The Possibility of Replacing Strands in the Core Layer of Oriented Strand Board by Particles from the Stems of Rape (*Brassica napus* L. *var. napus)*

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In this study, reducing the density of oriented strand board (OSB) in the core layer where strands were replaced by rape straw particles was evaluated. The use of rape particles in the core layer did not significantly affect the mechanical properties of OSB. This type of board had only slightly deteriorated properties compared with conventional OSB. However, with a decreasing density, significant changes occurred in the modulus of rupture (MOR) and modulus of elasticity (MOE) determined for the shorter axis. The lowest possible density value was determined based on statistical analysis, allowing for the production of OSB that met the requirements of EN 300 (2006) for OSB type 3. The analysis showed that panels of this type can be produced at a density of 530 kg/m^3.

Keywords: OSB; Low density; Mechanical properties; Rape straw

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INTRODUCTION

Oriented strand board (OSB) type 3 (load-bearing in humid conditions (EN 300 2006) is the most commonly used OSB type in Europe and the USA. Their properties depend mainly on the geometry of strands (Moriarty 2002), density of boards (Sumarid *et al.* 2007; Grandmont *et al.* 2010), and the adhesives used. Appropriate strands require the use of high quality wood, whose supplies are limited. As a result, the price of boards increases, which makes manufacturers search for alternative materials (Cheng *et al.* 2012; Akrami *et al.* 2014).

The utilization of cereal straw is one of the possibilities to reduce the cost of OSB. Straw is mainly used for animal bedding, as a soil improver, and in the production of vegetables and mushrooms. Its prevalence in many regions can solve the problem of wood supply continuity, but it requires a good storage system. As a supplement to wood, cereal straw is an annually renewable source of lignocellulosic materials, but it is more problematic because of the presence of wax on the surface, which decreases the bondability of straw. Another disadvantage is the percentage of chemical compounds. Straw has more hemicellulose and less cellulose than wood, which contributes to its lower mechanical strength (Dziurka *et al.* 2005). However, the benefits encourage its use in the wood-based panel industry. The advantages include lower hygroscopicity, better thermal insulation, and lower gravity. One solution to improve the bondability of straw is the use of a pMDI adhesive, which has a good straw wettability (Grigoriou 2000; Mo *et al.* 2003; Cheng *et al.* 2013).

The attempts to apply cereal straw in wood-based materials production have been undertaken for many years. OSB was manufactured from split straw with aspen strands or wheat straw (Han *et al.* 2010, 2012; Cheng *et al.* 2013). Particleboards were also manufactured with wheat straw (Boquillon *et al.* 2004; Zhang *et al.* 2003; Bekhta *et al.* 2013) and rape straw (Dziurka and Mirski 2013). When manufacturing OSB from material such as straw, it is more difficult to achieve the properties required for OSB type 3 (EN 300 2006), due to lower mechanical resistance. Rape straw is the most promising agricultural residue and an increasingly popular source of biofuels. Compared with other types of straw, rape straw has a high content of cellulose and a relatively low amount of wax on its surface (Dziurka *et al.* 2005).

The aim of this study is to determine the mechanical and physical properties of OSB made with a core layer of rape straw, as an alternative to classical OSB. The use of annual crop waste can significantly reduce costs, but boards have to meet the OSB/3 type requirements for load-bearing and resistance to humidity.

EXPERIMENTAL

The three-layer oriented strand boards were made from industrial wood strands (*Pinus sylvestris* L.), and the core layer was made from rape straw (*Brassica napus* L. var. *napus*), prepared in laboratory conditions. The moisture content in rape was 5.0%, and for wood particles, it was 8%. The basic parameters of materials are presented in Table 1. The flatness and slenderness ratio of rape straw is about 6 times lower than that of wood strands.

Table 1. Basic Parameters of Rape Straw and Pine Strands

Parameter	Formula	Rape Straw	Wood Strands
Average dimensions l, b, a (mm)	-	10.18 × 1.84 × 0.59	109.10 × 18.03 × 0.90
Slenderness ratio	$\lambda = \frac{l}{a}$	17.3	121.2
Flatness	$\psi = \frac{b}{a}$	3.1	20.0
Specific surface (m^2/kg)	$F_w = \frac{2}{\rho_o}\left(\frac{1}{a}+\frac{1}{b}+\frac{1}{l}\right)$	13.4	4.3

l, b, a: length, width, thickness

Rape straw and wood strands were glued with pMDI with the resin level, respectively, of 4% and 3%. Hydrophobic agents were not used. The percentage amount of rape straw in the core layer was constant and independent from the density of the boards. The adopted proportion in weight of individual layers was 1:2:1 (face/core/face). Strand-adhesive mass was used to form a three-layer OSB with a nominal thickness (t) of 15 mm and a density of 650, 590, 530, 470, or 410 kg/m^3. Each variant involved three boards. Prepared sheets were pressed for 300 seconds at 200 °C. After conditioning at 20 ± 2 °C and relative air humidity of 65 ± 5%, the following properties were assessed: modulus of rupture (MOR) and modulus of elasticity (MOE) according to EN 310 (1993), and internal bond (IB) according to EN 319 (1993). The assessments of MOR and MOE were conducted on 12 samples for both axes and on 15 samples for IB. Each variant of density was taken into account. Based on the values obtained during the assessments, the statistical analyses were made, using software Statistica 12.0 (StatSoft Inc., Tulsa, USA). To describe the result, the average value of a given property (*y*) and the relative change of this property (δ_y) were used. The latter is defined as the ratio of the mean value of the tested property at a given density to the average value of this property at a density of 650 kg/m^3. However, to determine the minimum value of the density at which the board will still meet the requirements for OSB/3 was used the values the lower 5% quantile.

RESULTS AND DISCUSSION

The mechanical properties of manufactured OSBs are presented in Table 2. The densities obtained by the measurements were similar to the values assumed in the methodology. Only for the lowest and highest densities, the differences were slightly higher than 10 kg/m^3. Moreover, the variation coefficients for all boards manufactured in laboratory conditions were within the range of 1.7% to 3.0%. Therefore, they were lower or comparable to the observed variability in the density of industrially produced boards. The assumed gradation of densities probably contributed to the fact that the properties of boards determined in the bending test, regardless of the direction in which the samples were selected, differed significantly (α = 0.05). The differences in the attained values were so substantial that they constituted a homogenous group for each density variant. In case of internal bond, the situation was quite different; there were three distinct groups, although there were five density levels.

Table 2. Mechanical Properties of Boards, including HSD Test for Homogenous Groups

Type of Board	Density ρ	MOR II	MOR ⊥	MOE II	MOE ⊥	IB
	kg/m^3	MPa				
OSB/3[1]	**590** 3.7[2]	**32.5** 11.1	**14.9** 6.6	**4940** 9.4	**2070** 6.4	**0.64** 8.9
650	**639** 1.7	**38.2**[a] 7.8	**16.6**[a] 7.1	**6590**[a] 5.9	**2370**[a] 7.7	**0.46**[a] 6.6
590	**585** 2.7	**35.0**[b] 7.4	**14.5**[b] 8.6	**5950**[b] 4.0	**2060**[b] 8.0	**0.43**[a] 10.3
530	**531** 2.5	**28.5**[c] 9.4	**11.7**[c] 12.9	**5340**[c] 6.3	**1700**[c] 5.7	**0.36**[b] 9.7
470	**479** 3.0	**22.4**[d] 11.5	**9.7**[d] 13.0	**4630**[d] 10.6	**1430**[d] 9.2	**0.33**[b] 9.5
410	**423** 2.1	**17.8**[e] 8.5	**6.6**[e] 15.8	**3740**[e] 7.4	**1020**[e] 9.5	**0.26**[c] 10.7
		y=a*(ρ)+b				
a [MPa/kg], b [MPa] R^2		**0.0995** -24.48 0.9896	**0.0464** -12.87 0.9963	**13.061** -1690 0.9944	**6.1752** -1567 0.9978	**0.001** -0.142 0.9845
α [°] for δ_y= c*(ρ)+d		14.58	15.61	11.21	14.63	11.71

[1] industrial board - Kronopl, Żary, Poland
[2] coefficient of variation
[a, b, …. e] homogenous groups

The modulus of rupture and modulus of elasticity determined for the shorter axis of laboratory boards, with the density of 590 kg/m^3, were very similar to the values of industrially produced boards. In this case, the strands in the core layer had no influence on mechanical properties. Slightly higher values of MOR and MOE were probably due to a higher amount of adhesive than that used in the industry. The influence of lower quality of particles in the core layer was obvious only for the internal bond. The value of this parameter was about 30% lower than for the industrial board.

A characteristic feature of wood-based materials is a linear increase in mechanical properties along with the increasing density. The range of linear changes of MOR and MOE is quite large. Generally, it is assumed that it starts at 400 kg/m^3. The lower limit is restricted by the multiplicity of bulk density of particles, which allows contact between particles during mattress pressing. In this study, the linear character of the density-induced changes in mechanical properties was also observed. The lower value of the coefficient of determination R^2 was 0.9845. This value was very high, and it was observed for IB values of coefficients of curve fit equation, which are important indicators of correlations between mechanical properties and the density of boards.

With an analysis carried out in this way, changes in the structure of the board should result in high values of an absolute term and narrow inclination angle of the curve. Table 2 also presents the values of inclination angle for the trend line for the relative changes in a given property. By referring to the relative changes, different mechanical properties were compared. Moreover, the values of inclination angles for the trend lines show the tendencies for changes in the specific mechanical properties more clearly. The low values indicate high resistance to changes in density. Thus, MOE II was the most stable value for this type of board. The changes in IB were also less significant than other parameters, which is probably due to small particles of rape being more susceptible to compression. The strong influence of the particles size in the core layer significantly affected the value of MOR determined for the lower axis. For this property, the value of angle α is larger than that for light OSB from strands (Mirski and Dziurka 2015). The use of small particles that are more susceptible to compression in the core layer resulted in bigger differences in densities between layers. Consequently, the density of the manufactured boards was reduced, and some of the strands moved to a deeper layer. Thus, the values of IB were more stable, and the changes in MOR and MOE for the lower axis were more significant. The length of particles in the face layer was less important.

The mechanical properties of boards at the density of 470 kg/m^3, except for MOR for the shorter axis, met the requirements for OSB type 3 according to EN 300 (2006). To compensate for the lacking 3% in the value of MOR, the density could be increased to 493 kg/m^3, as it was calculated. Figure 1 presents the results of a multivariate analysis, ANOVA, on the basis of the data from earlier papers on the use of small particles (Chips) in the core layer of OSB (Mirski and Dziurka 2011) and low-density OSB manufactured from strands (Strands) (Mirski and Dziurka 2015). The quality of manufactured boards was determined *via* the average density, type or form of material for the core layer, and mechanical properties (MOR, MOE, IB). According to the data shown in Fig. 1a, the correlation between the density of board and type of a material in the core layer was irrelevant. Regardless of the density, the mechanical properties of the boards made from strands were better than the properties of boards made with rape particles. The quality of boards made under laboratory conditions with the core layer from strands and fine chips was comparable (Fig. 1b). Although the quality of boards made with the addition of rape particles was worse than other boards made in laboratory conditions, it still had better properties than the industrially produced ones.

(a)

(b)

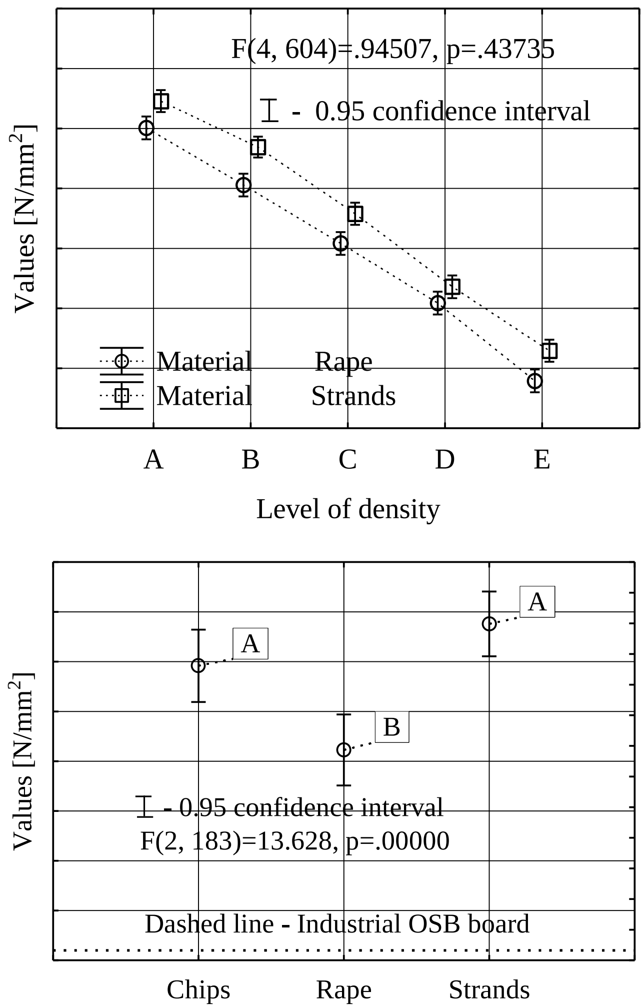

Fig. 1. Influence of different materials and density values on OSB properties. (a) Letters refer to density level A (max) to E (min); (b) Letters describe homogenous groups based on the Tukey test

CONCLUSIONS

1. Rape straw particles can be a full-fledged substitute for the strand chips in the core layer of OSB boards, because their mechanical properties are comparable to the industrial panels. When the density of these boards exceeds 530 kg/m^3, they meet the mechanical property requirements of the standard for OSB/3.
2. The reduction in average board density results in a significant decrease in the modulus of rupture and modulus of elasticity for the shorter axis. This result is probably due to replacing strands with rape particles, which have smaller dimensions.

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