Properties of Oriented Strand Boards with External Layers made of Non-Strand Chips

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This study evaluated the possibility of producing oriented strand boards (OSB) from non-strand chips. Properties of the produced boards were compared with commercially available OSB/3. Research has shown that replacing the strand chips of external layers with smaller chips allowed for the manufacturing of OSB/3 using chips up to four times shorter than standard strand chips. Oriented strand board manufacturers should consider preparing a new standard and introducing the market to a new type of OSB with very good mechanical properties and made of selected strand chips comprising one of the fractions obtained during screening.

Keywords: OSB; MFP; Strand; Fine chips; Mechanical properties

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INTRODUCTION

The feature distinguishing oriented strand boards (OSB) from other wood-based boards is mainly the size of chips used for their production. In general, the chips used for this purpose should be 75 mm to 150 mm long, 5 mm to 30 mm wide, and 0.4 mm to 0.8 mm thick (Barnes 2000, 2001; Chen *et al.* 2008). These linear dimensions make it possible to achieve the second essential property of these boards, *i.e.*, chip orientation within the individual layers. Perpendicular orientation of the chips within individual layers provides very good mechanical properties along one axis of the board. Chips of this type are usually obtained from aspen, poplar, or pine. The wood used for the manufacturing of these boards should be characterized by low brittleness. Obtaining chips of these dimensions requires raw materials of considerable size, and preferably in the round form directly from the forest. This, however, significantly affects the price of the final product. Attempts at reducing the price of wood include introducing new species or using wood from fire-impacted trees (Zhang *et al.* 1998; Shupe *et al.* 2001; Hermawan *et al.* 2007; Moya *et al.* 2009; Cheng *et al.* 2012). The final price may be also lowered by reducing the board density or using smaller chips in the core layer (Fakhri *et al.* 2006a, b; Han *et al.* 2006, 2007; Chen *et al.* 2008; Mirski and Dziurka 2011a,b; Mirski and Dziurka 2015). On the other hand, research conducted by Lee and Tahir (2003) and Sackey *et al.* (2011) has shown that using smaller chips on the outer layers of OSB smoothes their surface and reduces the linear expansion compared to particleboard.

An important alternative to OSB on the European market is multifunctional panel (MFP) construction board (Type P5, EN 312 2010), made of fine chips with geometric structures resembling the structure of chips used in the core layer of standard furniture particle boards (P2, EN 312) (Pfleiderer 2016). The modulus of rigidity in these boards is over 20 MPa, and their modulus of elasticity is greater than 3500 MPa, regardless of the direction of the sample collection. Therefore, they meet the requirements for OSB/3 boards as per the EN 300 standard (2006), even for their longer axis, irrespective of the sampling direction. Moreover, the coefficient of orientation for these boards is only 1.14, which means they can be used without paying attention to the chip orientation. Another advantage of the MFP board is their smooth surface that, after light sanding, may be finished with melamine foil, making the boards highly suitable for formworks.

Mechanical properties of industrial OSB are often much better than what is required by the EN 300 (2006) standard (Derkowski *et al.* 2014). This means there is a room for solutions improving both the economic aspect and the scope of the OSB use. A possible solution for improving functional quality of OSB is to give up on the orientation and manufacture unoriented strand board (USB) (Haute Innovation 2016). Unoriented strand board, manufactured by the Egger Company and Büsgen Institute of the University of Göttingen from soft wood of deciduous trees (birch, poplar, willow, alder), exhibited better mechanical properties and emitted less volatile organic compounds (VOC) than a pine-based OSB (Roffael *et al.* 2006). This paper evaluated the possibility of producing OSB with external layers made of non-strand chips which due to their properties will be able to replace traditional OSB in their construction applications.

EXPERIMENTAL

The study involved laboratory-manufactured three-layer boards with the core layer made of industrial strand chips intended for the internal layer of OSB panels. The external layers were made of microchips, fine chips, average chips, long chips, and strand chips from pine (*Pinus sylvestris* (L.)) (Table 1). The chips were glued with pMDI (Bayer, Fribourg, Switzerland) and therefore the reference boards were industrial OSB/3 (OSB) glued in both layers with the same adhesive.

Table 1. Chips used in OSB panels

Type of Chip	Abbreviation	Description
Microchips	AA	industrial chips intended for external layers of furniture particle boards
Fine Chips	BB	subscreen fraction obtained by screening industrial chips intended for the manufacture of OSB on a screen with 10 × 10 mm mesh and grinding in a laboratory mill
Average Chips	CC	industrial chips intended for the core layer of furniture particle boards
Long Chips	DD	fraction retained on a screen with 10 × 10 mm mesh and passing through 15 × 15 mm mesh during screening of industrial chips intended for the manufacture of OSB
Strand Chips	EE	fraction retained on a screen with 15 × 15 mm mesh during screening of industrial chips intended for the manufacture of OSB

The fractional composition, linear dimensions, slenderness (*l*/*t*), width coefficient (*l*/*w*), flatness (*w*/*t*), and specific weight (Fw) of chips were investigated. Specific weight is defined in Eq. 1,

$$F_w = \frac{2}{\rho_0}\left(\frac{1}{l^*} + \frac{1}{w^*} + \frac{1}{t^*}\right) \tag{1}$$

where F_w is specific surface (m^2/kg), ρ_0 is average density of dry pine wood intended for chip manufacture (0.511 g/cm^3) (Mirski and Dziurka 2015), l is length (mm), w is width (mm), and t is thickness (mm). The symbol * denotes the theoretical (calculated) linear dimension of the chips worked out based on linear dimensions of at least 100 chips and average (of 10 repetitions) weight of 100 to 200 chips taken from each screen. Dimensions of EE chips were determined based on 850 chips taken at random from the batch intended for board pressing.

Table 2. Conditions for OSB Pressing

Resin content (%)		MC Chips (%)		Pressing Time (s/mm)	Pressing Temperature (°C)	Unit Pressure (N/mm^2)
Face	Core	Face	Core			
4	3	9.25	6.10	15	200	2.5

The conditions of board manufacture are presented in Table 2. The materials with the above-described properties were used to prepare three-layer 750×450 mm, 15 mm thick OSB panels with a density of 590 kg/m^3 and weight ratio of face/core layers 1:2. Three pieces were prepared for each experimental variant.

The OSBs were then tested using relevant standards. The modulus of rigidity (MOR) and modulus of elasticity (MOE) were tested by EN 310 (1993). The internal bond (IB) was tested according to EN 319 (1993), and swelling in thickness (TS) after 24 h water soaking was tested according to EN 317 (1993). The properties of manufactured OSB boards were compared to industrial made OSB (Kronopol) and MFP (Pfleiderer).

Determination of the longer and shorter axis was based on the orientation of chips in the core layer. It was assumed that for the longer axis, the chips in the core layer were oriented perpendicularly to the longer axis of a sample. Statistical analyses were performed using the Statistica 12 (StatSoft Inc., Tulsa, USA) and TableCurve 2D v. 5.01 software packages (Systat Software Inc., London, England).

RESULTS AND DISCUSSION

Dimensional characteristics of the experimental chips are presented in Table 3. The investigated types of chips differed mainly in their length and width, and only slightly in their thickness.

Table 3. Dimensional Characteristics of Chips Used for External Layers of OSB

Size	AA		BB		CC		DD		EE	
-	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median
l (mm)	**4.15**	4.06	**10.15**	9.83	**15.07**	13.95	**49.69**	46.35	**96.79**	102.2
w (mm)	**0.54**	0.55	**1.10**	1.10	**1.46**	1.42	**3.38**	3.35	**12.76**	11.85
t (mm)	**0.17**	0.17	**0.45**	0.42	**0.61**	0.57	**0.61**	0.61	**0.61**	0.59
λ (l/t)	**24**	24	**23**	23	**25**	24	**81**	76	**159**	173
κ (l/w)	**8**	7	**9**	9	**10**	10	**15**	14	**8**	9
φ (w/t)	**3**	3	**2**	3	**2**	2	**6**	5	**21**	20
F_w (m^2/kg)	**1433.6**	1421.1	**819.2**	868.3	**614.4**	647.8	**512**	502	**435.2**	458

Due to the method of chip acquisition, neither their weight as the weight of wood material intended for board production, nor the chips retained on the screens during screening followed a normal distribution of linear dimensions. The linear dimension that was most often characterized by a normal distribution was chip width. Sample histograms of chip width distribution for selected screens are presented in Fig. 1.

The results indicated that, for the screening method used in this study, the presence of specific chip sizes on the screen was determined by at least two of their largest linear dimensions. Moreover, the finer the fraction, the more often the linear dimensions followed a normal distribution. However, as shown in Table 3, the differences between the mean and median were usually small (≤ 8%) and concerned mainly the length of the chips. Shape factors, except for slenderness determined for DD and EE chips, were practically the same, regardless of whether they were due to mean or median relationships. AA, BB, and CC chips had similar shape factors. The DD chips had the greatest width coefficient that affected the ease of orientation, and EE chips were characterized by the greatest slenderness. Chip slenderness significantly affected the board bending strength. Linear dimensions of the chips, presented in Table 3, significantly depended on the share of specific fractions in the total weight of the chips.

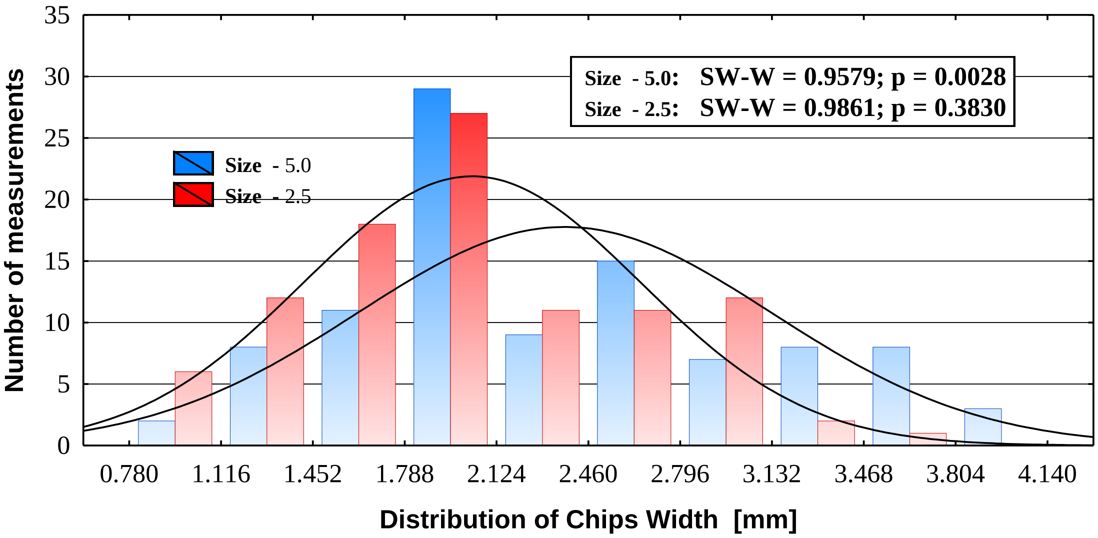

Fig. 1. Histograms of BB chip width distribution on the screens with 5 mm and 2.5 mm

As shown in Table 4, AA, BB, and CC chips were dominated by the fraction retained on the screen with 1 mm mesh. The DD and EE variants contained mainly the chips retained on the screen with 6.3 mm mesh. The share of fine fraction mainly affects the bulk density of the chips, and this parameter determines the shape of the board density profile or internal bond through greater or smaller densities of individual layers.

Table 5 shows the mechanical properties of the investigated particle boards. The experimental data indicated that both industrial boards (OSB and MFP) not only met the requirements of relevant standards, but often exceeded them by as much as 100%. The results for the OSB/3 were more favorable. However, of all the investigated boards, MFP was better than OSB as a multi-functional construction board, as MFP also met the requirements of EN 300 (2006) for OSB/3. Moreover, the MFP mean modulus of rigidity was comparable with that of OSB and was accompanied by a very low coefficient of orientation that was 1.14 compared to 2.18 for OSB. The MFP board also had a higher mean modulus of elasticity and a higher IB. This was most likely due to its density that was 130 kg/m^3 higher than that of OSB. The production of MFP boards requires more, but cheaper wood and may use lower quality wood material for the small chips necessary for MFP production.

Table 4. Fines Distribution

Fines Screen Size Dimensions	AA		BB		CC		DD		EE	
(mm x mm)	*x* (%)	υ (%)	*x* (%)	υ (%)	*x* (%)	υ (%)	*x* (%)	υ (%)	*x* (%)	υ (%)
> 6.3	0	0	5.23	19.1	5.54	12.1	85.21	1.20	90.52	1.18
> 5	0	0	1.76	27.3	6.09	15.2	0.52	38.6	1.34	37.2
> 4	0	0	1.96	21.29	5.80	14.1	0.75	30.1	0.97	41.7
> 2.5	0.25	40.21	25.16	3.21	40.62	3.21	5.32	16.7	3.61	5.50
> 1	51.24	2.37	55.55	4.29	39.63	2.89	2.46	7.22	3.56	8.54
> 0.5	20.13	3.17	5.42	24.2	1.92	21.1	2.45	17.0	0	0
<0.5	28.38	3.27	4.97	27.1	0.40	21.0	2.09	27.1	0.42	27.1

Considering the parameters for modulus of rigidity, all laboratory boards fell into the category of OSB/3 (Table 5).

Table 5. Mechanical Properties of the Boards and the Results of HSD Test for Homogeneous Groups

Type of Board	MOR II		MOR ⊥		MOE II		MOE ⊥		IB		TS	
	MPa	υ (%)	MPa	υ (%)	MPa	υ (%)	MPa	υ (%)	MPa	υ (%)	%	υ (%)
OSB*	32.5	11.1	14.9	6.6	4940	9.4	2070	6.4	0.64	8.9	5.6	12.7
MFP*	24.6	2.7	21.6	3.8	4430	2.0	3870	1.9	0.80	12.6	8.8	9.2
300**	20	-	10	-	3500	-	1400	-	0.32	-	15	-
312**	16	-	16	-	2400	-	2400	-	0.45	-	10	-
AA	14.1^{a}	6.4	21.0^{a}	9.1	2120^{a}	7.0	3030^{a}	6.3	0.60^{a}	8.8	13.8	6.1
BB	15.6^{a}	6.7	22.2^{a,b}	5.9	2770^{b}	7.3	3110^{a}	6.2	0.65^{b}	9.7	16.9	7.2
CC	18.4^{b}	10.9	24.2^{b,c}	9.8	3320^{c}	4.1	3290^{a,b}	10.6	0.81^{d}	16.5	16.6	11.1
DD	27.0^{c}	9.8	25.2^{c}	8.7	4380^{d}	8.3	3390^{b,c}	8.0	0.71^{c}	10.6	14.9	7.4
EE	41.0^{d}	10.8	27.8^{d}	8.2	6420^{e}	9.2	3580^{c}	7.1	0.68^{b}	10.9	17.3	9.9

* density of dry boards: OSB - 590 kg/m^3 (υ -3.7%), MFP - 720 kg/m^3 (υ -0.51%);

** EN - 310 for OSB/3, EN - 312 for P5

The boards made of fine chips (AA and BB) did not achieve a modulus of elasticity above 3500 N/mm^2 in either of their axes or at least 2400 N/mm^2 in both axes, and, therefore, they should be classified as P3 boards, *i.e.*, non-load-bearing boards to be used in humid conditions. The CC boards met the requirements for P5 particle boards, DD boards met the requirements for OSB/3, and EE boards matched OSB/4 standards. All manufactured boards had a very high internal bond, similar to the industrial boards. They also showed relatively low thickness swelling, considering the fact that no water resistance improving agents were used during manufacturing. Moreover, an analysis of the group homogeneity for the experimental boards demonstrated a much lower variability of their shorter axis properties, particularly regarding the modulus of elasticity. This was probably due to the fact that their core layer was made of the same type of strand chips arranged along the longer axis of a sample, thereby stabilizing their properties for transverse direction.

In manufactured OSB, a linear relationship with chip length was observed only for modulus of rigidity (Fig. 2). The equation for modulus of rigidity (MORII = 0.2884L + 13.005) was characterized by a high coefficient of fit (R^2) amounting to 0.9988. Large length differences in the individual types of chips, particularly between AA and EE chips made the coefficient trend towards a linear relationship (Anscombe's quartet). The other parameters investigated during the bend test fell into two intervals, depending on chip length. The first interval featured a strong increase of a specific value and comprised chips from 4.2 mm to 15.1 mm long, and the second interval included chips from 15.1 mm to 96.8 mm long belonging to CC and EE groups in which the parameter increase was slower.

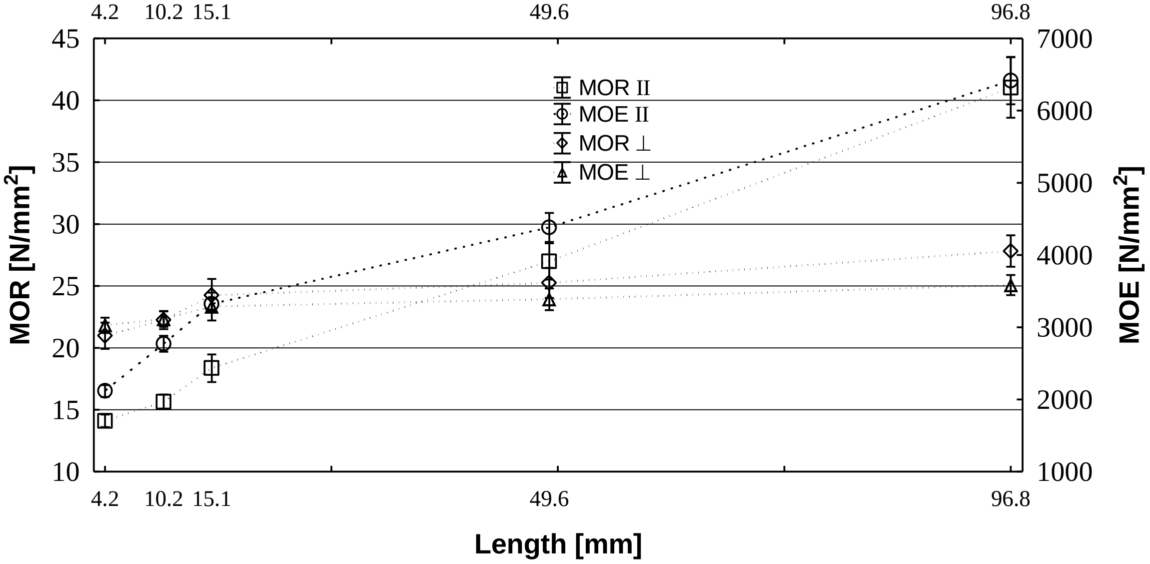

Fig. 2. Effect of the mean (weighted) average length of the chips on the static bending strength and modulus of elasticity

Even though the length of the chips within individual groups showed a high variability of linear dimensions, the obtained values fit the relationships described by Barnes (2000) (Fig. 2). The quality of the chip orientation in the individual layers of OSB was essential for MOR and MOE for specific board axis. The better the orientation was, the higher the orientation index. For OSB the expected orientation index is 2, and for the MFP panels it should be as close as possible to 1. Both industrial boards met the relevant requirements, and the lowest values of the investigated parameters for the laboratory-manufactured boards were observed in those made from CC and DD chips. Therefore, they may serve as an alternative for MFP boards, as their properties were also similar to the requirements of EN 312 (2010).

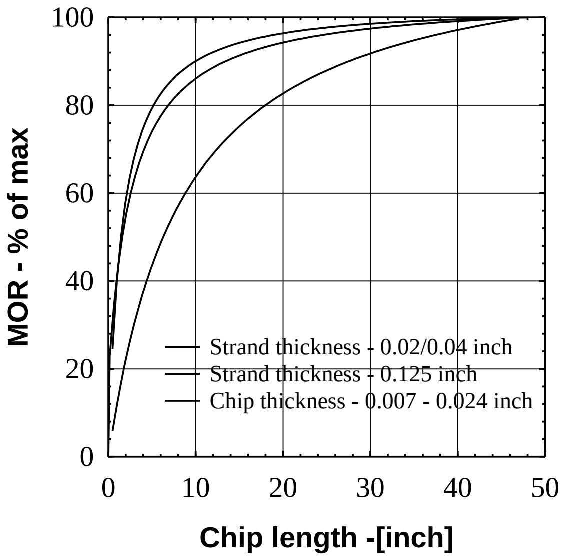

Fig. 3. Correlation of Hankinson equations with the effect on MOR of strand length (red and blue line (from Barnes 2000)

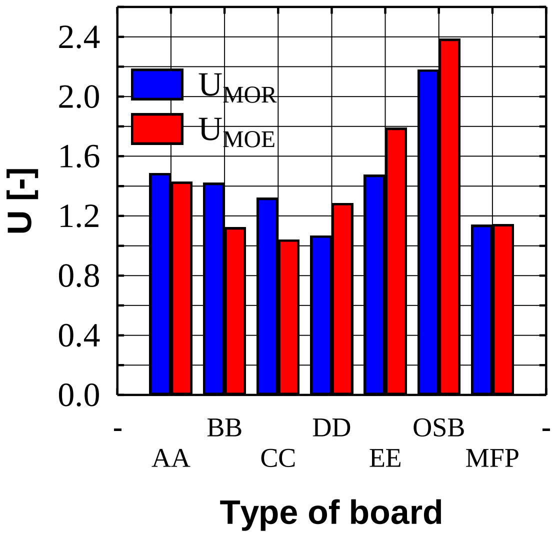

Fig. 4. Orientation coefficient of the investigated boards, where U=MOR(E)$_{max}$/MOR(E)$_{min}$

The parameter joining such properties as chip linear dimensions, their mutual relations (λ, κ, φ), fractional composition, or a resin content (treated as the ratio of the dry weight of adhesive to the dry weight of the wood) is a resination coefficient (RC), *i.e.*, the ratio of the dry weight of the adhesive to the specific surface of the chips. In this study, where the resin content was the same for all types of chips, the changes in the modulus of rigidity and modulus of elasticity should be treated as changes of exponential character (Fig. 5). Coefficient of fit (R^2) for the equation expressed as MOR(E) = $a + b$ exp($-RC/c$) was around 0.99, irrespective of the investigated axis. The nature of the MOR and MOE changes for the shorter axis may be also considered linear; however, the coefficient of fit was lower and ranged around 0.93.

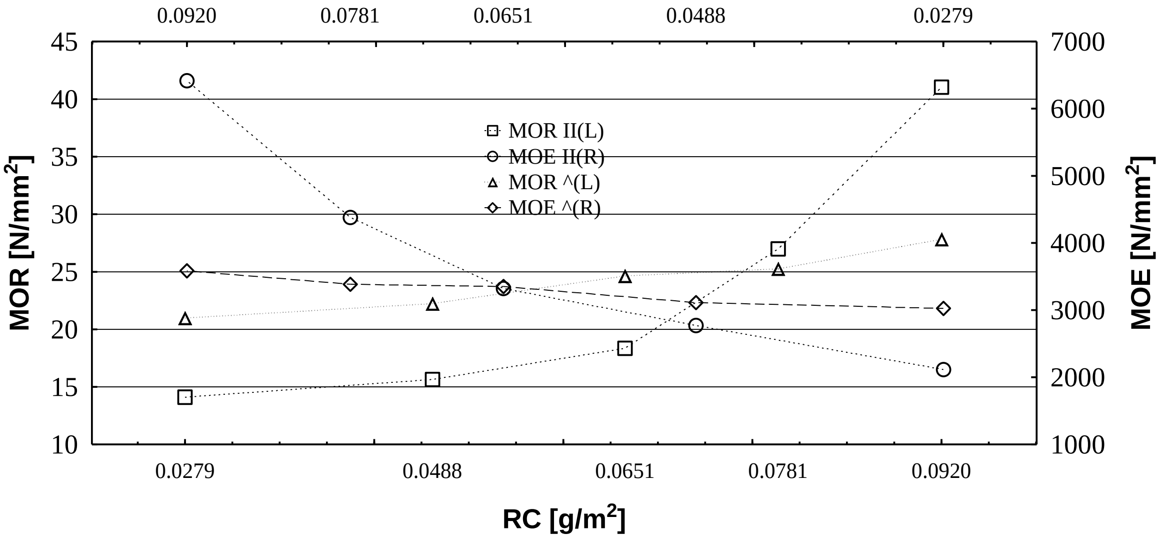

Fig. 5. The effect of resination coefficient on modulus of rigidity and modulus of elasticity

The highest IB was reported for the CC board, which was the board in which the chips in the external layer were those intended for the core layer of furniture particle boards that were also used in the manufacturing of MFP boards (Table 5). The value of this parameter was similar to the investigated MFP panel. Internal bond was strongly related to chip thickness and susceptibility of the mat to pressing. Although the average thickness of CC chips was similar to that of DD and EE chips, they also comprised about 20% of thicker chips, while in the other groups the share of chips with 1 mm or similar thickness was only a few percent. Therefore, assuming the same susceptibility of the core layer chips to pressing, CC chips were probably the most resistant during mat pressing, which translated into high IB of the boards made of this type of chips.

This study demonstrated that chips significantly shorter than strand chips, or even fine chips, may be successfully used in the manufacturing of external layers of OSB. Core layers made of strand chips provided high IB, whereas modulus of rigidity and modulus of elasticity strongly depended on the type of chips used in the external layers. Nevertheless, the boards made of the finest chips met all the relevant requirements for OSB/3 except for the requirements for modulus of elasticity for the longer axis set out in EN 310 (1993). The properties of the experimental boards were highly favorable when the chips in their external layers were the chips intended for MFP boards or for the core layer of furniture particle boards. Boards of this type met the requirements for P5 particle boards and, despite much lower density, they were only slightly less durable than MFP. High internal bond indicated that the resin content of the experimental boards was too high. It can be successfully lowered to 14.40 kg/m^3, and when accompanied by an increase in the gluing of external layers, a modulus of elasticity of 3500 N/mm^2 would probably be achieved. As far as the linear dimensions of the chips were concerned, the chips slightly longer than BB, *i.e.*, those with a computational length of 10.34 mm, should be enough to produce P2 boards in these experimental conditions. The chips suitable for OSB/3 production should be characterized by the computational length of about 25 mm.

The characterization of chips by both their linear dimensions and shape factors was found to be very cumbersome and did not provide an accurate description of the specific chip batch if they were not screened into a homogeneous dimension group. This was due to the fact that the dimensions of the chips retained on screens during screening for dimensional analysis and the chips in the entire batch rarely follow a normal distribution. Precise characterization of the experimental chip batch would require screening with several types of sorting machines and detailed statistical analysis for each screen and each sorting machine. Research publications usually report only the mean size, minimum, and maximum values for specific linear dimension. Specific surface of the chips seems to be a suitable parameter describing a chip batch, as it accounts for both linear dimensions relationships and the share of individual fractions. Following this assumption, the boards of P5 type with the core layer made of strand chips should have their external layers made of chips with specific surface of about 715 m^2/kg, which is of a mixture of BB and CC chips. The OSB/3 board, a serious alternative for MFP, due to low coefficient of orientation, can be manufactured using chips with specific surface of 590 m^2/kg, which is slightly larger than CC chips.

CONCLUSIONS

1. This study showed that the described modification of OSB structure, *i.e.*, replacing the strand chips of external layers with smaller chips, allowed for the manufacturing of OSB/3 using chips up to four times shorter than the standard strand chips.
2. With slight modifications of the gluing degree (core/face), the use of fine chips from a subscreen fraction of a 10 mm mesh screen, should enable the production of P5 type boards.
3. Reports from studies, including chips of different fractions, should be accompanied not only by a sieve analysis, but also by specific surface of the chips.

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