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PROPERTIES OF HEMP SHIVE PANELS WITH DIFFERENT RESIN CONTENT

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Abstract: *Wood-based panels are one of the leading materials for frame structures of furniture. The worldwide shortage of wood raw materials necessitates searching for alternative sources to produce panels. Hemp shives are a representative of precisely this type of raw material. They are characterised by low bulk density and high fibre strength. For this study, four types of one-layered panels from hemp shives were fabricated in laboratory conditions, with a resin content of 8, 10, 12, and 14%, respectively. Accordingly, their main physical and mechanical properties were determined and compared to those of particleboards from raw wood material. It was found that the obtained panels from hemp shives have very good mechanical properties, and their high edge screw withdrawal resistance is very promising in terms of applicability for furniture constructions. As a direct result of these findings, the resin content is not recommended to be above 10%.*

Key words: *one-layered particleboard, hemp shives, physical and mechanical properties, urea-formaldehyde resin, melamine-formaldehyde resin.*

1. Introduction

Wood-based panels are the most used materials for furniture production and furnishings, and it should be emphasised that particleboards are dominant in Europe. Thus, according to FAO data, in 2022 [11], the amount of particleboards produced was 105 mil. m^3, and for the same year, the production in Europe was close to 44 mil. m^3, or 42% of the entire quantity. That predetermines the growth in the production of this material, which, in turn, is accompanied by increasing deforestation worldwide [11]. That suggests the need to search for an alternative raw material for this industry.

In general, small-sized wood is used in the production of particleboards. Still, one of the advantages of this type of wood-based panel is the possibility of including non-wood lignocellulosic raw materials, which are most often residues from the agricultural industry [2, 4, 13, 27]. Such residues are cornstalks, vine stalks, hemp shives, flax shives, etc. It should be emphasised that these agricultural residues are characterised by a significant

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diversity of their properties (fibre strength, chemical composition, etc.), which also leads to a different possibility of their applicability as a raw material for the production of particleboards [12, 15, 17, 19]. It should be said that now, due to the use of hemp plants for cosmetic and other pharmaceutical needs, a significant increase in this type of plantation has been observed.

Hemp shives have a high mechanical strength of fibres and a low bulk density of particles. These two characteristics make them very promising for producing panels for the furniture industry [2, 3, 14, 20, 23]. This implies an interest in studying the properties of panels from hemp shives.

2. Materials and Methods

For the purpose of the study, panels were fabricated from hemp shives with different resin content in laboratory conditions (Table 1). Their properties were compared with laboratory-produced particleboards and industrially-produced wood particleboards (PB). Accordingly, hemp shive (particles and approximately 1.5% short fibres) panels had resin contents as follows: 8, 10, 12, and 14%. The hemp shives were industrially produced by the company "La Chanvrière", France.

A control particleboard with 10% resin content was also produced. Wood particles industrially produced by "Kastamonu-Bulgaria" were used to fabricate the reference panel. Particles were from mixed raw materials - 70% softwood (Scot pine and spruce) and 30% hardwood (beech and Turkish oak). Given previous research on producing one-layered particleboards, a resin content of 10% was determined as optimal [18].

The moisture content of the hemp shives and the wood particles was similar – 12 and 11%, respectively.

Experimental plan Table 1

Panel type	Target density, ρ [kg.m^{-3}]	Resin content relative to dry shives [%]
Hemp 8	650	8
Hemp 10	650	10
Hemp 12	650	12
Hemp 14	650	14
REF 10	650	10

The adhesive system to produce the panels was composed of 90% urea-formaldehyde (UF) resin and 10% melamine-formaldehyde (MF) resin. It is a standard adhesive composition for wood-based panels for use in humid conditions [4, 6, 14]. The resins have the following parameters: 1) UF resin – molar ratio 1.07; dry content 50%, dynamic viscosity 23.76 ± 0.52 MPa.s.; 2) MF resin - molar ratio 1.76; dry content 54%; dynamic viscosity 21±0.76 MPa.s.

As a hardener, ammonium sulfate was used in a content of 2% relative to the dry resin. Ammonium sulfate was introduced as a solution with a concentration of 30%.

Wax (paraffin emulsion) was used as a waterproof substance. The wax content relative to the dry particles was 0.5%, and the emulsion was introduced at a concentration of 50%.

A laboratory blender with needle-shaped paddles and a rotation frequency of 400 rpm was used for gluing. The adhesive system was sprayed through a nozzle with a diameter of 1.5 mm and at a pressure of 0.4 MPa.

The panels had the following dimensions: length – 40 cm, width – 40 cm, and thickness 16 mm. A laboratory hydraulic press, PMC ST 100, Italy, was used to fabricate the panels. Hot-pressing was carried out at a temperature of 175°C. The hot-pressing regime consisted in three stages: First stage – pressure 4.0 MPa and time of 1 min; Second stage – pressure 1.2 MPa and time of 1 min; Third Stage – pressure 0.6 MPa and time of 14 min. The press factor was 60 $s.mm^{-1}$. This regime of hot-pressing was determined based on previous studies to fabricate particleboards with a similar moisture content of the particles [16, 18, 23, 26].

The physical and mechanical properties of the panels were determined according to the standard methods defined by the relevant EN as follows – density EN 323:2001 [9], thickness swelling EN 317:1998 [7], modulus of elasticity (MOE) and bending strength (MOR) EN 310:1999 [5], internal bond (IB) strength EN 319:1993 [8], formaldehyde content EN ISO 12460-5: 2015 [10]. A universal testing machine, WDW – 50E, manufactured by the HST company, China, 2022, was used to determine the mechanical properties of the panels. The density profile of the panels was established by GreCon DENSITYPROFILER, Fagus-CreCon, Alfeld, Germany.

The properties of the panels were determined on eight test samples, and the main statistics - average (main value), standard deviation, coefficient of variation, probability, and confidence interval were determined.

3. Results and Discussion

3.1. Fractional Composition

Due to the significant importance of this property [22, 25], the fractional composition of the hemp shives and wood particles was determined, and the results are presented in Figure 1.

When analysing the fractional composition of the hemp shives and wood particles, the shives had a significantly more uniform composition, with the main amount of particles having a length in the range of 2.0 ÷ 4.0 mm. These are also the fractions with the larger presence of wood particles. However, longer particles (fraction 6.3 ÷ 4.0) were also observed in the hemp shives, while in the wood particles, the third largest fraction was 0.5 ÷ 0.2 mm. A great advantage as a raw material to produce particleboards is that hemp shives have a bulk density of 90 $kg.m^{-3}$. For comparison, in the case of wood particles, the value of this indicator is 150 $kg.m^{-3}$. This means that at the same target density of the particleboards, the panels from hemp shives will have a compression ratio 1.6 times higher than the panels from wood particles. That will lead to a significant reduction in the porosity of the panes and an increase in the adhesive and cohesive bonds in them.

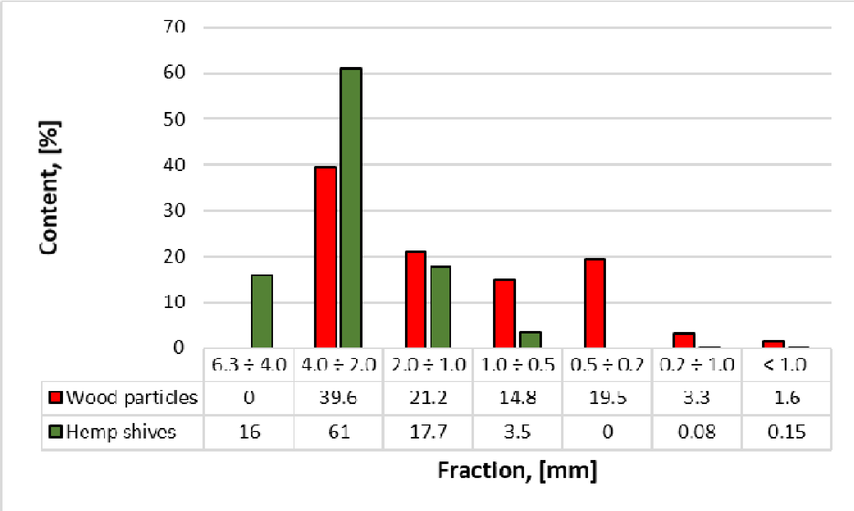


Fig. 1. *Fractional composition of hemp shives and wood particles*

3.2. Density

The results for the density of the fabricated panels and the main statistics are presented in Table 2. The moisture content of all panels was in the range of 5 to 6%.

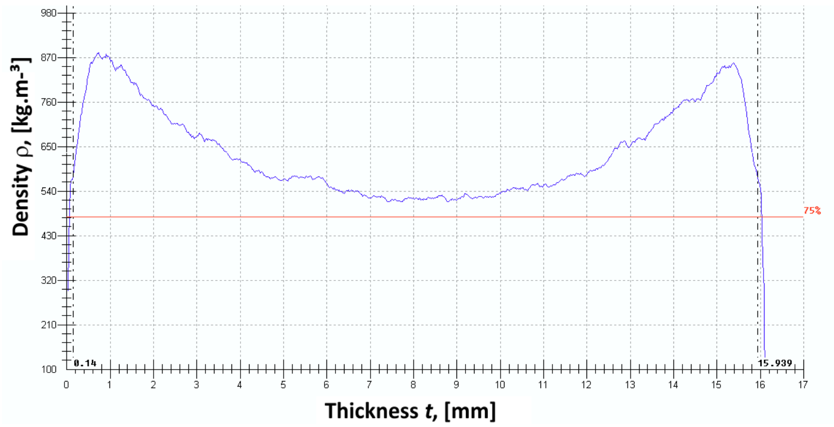
The densities of the panels were close to the target one of 650 kg.m^{-3}, and the maximal difference between the densities of individual boards is 1.8%, or within the limits of statistical error. That suggests that this property should not affect the other physical and mechanical characteristics, and the differences in these properties are due to the raw material used and the resin content.

Density of experimental panels Table 2

Panel type	Density, ρ [kg.m^{-3}]	Standard deviation, Sx [kg.m^{-3}]	Coefficient of variation, Vx [%]	Probability, Px [%]	Confidence Interval, Dx [kg.m^{-3}]
Hemp 8	660	18.34	2.78	0.88	649÷672
Hemp 10	662	24.04	3.63	1.15	647÷676
Hemp 12	661	16.35	2.47	0.78	651÷672
Hemp 14	659	24.41	3.70	1.17	644÷674
REF 10	671	32.08	4.78	1.51	651÷691

Figure 2 shows the density profiles of the panels.

The data on the density profile of panels from hemp shives show a relatively even distribution of this property, with the difference between the minimum and average density for hemp shive particleboards being 77 ÷ 80%. For wood particleboard, it is only 85%. Despite the uniformity of the materials used (production of one-layered particleboards), a characteristic U-shape profile of the panels is formed due to the more significant compression of the boards in the areas in contact with the hot-press plates. The more homogenous character of the wood particleboard compared to the hemp shive panels is distinguished. The more significant difference between the maximum and average density of the hemp shive panels should be reflected in improved MOE and MOR.



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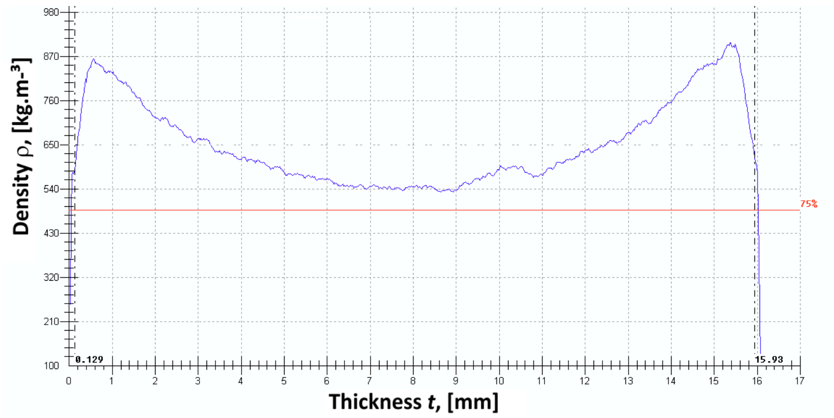

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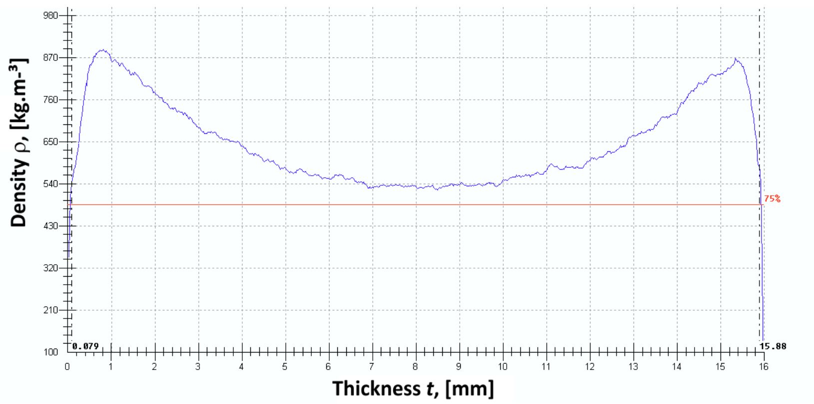

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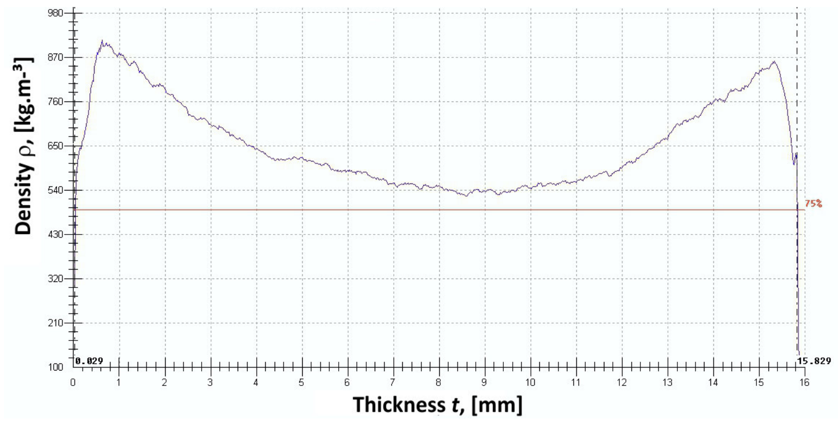

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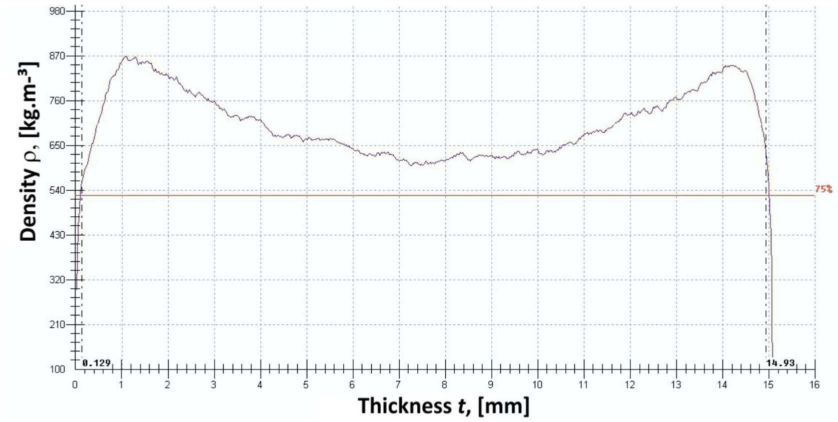

e.

Fig. 2. *Density profiles of panels from hemp shives and wood particles: a. Hemp 8 – panel from hemp shives with 8% UF resin; b. Hemp 10 – panel from hemp shives with 10% UF resin; c. Hemp 12 – panel from hemp shives with 12% UF resin; d. Hemp 14 – panel from hemp shives with 14% UF resin; e. REF 10 – panel from wood particles with 10% UF resin*

The data for the density profile of particleboards from hemp shives are also consistent with those reported in the study by Auriga et al. [3], the direct consequence of which is the good machinability of this type of panel.

3.3. Water Absorption and Thickness Swelling

The data on the water absorption of the panels are presented in Figure 3.

For hemp shive particleboards with increasing resin content from 8 to 14%, water absorption decreased by 1.63 times (63% improvement). The most significant improvement of 1.35 times was observed when the resin content increased from 12 to 14%. All panels fabricated from hemp shives had better (lower) water absorption than the control particleboard fabricated from wood particles and with 10% resin content. The data for the water absorption of the laboratory panels are also in accordance with those presented by Auriga et al. [2], where with an increase in the content of hemp shives in the particleboards from 0 to 25%, a decrease in water absorption of 1.1 times is reported. The data on the reduction of water absorption of the panels with increased resin content are also consistent with the research by Sarmin et al. [25]. In that study, a property decrease of about 1.2 times is reported when the resin content increases from 8 to 10%.

The data on the thickness swelling of particleboards are presented in Figure 4.

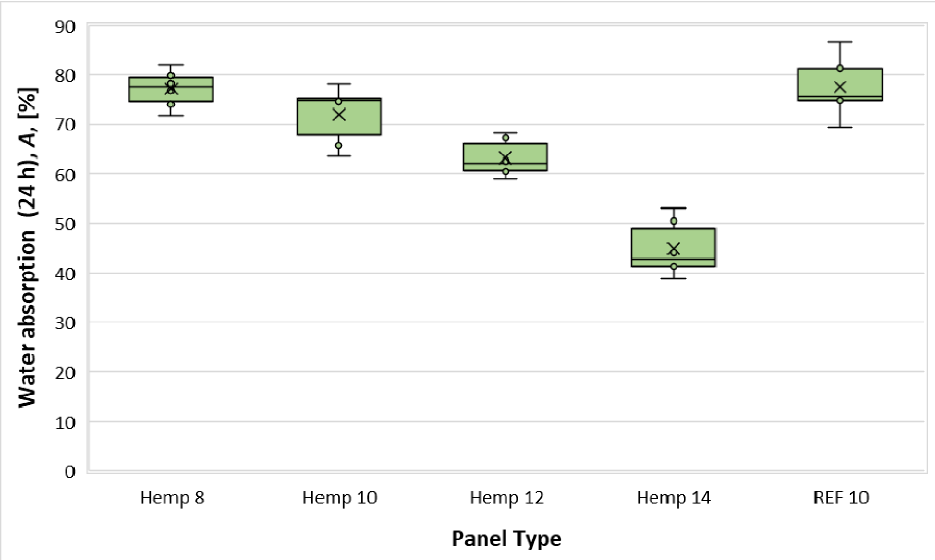

Fig. 3. *Water absorption (24 h) of the panels from hemp shives and wood particles*

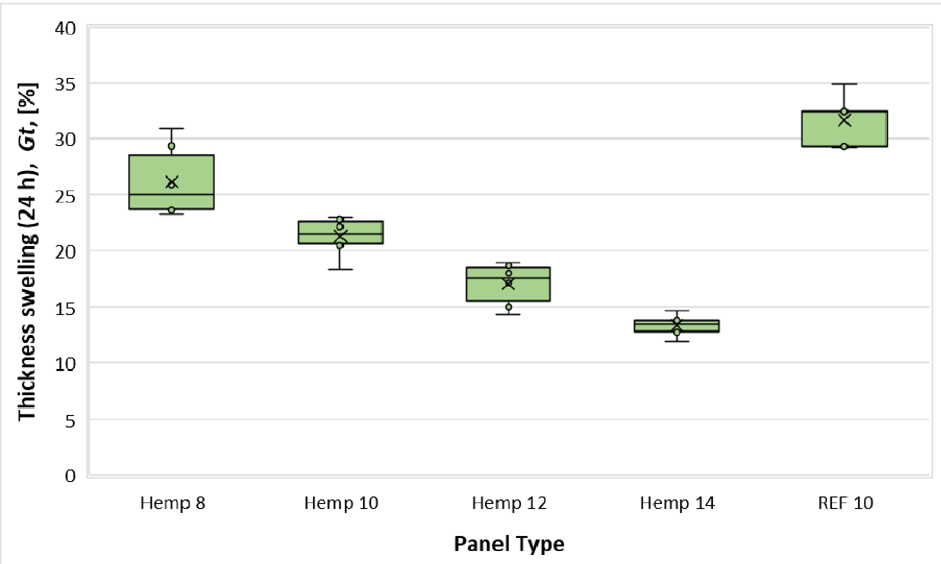

Fig. 4. *Thickness swelling (24 h) of the panels from hemp shives and wood particles*

The resin content significantly affects the thickness swelling of panels from hemp shives. When increasing the resin content from 8 to 14%, the thickness swelling decreases (improves) by 2.03 times. The panel with 14% resin content meets the requirements for particleboard type P3 (for application in humid conditions - maximum 13 %) [5].

Hemp shive panels have better (low)-thickness swelling than the control particleboard. Thus, the Hemp 10 panel has a 1.52 times lower thickness swelling than the experimental particleboard fabricated with the same resin content (panel type – REF 10).

Again, the trend of improvement in the waterproof properties of the panels, in this case, thickness swelling, is consistent with the data reported by Auriga et al. [2]. The cited research reported a decrease in thickness swelling by 1.16 times as the content of hemp shives increased from 0 to 25%.

The data on the improvement of thickness swelling with the increase of the resin content are in accordance with the studies by Asri et al. [1] and Sarmin et al. [25], where a decrease in the indicator is reported by 1.5 and 1.26 times, respectively.

3.4. Modulus of Elasticity (MOE) and Bending Strength (MOR)

The variation of the modulus of elasticity of the experimental panels is presented in Figure 5.

When the resin content increases from 8 to 14%, the modulus of elasticity of the panels from hemp shives increases by 1.27 times. All particleboards from hemp shives had a higher modulus of elasticity than the control particleboard from wood particles. The panel Hemp 10 has a 1.49 times better modulus of elasticity than the particleboard from wood particles with the same resin content.

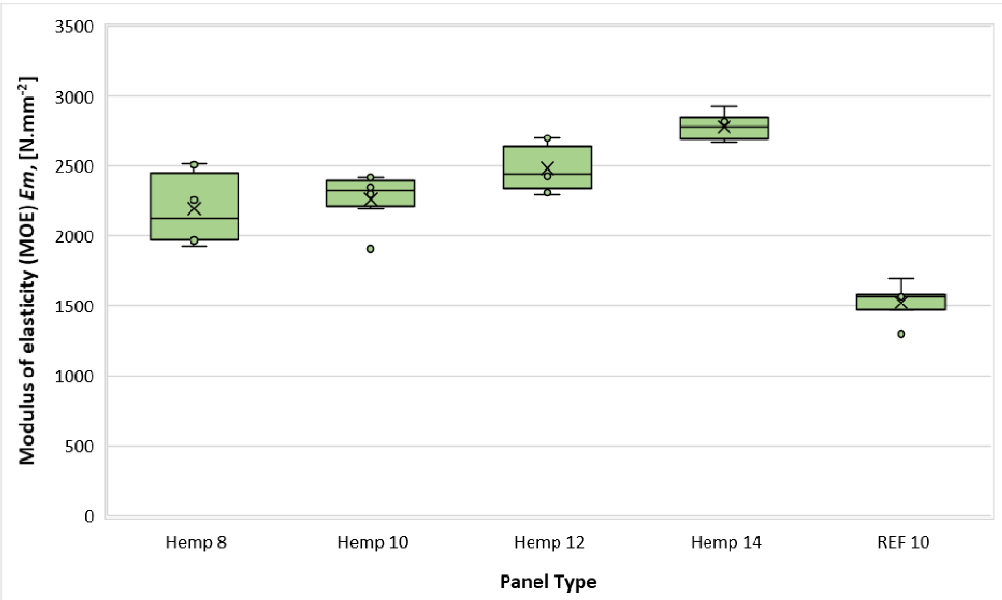

Fig. 5. *Modulus of elasticity (MOE) of the panels from hemp shives and wood particles*

All panels from hemp shives significantly exceed the standard requirement for the property for P2 particleboards - for furniture production - at least 1500 N.mm^{-2} [5].

The trend of improvement in the modulus of elasticity of the panels with increasing hemp shives content was also reported by Auriga et al. [2]. In this study, the modulus of elasticity increased by 1.17 times as the content of hemp shives in the composition of the boards increased from 0 to 25%.

The bending strength data of the hemp shive panels and the control particleboard are given in Figure 6.

As the resin content increases from 8 to 14%, the bending strength panels from hemp shives improve by 1.16 times. All particleboards from this raw material significantly exceed the requirements for the property for P2 particleboards (for furniture production) – at least 11 N.mm^{-2} [5].

All hemp shive panels had significantly higher bending strength than the control particleboard. The Hemp 10 panel has 1.86 times higher bending strength than the control particleboard made from wood particles and has the same resin content (10%).

Rimikenė et al. [22] reported similar bending strengths in hemp shive particleboards with a similar density but with a cornstarch binder. Auriga et al. [2] also reported an increase in the bending strength of the panels by about 1.18 times when the content of hemp shives in the particleboards rose from 0 to 25%.

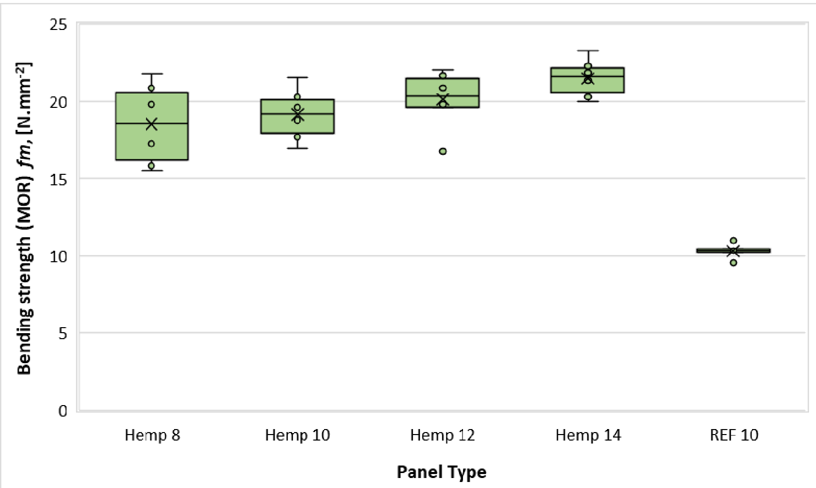

Fig. 6. *Bending strength (MOR) of the panels from hemp shives and wood particles*

The increase in MOE and MOR is also consistent with the findings of Asri et al. [1]. In this study, increasing the resin content from 8 to 10% led to an increase in MOE by 1.12 times and in MOR by 1.19 times.

3.5. Internal Bond

The variation of the Internal Bond (IB) strength of the panels is presented in Figure 7.

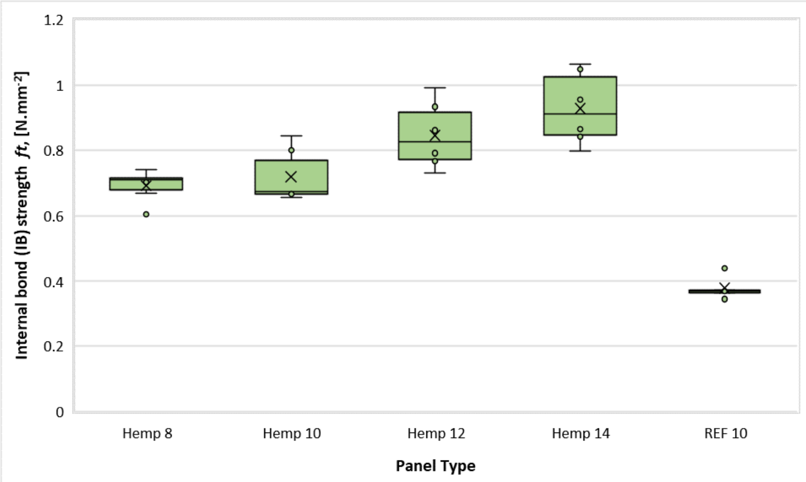

Fig. 7. *Internal Bond (IB) strength of the panels from hemp shives and wood particles*

In the hemp shive panels, as the resin content increased from 8 to 14%, the IB strength improved by 1.35 times due to the low bulk density of the raw material and the participation of short fibres in their composition.

A panel with 10% resin content has 1.95 times higher IB strength than a particleboard from wood particles with the same resin content.

The good IB tensile strength of the panels with or entirely composed of hemp shives is also confirmed in the studies by Reh and Vrtielka et al. [21], where values from 0.6 to 1.1 $N.mm^{-2}$ (depending on density and cornstarch content) are reported for these eco-friendly particleboards.

The IB strength is strongly affected by the resin content. The study of Asri et al. [1] also confirms that. In that study, an increase in the IB strength of 2.3 times was reported when the resin content was increased by 2%.

3.6. Screw Withdrawal

The data for screw withdrawal resistance - face (perpendicular to the broad side of the panels) are given in Figure 8.

As the resin content increased from 8 to 14%, the screw withdrawal resistance – face improved by 1.27 in hemp shive panels. All hemp particleboards have higher values of screw withdrawal resistance – face than both industrially produced and laboratory-fabricated wood particleboards. Hemp shive panels with 10% resin content have a higher value of this property.

The change in the screw withdrawal resistance - edge of the panels is presented in Figure 9.

In hemp shive panels with increasing resin content from 8 to 14%, screw withdrawal resistance - edge improved by 1.28 times.

All particleboards from hemp shives have significantly higher screw withdrawal resistance – edge than (laboratory or industrial produced) particleboards.

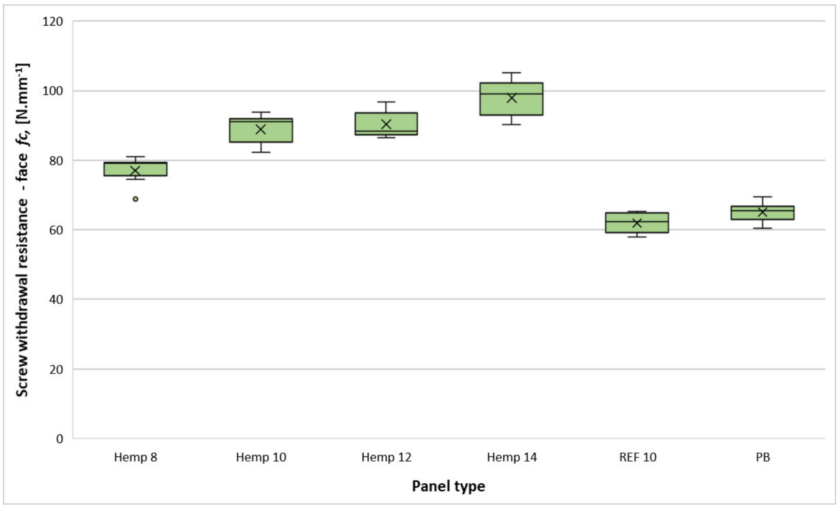

Fig. 8. *Screw withdrawal resistance – face of the panels from hemp shives and wood raw material*

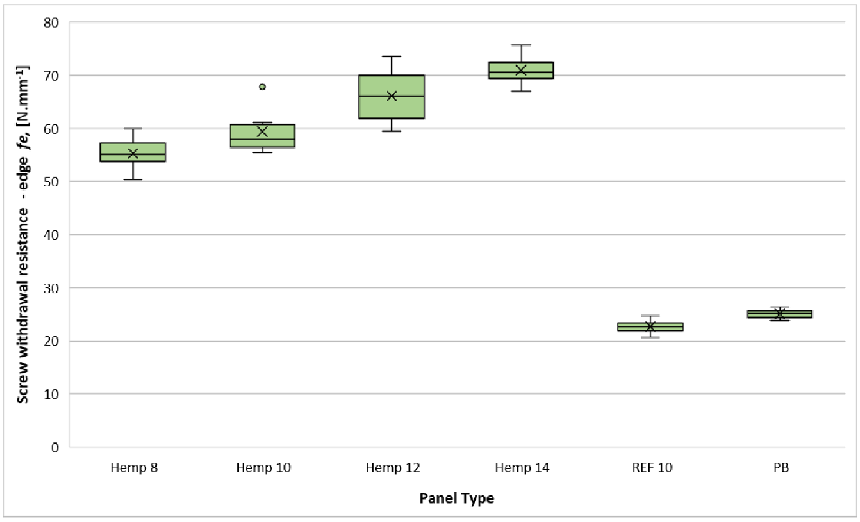

Fig. 9. *Screw withdrawal resistance – edge of the panels from hemp shives and wood raw material*

3.7. Formaldehyde Content

Figure 10 presents the free formaldehyde data of the hemp shive panels.

When the resin content increases from 8 to 14%, the formaldehyde increases by nearly 2.11 times. The most significant increase is observed when the resin content exceeds 8 to 10% - an increase of 1.51 times. The subsequent increase is with a smooth step of about 1.18 times. Panels with up to 12% resin content meet the requirements for emission class E1 (formaldehyde content ≤ 8 mg/100 g o.d.).

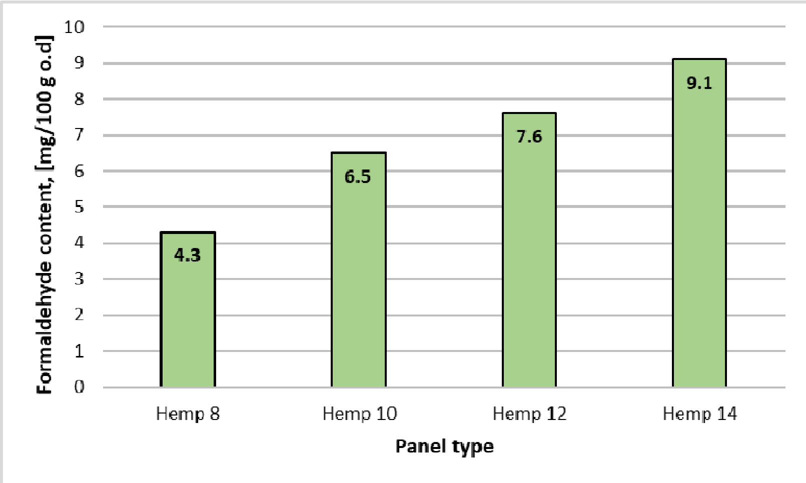

Fig. 10. *Formaldehyde content of the panels from hemp shives*

4. Conclusions

The fabricated experimental panels of hemp shives have very good physical and mechanical properties. These panels have significantly better properties than particleboards from raw wood material. That should be due to their low bulk density, high compression ratio, and fine fibres filling the pore space in the panels and increasing the contact area between the particles. Regarding their bending strengths and modulus of elasticity, panels from hemp shives are comparable to MDF, and they even surpass IB strength.

Due to the significant homogeneity of panels from hemp shives and the high compression coefficient, they have a better screw withdrawal resistance edge between two- and three times than industrially produced three-layered particleboards. In industrial particleboards, larger particles are used for the core layer, which is significantly less compressed and reflected in their screw withdrawal resistance – edge. The good screw withdrawal resistance-edge of hemp shive particleboards makes them particularly suitable for furniture production.

As a result of the conducted study, the resin content of the particleboards is not recommended to exceed 10% when used in dry conditions and up to 12% when used in humid conditions. Increasing the resin content to 14% will make the product more expensive, and the panels will have more considerable formaldehyde emissions.

Acknowledgements

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