The Possibility to Use Long Fibres from Fast Growing Hemp (*Cannabis sativa* L.) for the Production of Boards for the Building and Furniture Industry

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This paper describes an attempt to use long fibres from fast growing hemp (*Cannabis sativa* L.) as a raw material for the production of boards for the building and furniture industry. Hemp fibre boards with densities of 300 to 1100 kg/m³ were studied. The board surfaces were finished using a one-cycle method in which birch veneers were pressed to make the boards. The pulp was glued with pMDI (9 wt.% based on dry weight). The basic mechanical and hydrophobic properties of the boards were tested. The static bending strength and modulus of elasticity of the boards with a density of about 650 kg/m³ were comparable to P2 furniture boards. Only the higher density boards had adequate properties that met standards for the building industry, which were comparable to those of OSB/3 and MFP boards. Hemp fibre boards were characterised by relatively good water resistance, which was manifested by low swelling and low soaking susceptibility.

Keywords: Hemp; Fast growing raw material; Boards density; Mechanical properties

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INTRODUCTION

As wood resources are decreasing or remaining at the same level, it is necessary for the wood panel industry to seek new alternative materials (Akihiro and Eka 2001). The wood composites industry in Poland is highly competitive, especially in the European market of wood-based panels. In 2015, Poland became the second largest manufacturer of wood-based panels in Europe, following Germany. The main factor determining this high position on the European market is a constant supply stream of raw materials. Unfortunately, the wood-based panel industry has been facing a shortage of wood material. In response, there has been intense research on fast-growing lignocellulosic species and technologies based around these species.

Cereal straws, especially wheat and rapeseed straws, have increasing importance. These straws are mostly in the temperate climate zone but can also grow outside of it (Dalen and Shorma 1996; Sauter 1996; Han *et al.* 1998; Wang and Sun 2002; Dziurka and Mirski 2013). Initially, the use of cereal straws was regarded as difficult due to the wax layer covering the external part of the stem. Different methods of chemical and/or thermomechanical processing were proposed to remove this layer (Han *et al.* 1998, 1999; Zhang *et al.* 2003). The problem was considerably reduced through the application of isocyanate adhesives. Due to the high wettability between the straw surface and isocyanates, boards can be manufactured from materials other than wood (Mo *et al.* 2003; Boquillon *et al.* 2004). There is continuous development of traditional wood adhesives to increase their adhesion to straw, and new solutions to removing the wax layer of cereal straw are being proposed (Pease 1998; Grigoriou 2000; Zhang *et al.* 2011). There are fewer problems with rapeseed straw in this respect. As early as the 1960s, boards made of pinewood chips and rapeseed straw particles were manufactured. This straw can be successfully glued with resins such as UF, PF, or MUPF (Dziurka *et al.* 2005). Hybrid boards containing alternative materials that partly displace wood are becoming increasingly popular (Nurhazwani *et al.* 2015).

In Asia, the use of chips from rubberwood and bamboo shoots is increasing rapidly. Bamboo is a fast growing plant that could be very important for the production of large-size panels based on lignocellulosic particles (Abdul Halip *et al.* 2014; Nurhazwani *et al.* 2015; Jin *et al*. 2016; Zhou *et al.* 2016). Hemp is another alternative to wood that can be used for manufacturing boards. The plant very easily adapts to different climate conditions and achieves maturity within 100 days. It is used for the production of food, clothes, and even medicaments. Hemp is crumbled into chips and long or short fibres to manufacture lignocellulosic products. Depending on the degree of fragmentation, hemp is used to manufacture chipboards, insulation mats, and fibreboards. Short fibres are combined with cement to produce construction materials such as walls of buildings (Hemp Technologies Collective 2016; Musterkiste 2016; Realhemp 2016; The Hemp Connoisseur 2016).

The aim of this study was to determine the mechanical and physical properties of boards made from long hemp fibres depending on the density of the board.

EXPERIMENTAL

Industrial hemp fibres (*Cannabis sativa* L.) were provided by STEICO Company (Czarnków, Poland). The company periodically uses hemp fibres to manufacture insulation mats.

The fibres that were used in the test are characterized by a much greater length than wood fibres typically applied in the production of fibreboards. The average length of the latter is usually less than 5 mm (Klimczewski and Nicewicz 2013; Benthien *et al.* 2014; Ohlmeyer *et al.* 2015). The median length of the fibers used in the tests was as much as 65 mm, and their length range from 1 to 340 mm (Fig. 1). The length of the fiber did not have a normal distribution (Shapiro-Wilk W = 0.89511, p = 0.0000). Only about 9% were fibers with a length less than 5 mm, and 30% were longer than 100 mm. The thickness of fibers with a length above 100 mm also did not have normal distribution (Shapiro-Wilk W = 0.96619, p = 0.00000), and the thickness of 135 - 177 μm was predominant (min - 34 μm, max - 278 μm).

The material was stored on pallets and was strongly compressed, so a ventilator was applied to break up tangles and separate woody core particles. The fibers were adjusted to about 11% humidity before their use in boards. The use of very long fibres made it impossible to use traditional chip or fibre mass sealers. Thus, polymeric methylene diphenyl diisocyanate (pMDI) was applied with a manual spray gun. No other substances improving board hydrophobicity were applied. A manually formed mat was pressed at 200 °C and pressure factor of 15 s/mm per board thickness (15 mm). Four boards were made for each variation, with two boards per batch; the second batch of boards was pressed one week later. The initial assumption was to manufacture homogenous boards with densities of 300, 500, 700, 900, and 1.100 kg/m^3. However, due to the poor quality of the board surfaces (Fig. 2), boards were subsequently made with birch veneer coverings with a thickness of 1.5 mm and density of 460 ± 5 kg/m. Glue was applied at a rate of 25 g/m^2 to the veneer. Boards with a density of 300 kg/m^3 were manufactured at the maximum pressure of 1.8 N/mm^2. Each time the density increased by 200 kg/m^3, the compaction pressure increased by 0.2 N/mm^2.

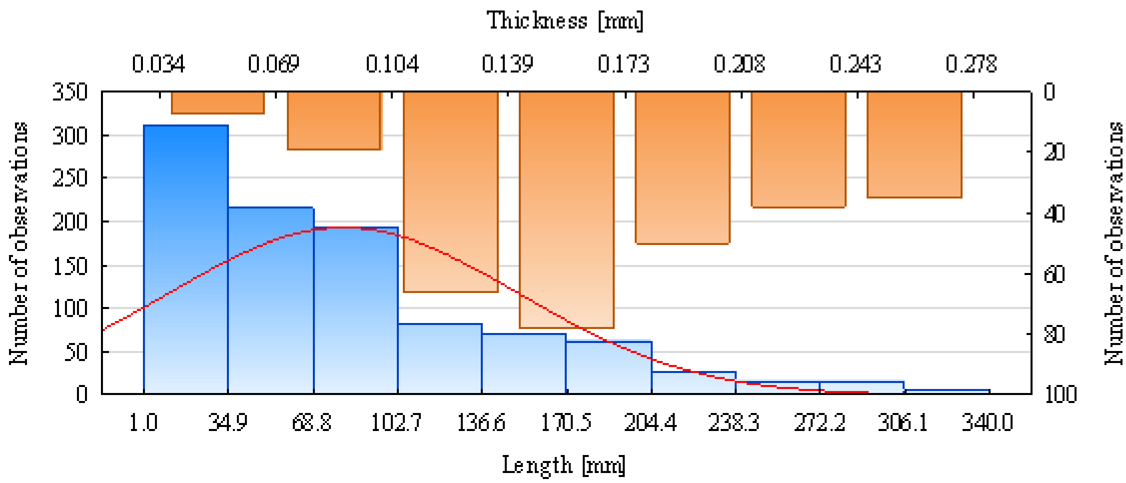

Fig. 1. Histograms of length and thickness fiber of hemp

Multiple properties of the boards were tested per their respective standards. The static bending strength and modulus of elasticity were calculated in accordance with EN 310 (1993). The compressive strength was determined per EN 826 (2013) and was measured on 50 x 50 mm samples and with a preload pressure of 250 Pa. Due to the changes that occurred in compressed samples, the compressive strength was assessed by determining the stress (σ10) at a deformation of 10%. Tensile strength perpendicular to the board planes was calculated by EN 319 (1993). The swelling and soaking susceptibility after 24 h was calculated using EN 317 (1993). Finally, water soaking susceptibility during short-term and partial immersion (absorption (W_p)) was measured in accordance with EN 1609 (2013) and was assessed on two 150 x 150 mm samples. A total of 12 to 16 samples of each board were prepared for the tests. Statistical analyses of the data were performed with Statistica 12.0 software (StatSoft Inc., Tulsa, OK, USA).

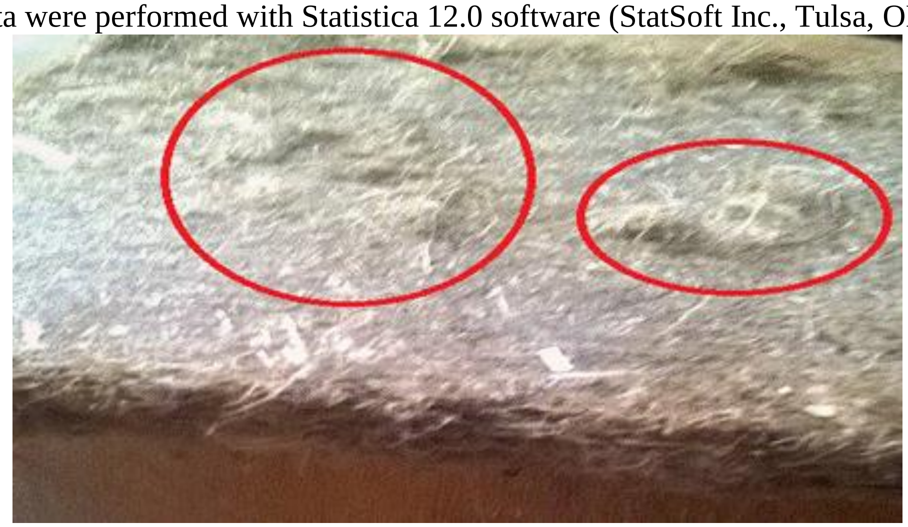

Fig. 2. The quality of hemp fibre boards at an assumed density of 300 kg/m^3

RESULTS AND DISCUSSION

The use of birch veneers as an external layer had a relatively noticeable influence on the mean density of the boards (Table 1). When the density of the veneers was greater than the assumed density of the central fibre mass layer, the mean density of such boards was greater than planned. However, when the density of the central layer was greater than the density of the veneers, the mean density of the boards decreased proportionally to the ratio between the veneer thickness and fibre layer thickness. This result is important because most mechanical properties, including the static bending strength and modulus of elasticity, strictly depend on the density of the wood material.

Table 1. Markings Used in the Study and Mean Board Density

Marking	Density of Central Layer (kg/m^3)	Mean Density of Board (kg/m^3)	υ (%)
A_3	300	330	3.5
B_5	500	470	3.4
C_7	700	630	2.9
D_9	900	750	3.0
E_11	1100	900	4.0
F_13	1300	1110	3.8

As shown in Table 2, the board with the lowest density was characterised by relatively low compressive strength. The value was similar to the insulation materials made from wood fibres, which were provided by STEICO. However the density of the latter was half the density used in the study. The compressive strength (compression stress at 10% deformation) of porous fibreboards with a density of 230 kg/m^3 was more than two times greater than the compressive strength of hemp fibre boards with a density of 300 kg/m^3 (A_3) (σ_{10} - 120 kPa; υ - 7.3% - unpublished author research). However, the compressive strengths of all the other boards were much greater than that of porous fibreboards and A_3. In addition, when the central layer density of the boards ranged from 500 to 1100 kg/m^3, they were characterised by a linear density dependence (Fig. 3).

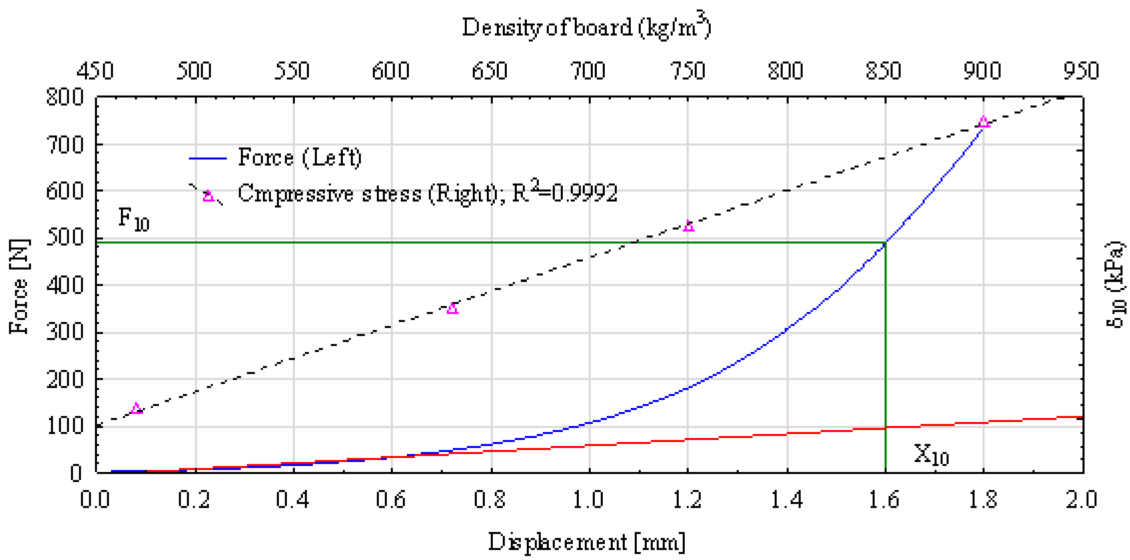

Fig. 3. The curve of attempted compression of the board with a density of 500 kg/m^3 and the influence of thickness on the compressive strength

Table 2. Mechanical Properties of Boards

Marking	σ_{10} [kPa]		MOR [N/mm^2]		MOE [N/mm^2]	
A_3	53.4	26.7*	1.3	17.8*	-	-
B_5	203	23.3	4.0	7	580	9.9*
C_7	2065	14.3	11.5	2.6	4720	3.2
D_9	3640	10.2	17.4	8.1	6520	5.0
E_11	5615	8.6	27.8	3.7	8070	5.6
F_13	-	-	37.2	4.3	10250	5.9
* coefficient of variation %						

Due to the high compressibility of the lower density boards (A_3 and B_5), it was difficult to assess their actual bending strength and modulus of elasticity. It was necessary to assume that boards made from long hemp fibres with densities less than 500 kg/m^3 are characterised by very low bending strength and stiffness, which renders them unsuitable for constructional elements or even elements of furniture. An increase in the mean board density to about 630 kg/m^3 (C_7), *i.e.* the density of P2 chipboards (per EN 312 (2010)), which are currently manufactured, resulted in a strength of about 12 N/mm^2 and thus, would meet the standards regarding constructional elements. Moreover, it is noteworthy that the modulus of elasticity in C_7 boards was nearly three times greater than the required standard and it was close to the modulus of elasticity of OSB/4 boards, which is determined along the major axis (Mirski and Dziurka 2013). Increasing the density by another 200 kg/m^3 (D_9) resulted in the strength increasing by nearly 260% and the modulus of elasticity increasing by more than 170%. Thus, as far as these parameters are concerned, hemp fibre boards with densities greater than 750 kg/m^3 can be competitive to both OSB (EN 300 (2006)) and P5 (EN 312 (2010)) boards, which are typical constructional boards used in the building industry.

Furthermore, the boards made from long hemp fibres were characterised by very low tensile strengths perpendicular to the board planes (Fig. 4). Light boards, which can be used for thermal or acoustic insulation, do not need to be very strong, but strength is of chief importance for boards used in the furniture or building industries. Boards of medium densities (C_7 and D_9) were characterised by strengths less than 0.1 N/mm^2. A considerable (double) increase in tensile strength was observed when the board density increased to more than 900 kg/m^3. However, even in this case the strength of these boards was half of what the standard required for P2 furniture boards. The low quality of the hemp boards can be attributed to deficiencies in establishment of regular adhesion of long fibres, which have a strong tendency to clump into tufts even when a slight airstream is applied. An interesting property of these boards was that they retained their strength when approaching the maximum applied force, despite the considerable deformation of the samples.

With traditional chipboards or fibreboards, when the maximum force value was exceeded, the strength of these boards dropped dramatically, and sometimes they immediately broke into two parts. In hemp boards, the stretching process was different, probably due to changes in the long fibres, which run through different areas of the board in a cross section.

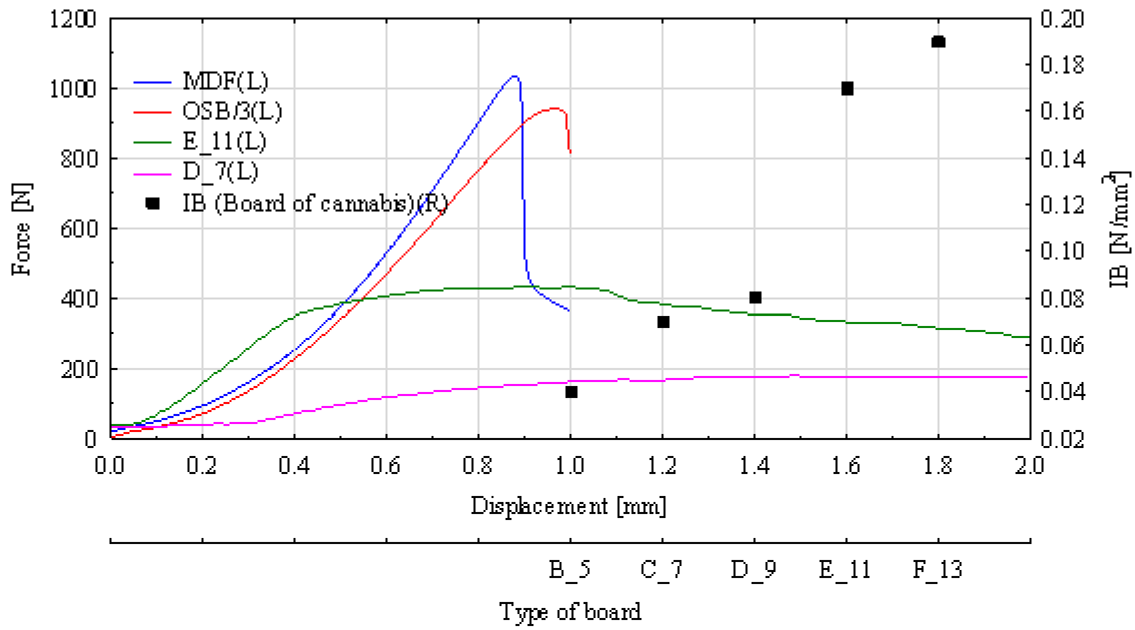

Fig. 4. The reaction of boards during a test of tensile strength perpendicular to the board planes

Table 3 shows the relatively high swelling and soaking susceptibility of the boards. Although no substance was applied to improve the hydrophobicity of the boards, the values observed were much greater than the values noted in laboratory tests on chipboards or OSB boards (Mirski *et al.* 2013; Dziurka *et al.* 2015). The swelling of boards A_3 and B_5 did not exhibit statistically significant differences, and these values were lower than the swelling of the other boards.

Table 3. Water Resistance of Hemp Fibre Boards

Marking	TS (%)		WA (%)		W_p (kg/m^2)	
A_3	26.7^a	12.7*	178^a	11.1*	1.22^a	8.9*
B_5	31.3^a	10.0	121^b	16.7	1.28^a	4.5
C_7	42.6^b	8.2	102^c	15.9	1.79^{b,c}	5.7
D_9	54.2^c	7.4	85.1^d	7.0	1.95^c	6.9
E_11	64.3^d	8.5	80.4^d	6.4	1.92^{b,c}	7.7
F_13	66.8^d	7.2	75.9^d	5.8	1.66^b	5.9

*coefficient of variation %
$^{a, b, c}$ homogenous groups

Regarding soaking susceptibility, the situation was the opposite. As density increased, soaking susceptibility decreased. Statistically, the higher density boards (D_9 to F_13) were characterised by similar soaking susceptibility values, which is most likely because the easy penetration of water between fibres was limited by the high density of the input material.

There was relative diversity in the water resistance of the boards. In this method, the susceptibility to water absorption during continuous rainfall was simulated. For this reason, only one side of the board was moisturised. To distinguish between soaking susceptibility after total immersion in water and soaking susceptibility after short-term immersion (W_p), the latter was also defined as absorption. Boards with densities up to 500 kg/m^3 (A_3 and B_5) were characterised by similar absorption values, which averaged out to 1.25 kg/m^2. In the higher density boards, absorption was about 50% greater.

Because there were no statistical differences between the boards with densities exceeding 500 kg/m^3 (C_7 to F_13), the maximum value of this property was achieved at 750 kg/m^3 (D_9). Although the expected soaking susceptibility of insulation materials should not exceed 1 kg/m^2 (Steico 2016), the values observed in hemp fibre boards were relatively low (Table 3). If additional hydrophobic protection was applied, they should have met adequate standards.

In sum, the industrial use of long hemp fibres as a material to produce boards for the furniture or building industries may be disadvantageous, despite the numerous advantages of the material. Two of the important issues in the manufacturing of wood products is the even application of the gluing substance to the material and the possibility of contact between areas or particles covered with the adhesive with those to which it has not been applied. Long and strongly tangled hemp fibres made it very difficult to apply the adhesive evenly, and consequently, the boards had relatively mossy surfaces. Unglued fibres sticking above the surface do not contribute to the aesthetic appearance of the board. Although this would not be a fault in mats or insulation boards, it is an unacceptable fault in construction boards. Finding a solution to this issue will be of key importance for the industrial use of these fibres to produce boards rather than mats. The use of wood veneers as external layers improved the appearance of the boards and their mechanical properties.

CONCLUSIONS

1. The static bending strength and modulus of elasticity of the boards with a density of about 630 kg/m^3 were comparable to those of P2 furniture boards.
2. An increase in board density considerably improved the static bending strength and modulus of elasticity. These values were much greater than the standard requirements for chipboards used in the building industry, such as OSB/3 or MFP.
3. Hemp fibre boards were relatively water resistant, which was manifested by their low swelling and low soaking susceptibility values. These properties are particularly important in view of the application of these boards in the building industry.

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