

The influence of hemp fibers (*Cannabis sativa* L.) on selected physical and mechanical properties of MDF boards

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Abstract: *The influence of hemp fibers (Cannabis sativa L.) on selected physical and mechanical properties of MDF boards.* This study assesses the potential of hemp fibers (*Cannabis sativa* L.) as a sustainable partial substitute for wood fibers in MDF for furniture applications. Laboratory-made panels (16 mm thickness, target density 700 kg/m³) containing 1–25% hemp fibers were evaluated with respect to bending properties and internal bond strength in relation to EN 622-5 requirements. Based on estimated values derived from experimental plots, panels with 5 – 10% hemp fibers exhibited the most favorable performance. The modulus of rupture (MOR) reached approximately 29 – 31 MPa, while the modulus of elasticity (MOE) ranged from 3600 to 3700 MPa, remaining comparable to conventional MDF. The highest internal bond strength was observed at 5% hemp fiber content, reaching approximately 0.80 MPa, and values for panels with up to 25% hemp fibers remained within standard limits. These results indicate that low-level hemp fiber substitution enables a meaningful reduction of wood raw material consumption without compromising key mechanical properties. Further research should focus on enhancing moisture resistance and validating the performance of hemp-modified MDF under industrial manufacturing conditions.

Keywords: hemp fiber, *Cannabis sativa* L., MDF, medium density fiberboard, furniture

INTRODUCTION

The search for alternative sources of lignocellulosic raw materials is becoming increasingly urgent. Rising environmental awareness and the negative impacts of deforestation have highlighted the need for sustainable practices. To meet this new demand, the search for new, alternative sources of these raw materials is imperative. Recent studies have investigated various potential sources, including African couchgrass (Mbereyaho et al., 2020), kenaf (Das et al., 2015), oak (Çamlıbel et al., 2024), paricá wood and Amazonian wood waste (Ribeiro and Bortoletto Júnior, 2024), coconut fiber (Puspaningrum et al., 2020), water hyacinth (Hasan et al., 2020), almond shell powder (Nazerian et al., 2015) and eucalyptus (Krzysik et al., 1999). As an annual crop, hemp represents a sustainable and stable source of fibers for various sectors, ranging from cordage and construction to the manufacturing of composite panels (Lialina et al., 2024) or as a potential replacement for synthetic fibers (Raja, Yuvarajan, 2023). The utilization of hemp in the textile industry dates back to antiquity (Clarke, 2010).

In recent years, hemp fibers have been used in various research projects, including their application in composites for additive manufacturing, such as 3D printing (Tanikella et al., 2025). Boards made from a mixture of hemp fibers and hemp shives have also been fabricated in laboratory conditions (Savov et al., 2025). Furthermore, hemp fibers show significant potential in the construction sector such as gypsum fiber boards (Trociński et al., 2024) and insulation boards (Mirski et al., 2019).

Previous research on MDF panels made from a blend of hemp and wood fibers (Savov et al., 2019) – focusing on water absorption, thickness swelling and bending strength –

demonstrated the potential of hemp fibers as supplementary material. The results indicated that at low substitution levels, hemp fibers did not significantly alter the physic-mechanical properties compared to reference boards.

The growing demand for wood-based panels, combined with increasing pressure on forest resources, necessitates exploring alternative lignocellulosic raw materials for MDF production. Fast-growing annual plants such as hemp (*Cannabis sativa* L.) offer a renewable and stable fiber source with high mechanical strength and significantly shorter regeneration cycles compared to wood. The incorporation of non-wood fibers into MDF aligns with circular bioeconomy and resource-efficiency strategies by reducing dependence on virgin wood while maintaining functional performance. Therefore, investigating hemp fibers as a partial wood substitute represents a timely and necessary step toward more sustainable fiberboard manufacturing.

The findings of this study aim to broaden the understanding of composites incorporating hemp fibers as an alternative lignocellulosic raw material. The objective was to evaluate the effect of these non-wood fibers on selected physico-mechanical properties and to determine the suitability of the resulting composites for the furniture industry. Specifically, the study assesses whether these materials comply with the required standards for furniture boards. This practical evaluation constitutes the primary novelty of the present work.

MATERIALS AND METHODS

The following raw materials were used to produce the tested boards:

- Hemp (*Cannabis sativa* L.) fibers with a moisture content (MC) of approximately 4% (Kombinat Konopny S.A., Gronowo Górne, Poland).
- The industrial wood fibers typically used to produce dry-formed fiberboards, with a moisture content of approximately 4% and were primarily derived from pine wood (*Pinus sylvestris* L.), accounting for 95%.
- A commercial urea–formaldehyde (UF) resin, Silekol S-123 (Silekol Sp. z o. o., Kędzierzyn-Koźle, Poland), was used. It featured a molar ratio of 0.89 and a solid content of 66.5%. An aqueous ammonium nitrate solution served as a hardener.

The bonding mixture, comprising resin, the aqueous hardener, and distilled water in a 100:4:10 (w/w) ratio, had a viscosity of around 380 mPa·s. The adhesive cured at 100°C in 89 seconds. No hydrophobic agents were added during the board production process.

Hemp fibers were mechanically crushed to a length of about 5 – 50 mm in a laboratory drum mill with three knives and a sieve. The resulting material was dried to approximately 3% moisture. Bulk density was then measured for both the wood and hemp fibers, resulting in 22.1 kg/m³ for industrial fibers and 21.9 kg/m³ for hemp fibers.

MDF Board Production

Under laboratory conditions, 16 MDF boards with a nominal thickness of 16 mm, dimensions of 320 mm x 320 mm and a density of 700 kg/m³ were produced, in 8 different variants with varying mass content of hemp fibers relative to the total board weight: 0%, 1%, 5%, 10%, 25%, 50%, 100%, and a 3-layer board with outer layers of 100% hemp fibers (16% of mass – each side) called 100f. An air gun was used to apply adhesive to the particles in a laboratory blender. The resination was 12%, calculated as the dry resin weight divided by the dry weight of the fibers. A 2.0% aqueous ammonium nitrate solution was also used as a hardener, based on the dry resin content.

The press inserts were prepared manually and hot-pressed using a hydraulic press (AKE, Mariannelund, Sweden) at a maximum pressure of 2.5 MPa, a pressing temperature of 180 °C, and a press time of 20 seconds per millimetre of nominal panel thickness. Before testing, the panels were conditioned at 20 ± 1 °C and 65 ± 2% relative humidity until they reached a constant mass. After conditioning, the panels were calibrated by double-sided sanding on an

industrial sanding machine, Bulldog 3 (Houfek, Golčův Jeníkov, Czech Republic), to achieve the nominal thickness. Fig. 1 shows the temperature distribution on the surface and at the centre of the board over time for two selected boards: reference (0% hemp fibers) and 50% hemp fibers.

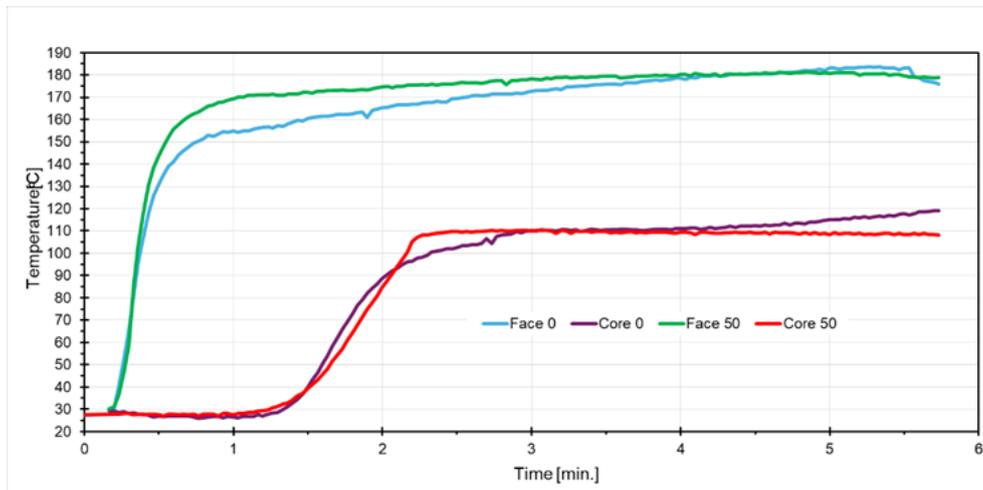


Figure 1. Temperature curves while pressing.

As a reference board, a board with zero hemp fiber content was made under the same conditions.

Mechanical and Physical Properties Tests

The manufactured boards were subjected to the following tests:

- Bending strength (MOR) and modulus of elasticity in bending (MOE) – according to EN 310:1993
- Tensile strength perpendicular to the plane of the board (internal bond – IB) – according to EN 319:1993
- Screw withdrawal resistance (SWR) – according to EN 320:2011
- Thickness swelling – according to EN 317:1993 standard
- Density profile

For the MOR and MOE tests, 10 samples were tested for each hemp fiber content variant. For the screw withdrawal resistance test, eight samples were tested. For both tests, the samples were measured for density (EN 323:1993). For thickness swelling, eight samples of each variant, measuring 50 x 50 mm², were used. The samples were measured after 2 and 24 hours of soaking. The density profile was measured using a Grecon DA-X device with a measurement step of 0.02 mm and a speed of 0.1 mm/s. Three samples were used for each variant; the graph shows the most representative profiles.

Statistical analyses

An analysis of variance (ANOVA) and t-test calculations were used to test ($\alpha = 0.05$) for significant differences between factors and levels, where appropriate, using IBM SPSS Statistics base (IBM, SPSS 20, Armonk, NY, USA). Where applicable, the mean values of the investigated features and the standard deviations are indicated as error bars on plots. The Results and Discussion section presents the statistically significant differences identified following data evaluation. The letters “a”, “b”, “c”, etc., in Table 1 indicate statistically homogenous groups.

RESULTS AND DISCUSSION

The graph in Fig. 2 presents the modulus of elasticity (MOE) values for the tested panel variants. Variants containing 1% to 10% exhibited no significant decrease in stiffness compared to the reference board. However, further increases in the hemp fiber content led to a progressive decrease in this value. The highest MOE value was recorded for the board with 10% hemp fiber

content, while the lowest was observed for the 100% hemp fiber panel. With the exception of the 100% hemp fiber variant, all panels meet the requirements of EN 622-5:2009 standard.

A similar trend was reported for panels containing coir (Mahzan et al., 2010). The three-layer boards exhibited MOE values intermediate between those of single-layer boards with 50% and 100% hemp fibers. The reduction in MOE observed at elevated hemp fiber contents can be attributed to changes in the elastic response of the fiber network. While individual hemp fibers exhibit high stiffness, their limited flexibility and lower bonding efficiency within the composite structure may reduce the overall panel rigidity. As a result, the effective elastic continuity of the fiber matrix decreases, leading to lower macroscopic stiffness despite comparable density profiles.

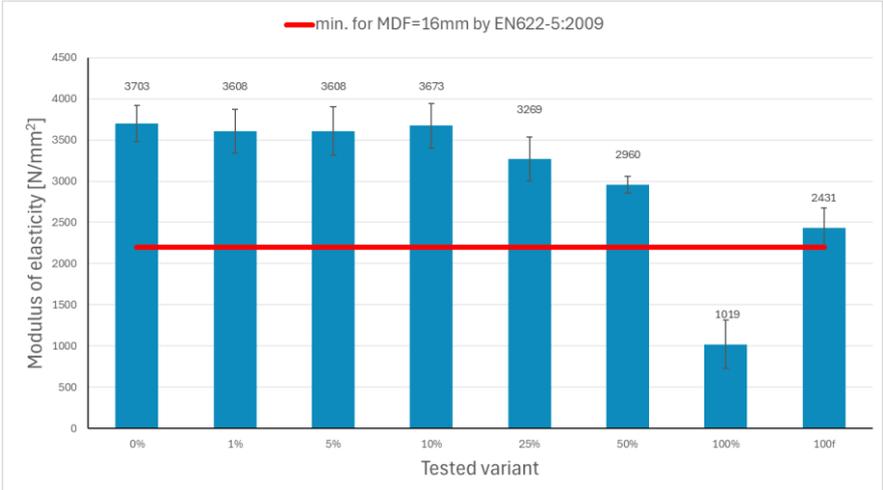


Figure 2. Modulus of elasticity of investigated panels.

The graph in Fig. 3 shows the bending strength (MOR) curves for boards with different hemp fiber content.

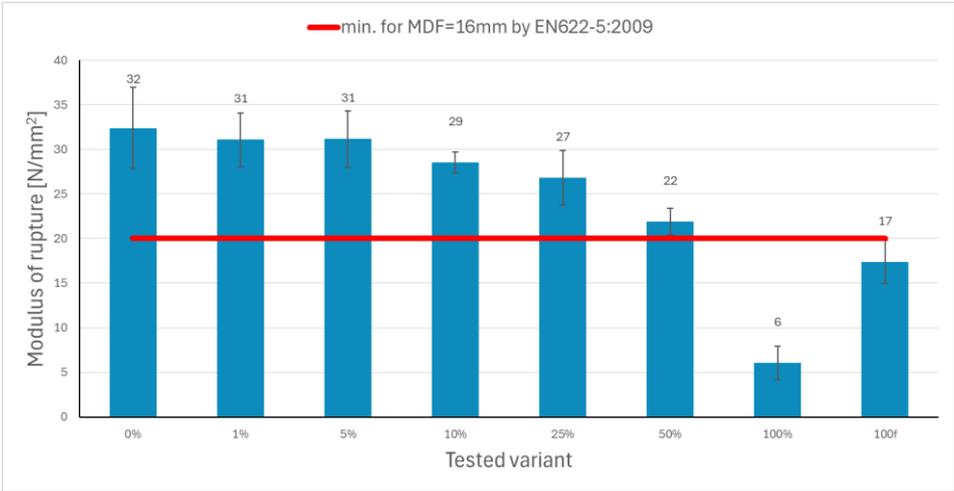


Figure 3. Modulus of rupture of investigated panels.

These results follow a similar trend to the MOE results: boards with up to 10% hemp fiber content exhibit values comparable to those of the reference board, and further increases in hemp fiber content lead to a decrease in strength. The highest values were observed for boards with 0%, 1%, and 5% hemp fiber content. As with MOE, except for the board made with 100% hemp fiber, all boards meet the requirements of EN 622-5:2009 standard. The 3-layered board also has a MOR value between that of single-layer boards with 50% and 100% hemp fibers,

and does not meet the standard. This 1-layer boards trend was also observed during the MOR study of MDF boards with the addition of rubberwood and oil palm empty fruit bunch biomass (Harmaen et al., 2013). The decrease in MOR with increasing hemp fiber content is primarily associated with reduced efficiency of stress transfer under bending loads. Hemp bast fibers are stiffer and less deformable than industrial wood fibers, which may limit their ability to align and interlock during mat formation. At higher substitution levels, this results in a more heterogeneous load-bearing structure and increased susceptibility to crack initiation under flexural stress.

The results of the internal bond (IB) tests are presented in the graph in Fig. 4. The highest value was observed for the sample with 5% hemp fiber, and the lowest for the sample with 100% hemp fiber.

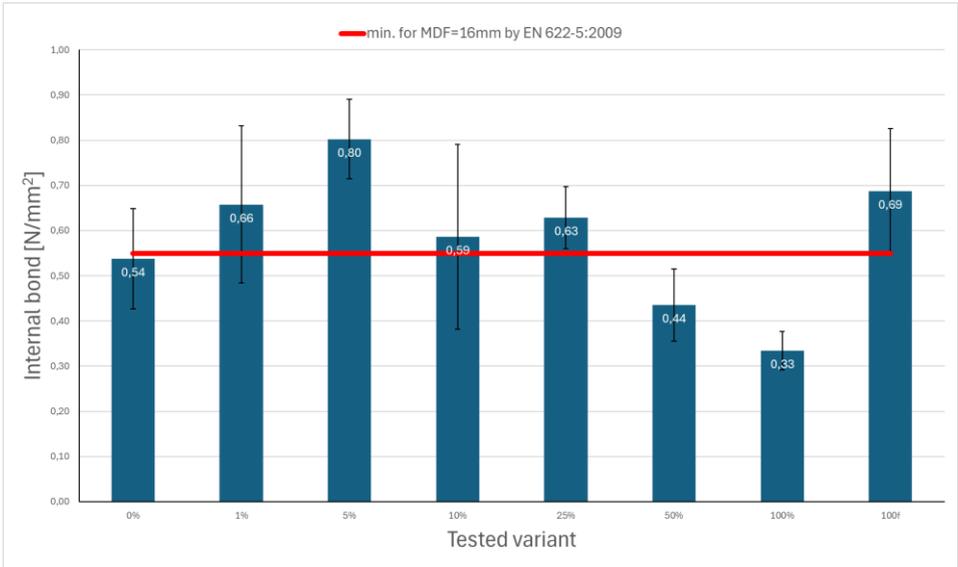


Figure 4. Internal bond of investigated panels.

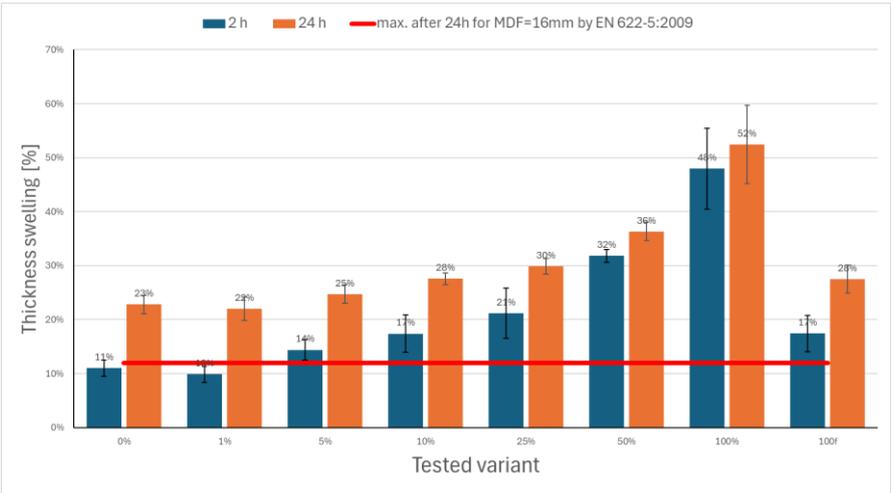


Figure 5. Thickness swelling of investigated panels.

A uniform trend, as in previous studies, cannot be clearly deduced. An increase in values with increasing hemp fiber content to 5% is followed by a subsequent decrease, with a particular focus on boards with a 25% content. Boards with 1%, 5%, 10%, and 25% hemp fiber content meet the requirements of the EN 622-5:2009 standard. A similar trend was observed in studies

on chicken feather fibers (Winandy et al., 2007). Three-layer boards meet the standard and have a significantly higher value than the 50% and 100% variants.

The reduction in internal bond strength at higher hemp fiber proportions can be explained by less effective inter-fiber bonding within the core of the panels. Hemp fibers possess lower lignin content and a different surface chemistry compared to wood fibers, which may reduce adhesive wetting and bonding efficiency when using urea-formaldehyde resin. At elevated substitution levels, insufficient resin coverage and weaker interfacial adhesion can promote cohesive failure within the board structure.

The graph of swelling values per thickness is shown in Fig. 5. Swelling increases with increasing hemp fiber content, with the most pronounced increase occurring at a 25% content, which is consistent with research on these fibers (Savov et al., 2019).

Most likely due to the lack of a hydrophobic agent, none of the tested boards meets the requirements of EN 622-5:2009 standard. The three-layer boards do not behave as expected. Due to their 32% hemp fiber content, one would expect their swelling to be between the properties of the 25% and 50% boards; however, these boards show swelling at the level of the variants with a lower content.

Fig. 6 shows a graph of screw withdrawal resistance values. The lowest value was again obtained for the board with 100% hemp fiber content, while the highest value was again observed for the boards with 1%, 5%, 10%, and 25% hemp fiber content, showing strength similar to that of the reference board. Similarly, a 3-layer board. The decline in screw withdrawal resistance at high hemp fiber contents is likely related to reduced local fiber compaction and weaker mechanical anchoring around the fastener. Hemp fibers tend to fracture rather than plastically deform when subjected to localized stresses generated during screw insertion. This behavior can limit the formation of a dense, interlocked zone around the screw threads, thereby reducing resistance to axial pull-out.

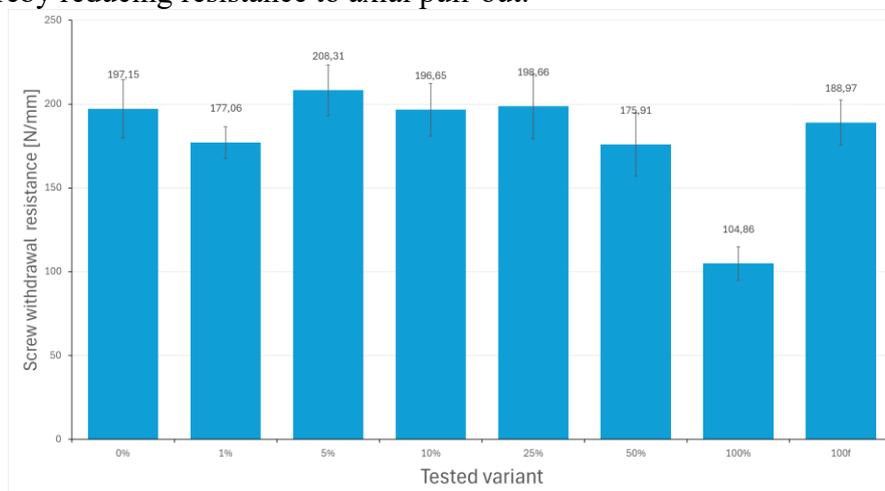


Figure 6. Screw withdrawal resistance of investigated panels.

The density profile is shown in Fig. 7. The graph displays data only up to the axis of symmetry (half of the thickness) to clarify the curve.

The profile shape presented is typical of classic MDF boards, with increased density at the edges and a slight decrease towards the centre of the board (Schulte and Frühwald, 1996). Except for the board with 100% hemp fiber, all boards have very similar density profiles, making it difficult to distinguish any deviations from the reference board. This is most likely due to the very similar bulk density values of the wood and hemp fibers. The shapes of the graphs for the 100% and three-layer boards suggest that the pressing process is different from that for wood fiberboards. However, it should be pointed out that with the increasing amount

of hemp fibers, the density profile flattens, which means that, with very similar average density, the face layers' density decreases with the increase of core layer density.

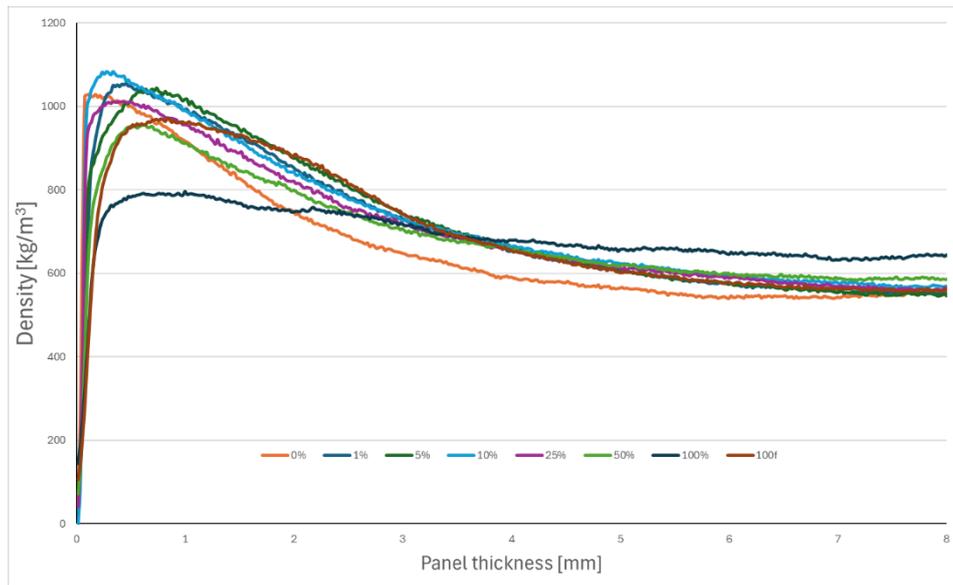


Figure 7. Density profile of investigated panels.

Based on the statistical analysis (Table 1), mean values marked with identical letters do not differ significantly, whereas values denoted by different letters indicate statistically significant differences.

Table 1. Statistical analysis results.

Attribute	Variant							
	0	1	5	10	25	50	100	100f
MOR	a	a	a	a	a	b	c	d
MOE	a	a	a	a	a	b	c	d
IB	a	a, b	b	a, b	a	a, c	c	a, b
SWR	a	a	a	a	a	a	b	a
TS 2 h	a	a	b	b	b	c	d	b
TS 24 h	a	a	a	a	b	c	d	a, b

For MOR and MOE, no statistically significant differences were observed among panels containing 0 – 25% hemp fibers, as all variants belonged to the same homogeneous group. In contrast, panels with 50%, 100%, and 100f hemp fiber content exhibited significantly lower values, forming distinct statistical groups. For IB, partial overlap of statistical groups was observed, indicating a less uniform trend. Variants containing 1%, 5%, 10%, and 100f hemp fibers shared common statistical groupings, suggesting no significant differences between these panels, while the lowest IB values were recorded for panels with 50% and 100% hemp fibers. No statistically significant differences in SWR were found among panels containing up to 50% hemp fibers. A statistically significant decrease was observed only for the 100% hemp fiber variant. For thickness swelling after 2 h and 24 h, statistically significant differences were identified with increasing hemp fiber content. Panels containing 5 – 25% hemp fibers showed significantly higher swelling compared to the reference boards, while the highest swelling values were recorded for panels with 50% and 100% hemp fibers, forming distinct statistical groups.

CONCLUSIONS

The results of the present investigation indicate that the incorporation of hemp fibers at levels of 1 – 10% by mass does not result in statistically significant changes in the bending properties of MDF panels, as expressed by the modulus of elasticity and modulus of rupture. At higher substitution levels, a gradual reduction in both parameters was observed, suggesting reduced stress-transfer efficiency within the composite structure under the applied processing conditions. Internal bond strength exhibited a non-linear response to increasing hemp fiber content. An increase in IB was recorded at low substitution levels, with the highest values observed at 5% hemp fiber content, followed by a decline at higher contents, which may be associated with reduced inter-fiber bonding continuity in the panel core.

Thickness swelling increased with increasing hemp fiber content, with a pronounced deterioration observed at 25% hemp fibers and above, indicating moisture sensitivity as a limiting factor in the absence of hydrophobic additives. Axial screw withdrawal resistance remained comparable to that of reference MDF for panels containing 5 – 25% hemp fibers, whereas a systematic decrease was observed at higher substitution levels. Density profile analysis showed no substantial deviation from the characteristic profile of conventional MDF, except for panels manufactured entirely from hemp fibers, which exhibited a flattened density gradient. Within the investigated parameter space, the results suggest that hemp fibers may be considered a supplementary lignocellulosic raw material for MDF production at low to moderate substitution levels, provided that appropriate process control is maintained.

From an application-oriented perspective, the investigated substitution range of up to 25% hemp fibers may be regarded as technically compatible with furniture-grade MDF, subject to compliance with relevant standard requirements. From a strategic standpoint, the partial replacement of wood fibers with annually renewable hemp fibers may contribute to improved resource efficiency and reduced dependence on virgin wood raw material, aligning MDF production with broader bioeconomy and circular material use objectives.

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Streszczenie: *Wpływ udziału włókien konopnych (Cannabis sativa L.) na wybrane właściwości fizyczne i mechaniczne płyt typu MDF.* Celem badań była ocena wpływu dodatku włókien konopnych (*Cannabis sativa* L.) na wybrane właściwości fizyczne i mechaniczne płyt MDF przeznaczonych do zastosowań meblarskich oraz weryfikacja ich zgodności z wymaganiami normy EN 622-5. W warunkach laboratoryjnych wytworzono płyty MDF o nominalnej grubości 16 mm i gęstości 700 kg/m³, zawierające od 0 do 100% włókien konopnych w masie surowca, w tym wariant trójwarstwowy z okładzinami z włókien konopnych. Zakres badań obejmował wytrzymałość na zginanie (MOR), moduł sprężystości przy zginaniu (MOE), wytrzymałość na rozciąganie prostopadle do płaszczyzny płyty (IB), opór przy osiowym wyciąganiu skrętów, spęcznienie na grubość oraz profil gęstości. Wyniki wykazały, że płyty zawierające do 10% włókien konopnych charakteryzowały się wartościami MOR i MOE porównywalnymi z płytami referencyjnymi (MOR 29 – 31 MPa, MOE 3600 – 3700 MPa). Najwyższą wartość IB, 0,80 MPa uzyskano dla wariantu z 5% udziałem włókien konopnych, przy czym płyty zawierające do 25% tego surowca spełniały wymagania normowe. Wraz ze wzrostem udziału włókien konopnych obserwowano zwiększenie spęcznienia na grubość, co przypisano braku dodatku środka hydrofobowego. Profile gęstości były zbliżone do typowych dla klasycznych płyt MDF, z wyjątkiem płyt wykonanych w 100% z włókien konopnych. Uzyskane wyniki wskazują, że włókna konopne mogą stanowić perspektywiczne, odnawialne uzupełnienie surowca drzewnego w produkcji płyt MDF, bez istotnego pogorszenia kluczowych właściwości mechanicznych przy niskim poziomie substytucji.

Słowa kluczowe: włókno konopne, Cannabis sativa L., MDF, płyta pilśniowa średniej gęstości, meble

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