Possibility of Using Fine Wood Strands for the Production of P5 Type Building Boards

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This paper investigated the possibility of using very fine wood chips for the production of P5 type building boards according to the EN 312 (2010) standard. Small wood chips are more evenly compressed during mat pressing because they have a high bulk density. Therefore, the beneficial effects of forming denser outer layers is lost. To achieve the desired shape of the density profile curve of a board, the moisture content of the chips used in the outer face layers was increased considerably (up to about 30%). As a result of the conducted tests, the mechanical properties of the manufactured boards met the EN 312 requirements for P5 boards above a density of 650 kg/m^3. In cases when the additional conditions are being met, the standard requirements may be met at an even lower density level of approximately 550 kg/m^3.

Keywords: Small chips; Multi-functional panel; Mechanical properties; Density profile

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INTRODUCTION

For many years, there has been a strong development of boards manufactured from relatively large sized chips, including those that can be oriented easily (Keiser 1987; Barnes 2000; Barnes 2001; Chen *et al.* 2008). Oriented strand boards (OSBs) have quickly gained wide recognition among both customers and producers of wood-based materials because of their relatively low price. As a cheaper product, they can replace plywood within its traditional applications. Nevertheless, OSBs have recently gained strong competition, challenging their dominant position in applications such as sheathing elements, ceiling and floor linings, and formworks. The Pfleiderer company (2016) believes that the future belongs to the "Multifunktionsplatten" (MFP), which works well at every stage of a construction or renovation work, from the foundation to the roof (Premium Board MFP P5). According to Pfleiderer, the most important advantages of an MFP product stem from its homogeneous structure, which is achieved due to a specific technological process. Its strengths include high resistance to loads in each direction, increased water resistance, and increased fire resistance. Concurrently, the compact structure of the MFP board (average board density is 750 kg/m^3) reduces edge shredding, helps in precise hole drilling, facilitates cutting, and improves the fixing of screws, nails, and staples. Despite similar physical and mechanical properties displayed by both types of boards, the cost of producing MFP boards can be 20 to 25% lower than the cost of producing OSBs, due mostly to a difference in the quality of the raw material needed to obtain wood chips for board production. However, previous studies have pointed to the possibility of reducing OSB production costs by widening the raw material base (obtaining chips from less valuable species) (Zhang *et al.* 1998; Shupe *et al.* 2001; Hermawan *et al.* 2007; Cheng *et al.* 2012) by using finer wood chips (up to 100% in the middle layer) (Mirski and Dziurka 2011a,b; Fakhri *et al.* 2006a,b; Han *et al.* 2006. 2007) or by the reduction of the average board density (Chen *et al.* 2008; Mirski and Dziurka 2015). In the near future, one can expect general production of OSBs with density of around 500 kg/m^3. Current OSBs are over 100 kg/m^3 lighter than the equivalent MFP boards. There are a wide range of possibilities in shaping the mechanical properties of OSBs which result from the quality of chips used for their production. Thanks to their slenderness, the ability to orientate strands to maintain the cross construction of the board, as it happens in plywood.

One of the most interesting solutions is the method of reducing the average density of boards by increasing the density of the surface layers in relation to the middle layer (Sean and Brunette 2004). In this case, the decrease in the static bending strength and the decrease in the modulus of elasticity due to the lowering of the average board density is inhibited by the increase of the density of the outer layers responsible for these properties. The boards density profile can also be controlled by appropriate selection of compression parameters (*e.g.* the speed of closing the press), so that it is possible to affect the denser top layers. In the pressing process, the water content is extremely important, whereby the heat required for curing of the adhesive is rapidly transported into the deeper layers of the board.

Hence, the purpose of this work was to determine the impact of varying moisture levels of wood chips used to produce a three-layer, fine-chips on the physio-mechanical properties of such manufactured board. Research hypothesis of the study was to check whether using diverse moisture of chips can achieve the effect of a three-layer board.

EXPERIMENTAL

The researched boards were made of fine chips produced on the laboratory scale, and their properties were compared to a standard industrial MFP board. The boards were made from pine chips (*Pinus sylvestris* L.) obtained as a result of wood fragmentation in a laboratory mill. This treatment produced chips much smaller than the commonly used chips in the core layers of an MFP board and were relatively more homogeneous. The data presented in Table 1 shows more than 92% of the whole chip mass resulted from chips remaining on a sieve with a 1 mm mesh and passing through a 4 mm mesh. The chips prepared in this way did not contain larger chips, which would normally account for 15 to 20% of the whole chip mass (Mirski *et al.* 2013, 2016). A higher proportion of fine chips in a given volume increased the bulk density. The bulk density of wood chips used in testing was 170 ± 1.23 kg/m^3. The bulk density of industrial chips commonly used for the middle layer of furniture boards is approximately 120 kg/m^3. The MFP boards are most commonly produced from these industrial chips.

Table 1. Fractional Composition and Average Dimensions of Chips

Mesh Size	Split		Length	Width	Thickness
(mm)	(%)		(mm)		
6.3	0.10	59*	23.70**	4.79	0.90
5.0	0.31	22	23.92	3.46	0.74
4.0	1.01	26	17.94	2.79	0.85
2.0	32.68	5.9	10.91	1.79	0.66
1.0	59.59	6.6	7.06	1.65	0.58
0.5	4.47	3.3	4.33	0.95	0.36
0	1.84	12	-	-	-

Note: *Variation coefficient (5 replications were made) **Average of all chips remaining on the sieve or 20 pcs

Three-layer boards with a thickness of 15 mm were produced from such chips. The split of the layers was 1:2:1. Chips with a moisture content of 7.94% (υ = 4.63%) and 29.26% (υ = 3.80%) were used in the tests. Wet chips were obtained by spraying water on dry chips and leaving them in a sealed bag for three days. The bounding agent used was pMDI. No agents that would increase the hydrophobicity of the panels were used. The temperature of the heating plates was 200 °C. Variable factors was density of boards, resin content and pressing time. The production details are shown in Table 2.

Table 2. Characteristics of the Board Manufacturing Process with Various Layers' Moisture Content

Factor	Variant Designation							
	PB1	PB2a	PB3a	PB3b	PB4a	PB4b	PB5a	PB5b
Board Density (kg/m³)	650				525		400	
Resin Content (%)	4				5		6	
MC of Chips - top l. (%)	7.9	7.9	29.3					
MC of Chips - core l. (%)	7.9	29.3	7.9					
Pressing Time (s/mm)	22	49	29	20	29	20	29	20

Boards produced in this way were conditioned to the constant weight (7 days, 65 ± 5% RH 20 ± 2 °C) (Table 3) and after a period of conditioning, were tested in accordance with relevant standards for the following properties: modulus of rupture (MOR) and modulus of elasticity (MOE) according to EN 310 (1993); internal bond (IB) according to EN 319 (1993); internal bond after the boiling test (V-100) according to EN 1087-1 (1995); thickness swelling (TS) after 24 h according to EN 317 (1993); and water absorption (WA).

Table 3. Absolute Moisture Content of the Boards Immediately after Press Process and After Conditioning

Board Type	MC After Pressure (%)	MC For Tests (%)
PB1 (650 kg/m³)	1.91	4.68
PB2a (650 kg/m³)	0.31	2.73
PB3a (650 kg/m³)	0.53	2.98
PB4a (525 kg/m³)	-	3.35
PB5a (400 kg/m³)	-	4.03
PB3b (650 kg/m³)	2.70	6.28
PB4b (525 kg/m³)	2.28	6.04
PB5b (400 kg/m³)	2.15	5.47

The board density profile tests were performed with a DA-X profilegraph (GreCon Company, Hannover, Germany). For the assessment of mechanical properties and water resistance, 10 to 16 specimens were prepared for each variant, while the profile of density were determined based on 3 or 5 repetitions. Statistica 12.5 software (StatSoft Inc., Tulsa, OK, USA) was used to analyze the test results.

RESULTS AND DISCUSSION

In the wood-based industry, microchip technology is used in the outer layers for the production of furniture boards. Such treatments increase the surface smoothness of the boards and is important in the process of their refining. It also notably affects the density profile of such boards. Microchip pieces offer less resistance during pressing and show greater compression ability due to their finer structure. For that reason, the maximum densities obtained in these layers were up to two times higher than the minimum densities of the board's core layer. The use of a special technological process in which the chips in the outer layers were of higher moisture content than the chips of the inner layer aimed at achieving a similar density profile as in the case of a three-layer furniture board. Density profiles of laboratory produced boards with an average density of 650 kg/m^3 produced from chips with different moisture levels and an industrial MFP board are shown in Fig. 1, and the characteristic values for these runs are shown in Table 4.

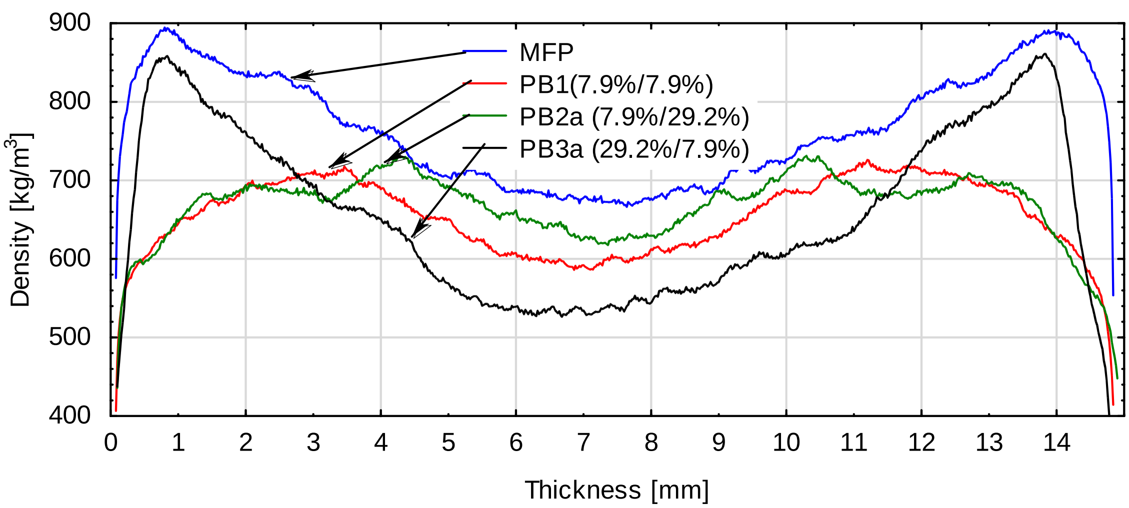

Fig. 1. Density profiles of industrial MFP and laboratory boards with density of 650 kg/m^3

Table 4. Relevant Values of Board Density Profiles for MFP, PB1, PB2a, and PB3a

Board	Average Density*	Thickness	Outer Layer (Up)		Core Layer			Outer Layer (Down)	
			Th.**	Max	Th.	Average	Min	Th.	Max
	kg/m³	mm	mm	kg/m³	mm	kg/m³	kg/m³	mm	kg/m³
MFP	765	14.88	3.46	895	7.96	712	666	3.42	891
PB1	649	14.88	3.76	717	7.84	638	586	3.70	726
PB2a	651	14.98	3.80	709	7.36	674	617	3.82	709
PB3a	650	14.88	3.28	860	8.30	576	526	3.30	860

Note: * Average value for tested samples; ** Layer thickness

The tested MFP boards were characterized as having a typical M-shaped density profile. However, the relationship between the maximum density values of the outer layers and the minimum density value of the core was much smaller than the OSB and furniture three-layer boards. In particular, the difference was only 230 kg/m^3 for the MFP boards, approximately 270 kg/m^3 for the OSB/3 boards (Mirski and Dziurka 2013), and can reach up to 500 kg/m^3 for the board for interior fitments (including furniture – type P2). These results are achieved manly through the use of much finer chips or chips more susceptible to compression in the outer layers. Similar to the PB1 laboratory produced (control) boards, the use of fine chips with the same compression ability in board production caused the profile to become flat. The difference between the maximum density of the outer layers and the minimum density of the middle layer was only 140 kg/m^3. In addition, the maximum density values in the outer layers were obtained at depths close to the middle layer, which is contrary to the results of the industrial MFP boards. This is most likely due to the fact that fine chips, which by their very nature form a compact mat, press on the subsequent layers, putting a uniform resistance against the pressing heating plates. This hypothesis is supported by the shape of the board density profile for PB2a in which the wet chips formed the middle layer. In this case, the maximum and minimum densities were in the middle layer. Because the outer layers were less susceptible to compression, they pressed harder against the more susceptible wet chips of the middle layer. The thickness of the outer layers in both board types described above was similar at approximately 3.75 to 3.80 mm. Accordingly, the use of wet chips to form the outer layers, even those of small linear dimensions, allowed for high compression of these layers (PB3s). The thicknesses of the outer layers were much smaller than in other cases and amounted to 3.30 mm. In addition, the maximum density values were in the outer layers and placed at relatively shallow depths. The difference of the maximum to minimum density for this board reached 340 kg/m^3. The density profile of the boards pressed in the longer time is shown in Fig. 2. Regardless of the press control method, the density profiles of the PB3a and PB3b boards were similar to each other. Lowering the average board density caused proportional changes in the density of the outer layers as well as the middle layer and expansion of the low density range.

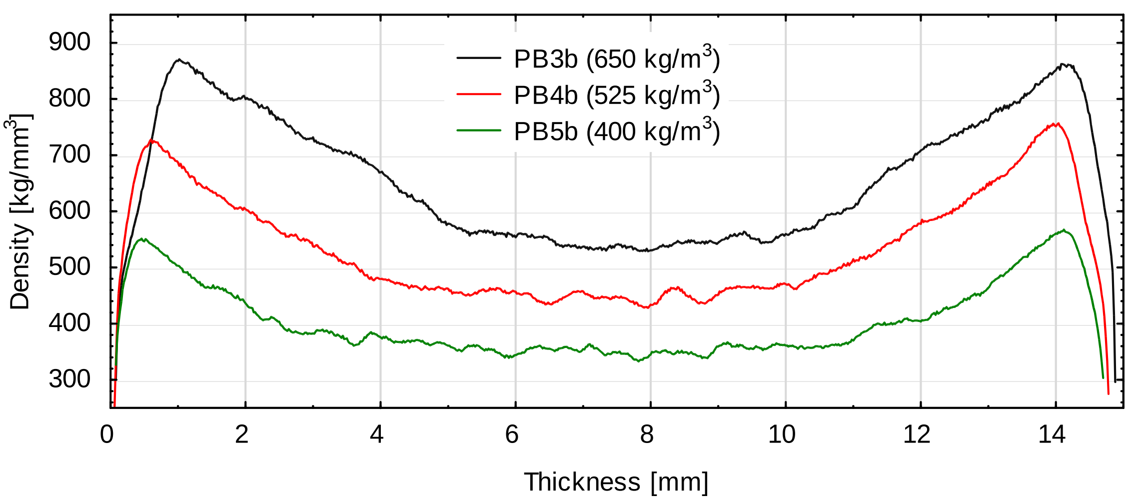

Fig. 3. Density profiles of boards pressed in an automatic cycle

The results of the static bending strength and modulus of elasticity tests are presented in Table 5. The control board (PB1) was characterized by a relatively high resistance to static bending over 17 N/mm^2, and its modulus of elasticity was over 3000 N/mm^2. The use of moist chips in the middle layer only slightly reduced these properties (PB2a board). The decrease in static bending strength was only 4% and the modulus of elasticity was lower by less than 3%. In contrast, the PB3a board which used wet chips to form the outer layers was characterized by much better properties than the Pb2a board, including 12% greater modulus of elasticity and 9% higher static bending strength than the reference board. However, when the average density of the board was reduced from 650 to 540 kg/m³, the bending strength and the modulus of elasticity decreased by 23% and 22% respectively, despite the use of wet chips in the outer layers. Further reduction of density caused strong reductions in the discussed properties that boards with the density of 410 kg/m³ could not even be classified as furniture boards. This was most likely due to too short pressing time, not sufficient to form a high-strength joint. Confirmation of this reasoning are the results of the second series, in which the boards were pressed in a longer time, which provided in a better join strength, as a result of complete curing of the resin. In this case a board with an assumed density of 650 kg/m³ had a static bending strength that exceeded 22.5 N/mm² and a modulus of elasticity above 4000 N/mm². That was an increase of approximately 30% in comparison to the control board. The board with a density reduced by over 100 kg/m³ still showed high parameters, with modulus of elasticity higher than the control board and static bending strength lower by just 1.2 N/mm². In contrast, the board with an assumed density of 410 kg/m³ was characterized by very low properties. In this case, despite the increase of over 20% in properties as compared to the board pressed in the shorter time, the obtained values were still unsatisfactory.

Table 5. Resistance to Static Bending and Modulus of Elasticity of Pressed Boards

Board Type	Density		MOR		MOE	
	$\bar{x}$ (kg/m³)	υ (%)	$\bar{x}$ (N/mm²)	υ (%)	$\bar{x}$ (MPa)	υ (%)
PB1	650	*2.57*	17.2	*8.4*	3008	*5.3*
PB2a	640	*3.3*	16.5	*11.50*	2920	*8.09*
PB3a	650	*2.1*	19.3	*11.1*	3369	*5.93*
PB4a	540	*6.6*	13.2	*19.8*	2624	*14.2*
PB5a	410	*3.1*	6.2	*20.9*	1256	*13.7*
PB3b	650	*2.0*	22.6	*7.4*	4191	*5.6*
PB4b	555	*3.3*	16.8	*6.5*	3281	*7.5*
PB5b	410	*5.5*	7.5	*24.9*	1595	*10.3*

The results of the tensile strength measurements perpendicular to the board planes are given in Table 6. From boards manufactured in the first series of tests, the highest tensile strength perpendicular to the board planes was observed in the control board. The average strength for this board was 0.75 N/mm² and was higher by 0.05 N/mm² than the strength of the boards with wet chips used to form the outer layers and as much as 0.11 N/mm² when the wet chips were used to form the inner layer. Increasing the moisture content of chips for the external layers should automatically affect the density reductions in the middle layer. This procedure led to a reduction in tensile strength in the direction perpendicular to the plane of the board. However, according to the data obtained for the second series of tests, better heat transfer into the mat and better cross-linking of the glue inside the manufactured board compensated for changes in the density. Therefore, the strength of the PB3b boards was nearly 25% greater than the strength of the control board. The high water resistance measured with the V100 test was characteristic to all tested boards regardless of the production conditions and density levels adopted. This was due to the high quality of the material used in the research, which contained only small amounts of bark and favourable shape geometry. When the average density is decreased, the degree of chip gluing increased. In contrast, the swelling volume of the layers was characteristic for boards manufactured with unprotected chips.

Table 6. Tensile Strength in the Direction Perpendicular to the Board Plane

Board Type	IB		V100		TS	
	$\bar{x}$ (N/mm^2)	υ (%)	$\bar{x}$ (N/mm^2)	υ (%)	$\bar{x}$ (%)	υ (%)
PB1	0.75	7.2	0.28	10.5	30.7	10
PB2a	0.64	7.2	0.41	9.7	20.2	6.4
PB3a	0.70	11.3	0.30	7.4	22.4	5.5
PB4a	0.48	11.2	0.29	14.4	17.9	7.4
PB5a	0.25	16.0	0.16	12.4	12.7	7.0
PB3b	0.93	5.7	0.36	11.2	27	6.1
PB4b	0.68	5.7	0.29	7.8	17.9	5.6
PB5b	0.27	16.4	0.15	17.9	14.2	5.7

Table 7 shows the values of the 5th percentile of mechanical properties of both the manufactured boards and the MFP industrial board, as they are related to the requirements of EN 312. The results showed that the MFP industrial board met not only the requirements for P5 or OSB/3 boards, but that its parameters were much higher than maximum requirements for any of the standards. Therefore, these boards were strong competition for OSBs. From all the boards produced in laboratory conditions, the requirements for P5 boards were fulfilled only by the PB3a and PB3b boards, *i.e.* boards with modified density profile and an average density of 650 kg/m^3. The PB4b board did not meet the requirements only in terms of static bending strength. Perhaps this is a result of manually forming the mat or of the uniformity of applying glue to the chips. The industrial boards were characterized by a much smaller spread around the average value, which in addition was relatively high. It therefore seems likely that in case of better mat preparation, not only the average level, but also the 5th percentile will be achieved.

Table 7. Board Properties in Accordance with the Requirement of EN 312 (2010) and EN 300 (2006)

Board Type	5th Percentile					
	MOR II	MOR ⊥	MOE II	MOE ⊥	IB	V100
EN 312*	16		2400		0.45	0.14
EN 300**	20	10	3500	2400	0.45	0.15
MFP	23.4 (2.7***)	20.3 (2.9)	4230 (2.0)	3740 (1.9)	0.64	0.20
PB1	15.3		2830		0.65	0.26
PB3a	16.3		3110			
PB3b	19.4		3870		0.87	0.29
PB4b	15.6		3000		0.62	0.27

Note: *Required values for P5; **Required values for OSB/3; ***Coefficient of variation

CONCLUSIONS

1. The moisture content of the chips in a mat was important for the formation of the board density profile.
2. The use of much higher moisture chips in the core layer of the mat caused strong density increases of this layer and contributed to the increased properties related to tensile strength perpendicular to the board planes.
3. The use of much higher moisture chips in the outer layers of the mat caused a high density increase of these layers and contributed to the increased properties determined in the three-point bending test.
4. The use of much higher moisture chips in the outer layers of the mat allowed production of boards with better mechanical properties as compared to boards produced from chips with similar moisture in all layers.
5. Despite the use of relatively small chips in the research, the applied modification allowed production of boards with a density of 550 kg/m³ with mechanical properties similar to those required by the EN 312 standard for P5 type boards.

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