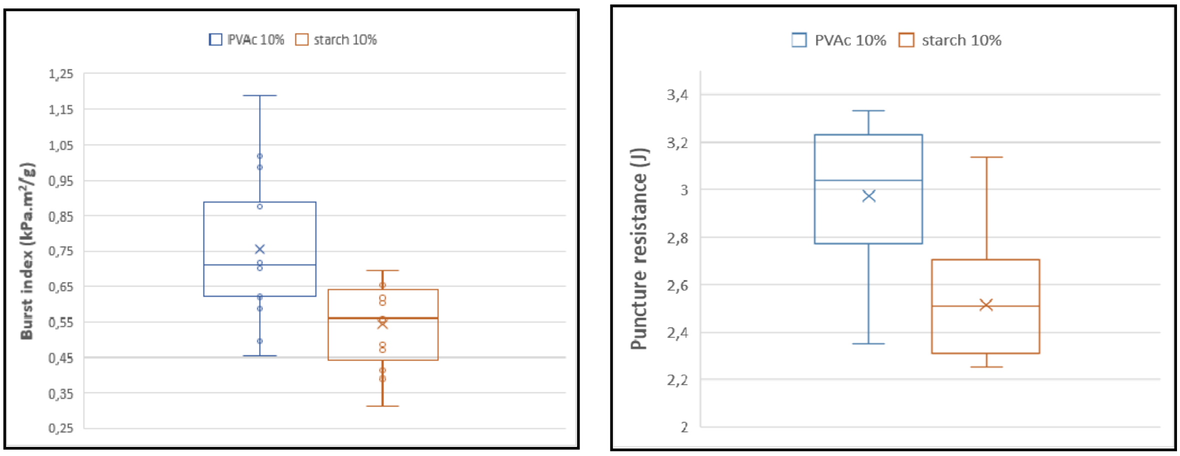
Tab. 2: Tensile strength of LC liners made of wood wool (average values) according to Eq. 6. Sample width = 0,015 m.

PVAc content (a.d.)	PVAc 10%	starch 10%
Tensile strength (MPa)	10,95	6,55
Standard deviation	2,90	1,65

Burst index and puncture resistance

The graph in Fig. 4a shows that the Burst index of PVAc liners is significantly higher than that with glued with starch glues. The average values are 0.76 kPa.m^2/g (St dev = 0.2 kPa.m^2/g) for PVAc and 0.54 kPa.m^2/g (St dev = 0.12 kPa.m^2/g) for starch glue. The Burst index of liners based on wood wool is over 50% higher than that based on shavings (Ihnát et al. 2024).

The average puncture resistance of liners based on PVAc glue is 2.97 J (St dev = 0.27 J) and 2.51 J (St dev = 0.26 J) for liners based on starch glue (Fig. 4b). The puncture resistance was nearly 2 times higher than it was with liners based on shavings using the same PVAc glue content. The puncture resistance strongly depends on the amount of glue in the mat, the minimum amount was used, which is 10%, in this case. The energy required to break through the LC liner correspond to the values measured by Bivainis and Jankauskas (2015) for 5 layered cartons weighing 580-630 g/m^2.



a) b)

Fig. 4: a) Burst index, and b) puncture resistance of LC liners based on wood wool.

Gurley porosity

The principle of the Gurley measurement is to push air through cross-section of a sample, that is, the more compact the cross-section (without internal defects), the longer the time. Gurley values are evaluated in seconds. Porosity expresses the compatibility of the cross-sectional structure of the LC liner. Porosity and also other mechanical properties were measured on parts of the samples that did not have visible defects in the structure (Kuňa et al. 2021). It was detected optically against the light, while the defect in the internal structure of the cross-section of the LC liner was marked. The average values for Gurley porosity high variability at 14.0 s (St dev = 11.1 s) for the 10% of PVAc glue content and 5.1 s (St dev = 4.5 s) for the 10% of starch glue content (Fig. 5). Very low values indicate high porosity, values are 8 times smaller than for liners made from shavings (Ihnát et al. 2024). The porosity of LC liners based on wood wool would be even higher if the individual particles were not cut to a length of 2-4 cm before pressing the mat.

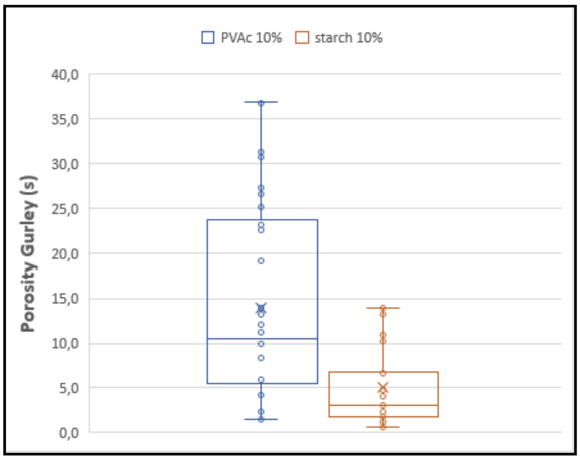
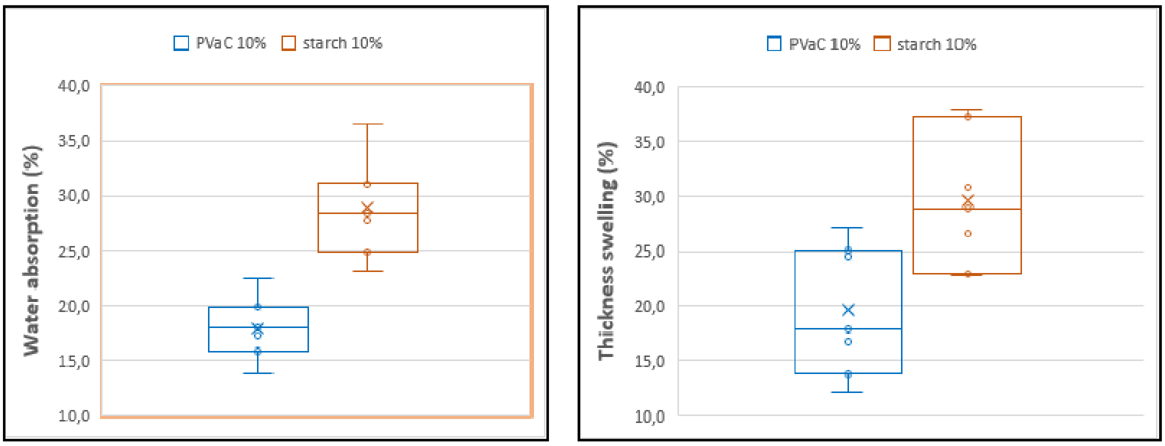


Fig. 5: Gurley porosity measured on LC liners based on wood wool.

Water absorption

Water absorption values represent the amount of water taken up by 10 x 10 cm samples during 10 s immersion in water. Water absorption is calculated as absolute, that is, with respect to the initial mass m_0 according to Eq. 4. The average value of water absorption of the samples based on wood wool were 17.8% (St dev = 2.8%) for PVAc glue and 28.9% (St dev = 4.5%) for starch glue (Fig. 5b). If we do not take into account the starch glue, whose resistance to water is generally low, the average value of water absorption for the same content of PVAc glue was 38% higher than that of LC liners based on shavings (Ihnát et al. 2024).



a) b)

Fig. 6: a) Water absorption, and thickness swelling of LC liners based on wood wool.

Although a short term 10 s immersion in water still causes a thin composite glued with starch glue, significant damage to the surface, which is associated with significant thickness swelling 29.6% (St dev = 6.2%) (Fig. 6b). PVAc based LC liners are more durable after soaking in water, and thickness swelling is significantly smaller 19.6% (St dev = 5.9%). Thin wood fractions as well as straw used to create composite materials generally have a low resistance to moisture (Lübke et al. 2014). Mitigating the effects of moisture damage is possible through heat treatment before pressing into mats (Ihnát and Lübke 2023).

CONCLUSIONS

To determine the basic physical and mechanical properties of LC liners made of wood wool was the aim of the article. Test methods according to CEPI standards were chosen due to thin cross sectioned flat material. Characteristic values (average testing values) are listed in Tab. 3.

Tab. 3: Mechanical and physical properties of LC liners made of spruce wood wool (average values).

Glue used	**PVAc**	**Starch glue ECO 2777**
Content of PVAc (a.d.)	10%	10%
Average thickness (mm)	1.311 (0,177)	1.384 (0.180)
Basic weight (g/m^2)	970	960
Tensile index (Nm/g)	14.87 (4.67)	9.31 (2.23)
Comparative tensile strength values (MPa)	10.95	6.55
Burst index (kPa.m^2/g)	0.76 (0.2)	0.54 (0.12)
Puncture resistance (J)	2.97 (0.27)	2.51 (0.26)
Water absorption (%)	17.8 (2.8)	28.9 (4.5)
Thickness swelling (%)	19.6 (5.9)	29.6 (6.2)
Porosity (Gurley) (s)	14.0 (11.1)	5.1 (4.5)

*Standard deviations in brackets.

ACKNOWLEDGEMENT

This work was supported by the Slovak Research and Development Agency under contract No. APVV-21-0500.

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