The Influence of Speed and Press Factor on Oriented Strand Board Performance in Continuous Press

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Three-layer cross-oriented strand boards, OSB type 3 of 10 mm thick, were industrially manufactured from a mixture of wood species including 50% softwoods, 25% beech, and 25% low hardwoods, using a continuous press line. The effects of line speed and press factor on physical and mechanical properties of OSB/3 (exterior grade) were evaluated, keeping nearly constant the face-core adhesive ratio. The manufactured boards were classified into five groups depending on the pressing parameters. The experimental results showed that all mechanical properties increased, with increasing press factor and decreasing line speed. The ratios of bending strength (MOR) and the modulus of elasticity (MOE) parallel to perpendicular were 1.73 to 1.89 and 2.18 to 2.24, respectively. No significant differences in thickness swell and water absorption were observed. The lowest density was achieved at higher speed, although there was no large variation in densities between groups. Thickness swelling and internal bond after boil test exceeded the EN 300 standard requirements for OSB/3 moisture resistance, excepting a few boards. The results revealed that a correlation between speed and press factor is necessary in order to improve mechanical properties and to keep the physical performance of boards within a limited range of values.

Keywords: Oriented strand board (OSB); Continuous press; Press factor; Speed line; Physical properties; Mechanical properties

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INTRODUCTION

The commercial production of oriented strand boards (OSB) started in the 1980s in the U.S., Canada, and in Europe (Germany), based on the invention of Armin Elmendorf, who first referenced the use of strands in structural particle board in 1949 (Dick 2009; Thoemen *et al*. 2010). Since then, extensive research has been carried out to improve the manufacturing process and allow for OSB panels in structural applications. The stiffness and strength of OSB are increased by orienting the surface strands parallel to the forming line direction and the core strands at right angles to surface layers. The OSB production has continued to increase, reaching 13.5 million m^3 in North America in 2011, 4.7 million m^3 in Canada, and 4.5 million m^3 in Europe (Eastin *et al.* 2012). Increasing demands for more competitive products on the market has pushed the manufacturers to raise their capacity utilization rate and diversify their production. OSB is well known for its usage as building material in roofs, walls, and ceiling construction.

It has good mechanical properties suited for load-bearing structure in wood–frame construction as wall reinforcement, I-joists, roof sheathing, and sub-flooring. Therefore, from general use to structural applications, OSB has found success and currently dominates more than half of the structural panel market (Ainsworth 2007).

The OSB manufacturing process is highly automated, using mostly batch presses (cycle presses) of either single or multi-opening design. With tendency for increasing productivity and efficiency, continuous presses started to be the leader among OSB manufacturers. In contrast to traditional batch presses, the continuous presses show a favorable acceptance by the wood based panel manufacturers due to their multiple advantages. Continuous presses run with a defined pressure and temperature profile over the whole effective length and are economical consumers of electrical and thermal energy. They need minimal hydraulic forces to maintain the pressure applied, or to decrease or increase it slightly, whereas in batch presses such forces vary between zero and maximum due to closing-opening cycles (Sandvik 2009). The extraordinary length of a continuous press (53 to 70 m) and pre-heating system allow it to work with a speed up to 2000 mm/sec (Bielfeldt *et al.* 2013). A further plus for continuous presses is the pressing time factor, which was estimated at 4.0 s/mm for the optimal panel thickness of 16 to 19 mm. The factor depends on press temperature, which can reach 240 ^{o}C (Sandvik 2009).

As the hot-press represents the key operation in any wood-based composite manufacture, studies have been carried out to understand and evaluate its influence on board properties. During such an operation, mats of wood flakes mixed with adhesive are consolidated under heat and pressure, creating close contact and forming bonds between the wood constituents (Dai and Wang 2004). To increase production capacity and decrease product cost, the industry uses extreme conditions for pressing (in cycle presses), such high temperatures (up to 200 °C) and short pressing cycles. Long press closure times will cause a reduced bond between surface particles and surface peel-off in OSB (Wang *et al.* 2000). The increase of pressing time from 3 to 7 min improved the OSB properties at 0.4 MPa pressure, in a single opening press (Gündüz *et al*. 2011).

Many such studies have been performed in laboratory conditions on single opening presses and have been focused mainly on the effect of board density (Han *et al.* 2007; Suzuki *et al.* 2007), strand length and orientation, strand combination (Febrianto *et al.* 2010; Akrami *et al*. 2014), adhesive ratio (Cavdar *et al*. 2008; Gündüz *et al*. 2011), and new raw material (Han *et al*. 2005; Febrianto 2010; Mulik and Febrianto 2013), on physical and mechanical properties of OSB. Few studies have reported data derived from commercially tested OSB board concerning their mechanical properties and behavior under different conditions (Thomas 2001; Wang *et al*. 2003, 2004; Rebollar *et al.* 2007; Hrázskýand Král 2011). Data directly obtained from industrially pressed boards are limited. Some improvements in mechanical properties of OSB/3, by changing pressure, temperature, and distance between frames of continuous press, were reported by (Hrázský 2011).

Pressing parameters are closely associated with the product quality (board properties) and manufacturing costs. Manipulating pressure parameters within some limits leads to process improvement.

The objective of this research was to evaluate the influence of press factor and speed line of continuous press on physical and mechanical properties and give information valuable for manufacturers in order to improve their products quality by proper set of pressing parameters. Another important issue derived from this study is that not solely pressing parameters can be manipulated to control the OSB properties. There are other factors that interact with each other, leading to improved behavior relative to moisture, especially in the case of boards used in structural applications (OSB/3).

EXPERIMENTAL

Materials

OSB type 3 boards (OSB/3 - according to EN 300) of 10 mm thickness were manufactured from a mixture of strands including 50% softwoods (spruce-*Picea abies*, fir-*Abies alba*, pine-*Pinus sylvestris*, larch-*Larix decidua*), 25% beech (*Fagus sylvatica*), and 25% different low density hardwood species (poplar-*Populus tremula*, birch-*Betula pendula*, willow-*Salix alba*, alder-*Alnus glutinosa).* The raw material moisture content was about 42% and 46% for softwood and hardwood species, respectively. The strands were generated by a Leonhardt type flaker to an average size of 120 mm long, 25 mm wide, and 0.55 mm thick. After drying to a moisture content (MC) of 3%, the graded strands were then blended with MUF (melamine-urea-formaldehyde) adhesive for faces (F) and PMDI (polymeric diphenylmethane diisocyanate) for core (C), adding also wax and water. The amount of adhesive and wax was based on the oven-dried weight of the strands. Wax emulsion was a mixture of 54% water, 45% paraffin, and 1% emulsifier. In-line adhesive blending was used; thus, all components were added simultaneously into the blender. The adhesive percentages, varied within certain limits, consequently the lowest and the highest values of the boards within a group and the average, for both face and core layer, are presented in Table 2. After blending, the strands MC ranged from 3.0% to 4.0% and 17% to 19% for core and faces, respectively.

Mat formation and pressing were performed under industrial conditions, the parameters being automatically set by computer according to the OSB type. A forming line was used with a 53.03 m Dieffenbacher continuous press, which operates at a speed up to 1200 mm/s. The shell ratios used (the ratio on a weight basis of face to core materials) of the three-layer boards, with a cross-oriented core, was kept within the range 30-40-30 percent. The common shell ratio is 30-40-30 percent, but may be used also 25-50-25 percent (Wang *et al*. 2003, Gu *et al*. 2005)

The pressing process is carried out between two steel belts running along a fixed pressing line. There are 41 pressing frames and six upper and lower heating plates warmed with thermal oil. In the continuous press there are six groups of pressing, characterised by different temperatures and pressures as is specified in Table 1.

Table 1. Pressing Parameters

Press frames	Pressing areas	Temperature (°C)	Specific pressure (N/mm^2)
1-19	High pressure	230-250	4.0-5.0
20-30	Medium pressure (heating area)	220-230	2.5
31-41	Low pressure (calibration area)	190-220	1.5

After pressing, the boards were trimmed to remove the edges, cooled, and transported to the storage area. The target density ranged between 580 kg/m^3 and 615 kg/m^3.

Specimen Preparation

From a total of 75 boards, only 20 boards, dimensioned at 2500 x 1250 mm, were subjected to analysis. The selected boards were labeled OSB type 3 (OSB/3- load-bearing boards for use in humid conditions) according to EN 300 (2006). The selected boards were divided into 5 groups (4 boards in each group) depending on the pressing parameters (speed and press factor). The characteristics of the tested boards and the press parameters are presented in Table 2.

From each type of boards, specimens were prepared for determination of physical and mechanical properties such as: density, moisture content (MC), thickness swelling (TS), water absorption (WA) after 24 h soaking in water, modulus of rupture and modulus of elasticity (MOR/MOE), internal bond strength (IB), and internal bond after boiling test (IB-BT). The specimens were conditioned at 20±2 °C temperature and 65±5% relative humidity before evaluating the properties.

Table 2. Test OSB/3 Specifications

The board code	Adhesive ratio (average value*)		Target density (kg/m^3)	Pressing parameters	
	MUF (F) (%)	PMDI (C) (%)		Speed line (mm/s)	Press factor (s/mm)
1A	2.7-3.6 (3.15)*	2.8-3.1 (2.95)*	580-610	500-580	8.90-11.00
2B	3.4-3.7 (3.55)*	2.7-3.2 (2.95)*	590-620	700-720	7.50-7.9
3C	3.3-3.5 (3.4)*	2.6-3.0 (2.8)*	590-600	800-830	6.7-6.9
4D	3.4-3.5 (3.45)*	2.8-2.9 (2.85)*	610-615	1040-1100	5.07-5.30
5E	3.4-3.5 (3.45)*	2.8-2.9 (2.85)*	582-615	1140-1190	4.7-4.9

Research Methodology

The number and dimensions for the tested specimens were in accordance with each standard methodology. The bending strength (MOR) and the modulus of elasticity (MOE) were tested according to EN 310 (1993) on 12 specimens, six for parallel direction (long axis of the board), and the other six for perpendicular direction (minor axis of the board). Eight specimens of 50 x 50 mm were used for internal bond strength according to EN 319 (1993) and boiling test (EN 1087-1, 1995), and thickness swelling and absorption based on EN 317 (1993).

On the same specimen dimensions, the moisture content (4 samples) and density distribution (22 samples) tests were performed according to EN 322 and EN 323 (1993) standards. IB, MOE, and MOR measurements were made on a Zwick/RoellZ010, universal testing machine (Germany).

RESULTS AND DISCUSSION

Physical Properties

The physical properties are presented in Table 3. The average density for the groups 1A, 2B, and 3C was within the density target limits, while for 4D and 5E groups it was below the target density (with 593 kg/m^3 and 584 kg/m^3, respectively). The compactness of the individual particles in a board is represented by density, which is dependent on the furnish characteristics, configuration, MC and its distribution, and pressing parameters (Maloney 1993). It was observed that high speed and corresponding low press factor led to boards with lower density and higher moisture content than those pressed under lower speed and higher press factor. The mat compaction during pressing and the raw material density control the final density of board. Therefore, the pressing factor had a major influence in the degree of compaction at the same density and characteristics of the raw material. Decreasing the press factor decreases the mat compression, resulting in more voids inside the board structure, thus influencing the board density. Generally it is recommended to compress the board to a density in the range of 1.2 to 1.6 times that of the initial strands density to have a satisfactory contact between strands in the board (Bowyer *et al*. 2003). However, no great differences in densities between groups were observed. The lowest density was registered for 5E group (564 kg/m^3, E-1 board) and the highest for 1A and 2B groups with about 616 kg/m^3 (A-2 and B-4 boards) (Fig. 1).

To determine significant differences between and within the density of groups, a statistical analysis using one-way ANOVA and Tukey's HSD (honestly significant difference) at $\alpha = 0.05$ significance level was used. No statistically significant differences between the average densities in boards level were found ($F(4,15) = 0.763$, $p=0.565$). All the boards met the requirements for density tolerance ±15% as specified in EN 300 Standard (excepting 2 boards from the 3C group).

Table 3. Results for Physical Properties

Board code	Board characteristics							
	Density (kg/m^3)		Moisture content (%)		TS-24h (%)		WA-24h (%)	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
1A	597.75	26.82	3.87	0.36	20.04	3.08	67.02	7.98
2B	598.25	28.35	3.55	0.24	20.47	2.32	66.30	6.65
3C	595.25	34.45	3.82	0.37	22.60	3.85	79.53	7.57
4D	593.25	27.21	4.66	0.77	20.23	2.81	68.60	6.92
5E	583.75	24.37	5.44	0.71	21.42	3.08	70.93	4.97
SR EN*	±15%		2-12		15			
*Minimum requirements according to EN 300:2006 (OSB/3)								

The average values of moisture content (MC) ranged from 3.55% to 5.44%. The lowest and the highest moisture content values (3.55% and 5.44%, respectively), were reached by the 2B and 5E groups respectively. Therefore the boards from 2B group were more homogenous relative to moisture content values and mechanical properties than the other four groups. According to EN 300, all boards met the requirement for moisture content (2 to 12%).

Dimensional Stability

The board dimensional stability was evaluated by TS and WA parameters. Thickness swell is a disputed subject, density playing an important role in the board behavior. Researchers have reported contradictory results concerning the TS relation with the board density. Normally, TS tends to increase with density (Wu and Piao 1999; Linville 2000; Wu and Lee 2002; Akrami 2014a). However, according to other previous research, an increase in swelling should be expected with decrease in board density are anticipated (Maloney 1993). A decrease of TS and WA with increasing board density was observed also by Chen *et al*. (2010) and by Akrami *et al.* (2014a) in case of boards made of pure beech and those with core made of beech strands. This phenomenon is not common for all types of boards from the analysed groups. The lowest values of TS were achieved by boards either with high density (A-1, A-4, B-1 boards), or with low density (D-1, E-1). The same situation was observed for highest TS values (C-4, E-3 and C-1, E-2 boards, respectively) (Fig. 1). It is important to emphasize that due to small variation in densities between and within group, and at similar amounts of adhesives, the panels did not show significant variation in TS between groups; TS values ranged from 17.56% to 24.15%, the highest values being achieved by the boards from 3C group.

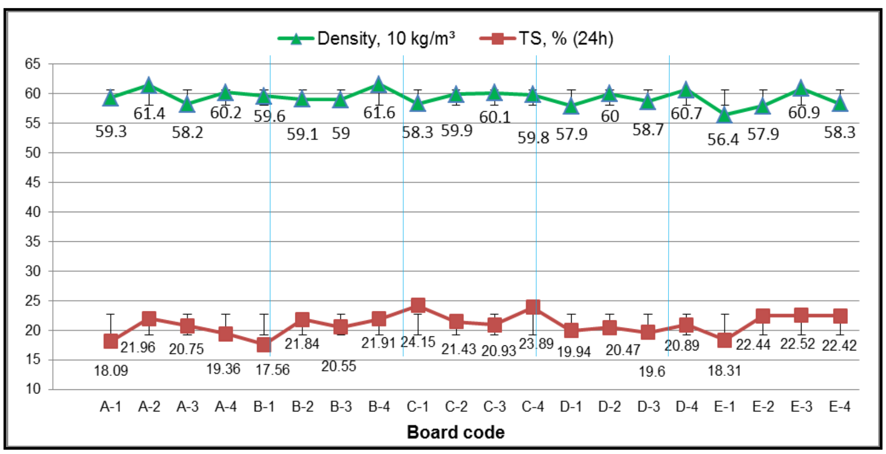


Fig. 1. Thickness swelling dependence on density within the boards of each group

Water absorption ranged between 66.30% and 79.53% with small differences between the boards within all groups. Similar results on TS and WA were reported by Wang (2003) and Rebollar (2007) for commercial OSB boards. It seems that group C was the most unfavorable in terms of dimensional stability, whereas an increase with about 11% and 17% was registered for TS and WA, respectively. The boards of this group had a slightly lower amount of adhesive for both faces and core compared to the other groups, which might have influenced the TS. Even though differences in TS were small, they could be a result of nonuniform densification in the face areas due to high speed and low press factor. Unfortunately, no evidence on VDP was available from production.

Thickness swelling values exceeded the minimum OSB requirements of 15% based on the EN 300 standard. This could be a result of less uniform density distribution of strands in the board thickness, degree of bonding (Lin *et al.* 2013), and delaminations occurring between unbalanced swelling layers (Gu *et al.* 2005). Springback of the panels as they are soaked in water leads to lower dimensional stability, which is a common behavior of any wood composite (Kalaycioğlu *et al.* 2005). Akrami *et al.* (2014a, b) found that panels made with beech fine strands in the core layer (up to 30%) and those with 100% poplar strands and 75% poplar core strands, showed also high thickness swelling, exceeding the EN 300 standard requirement.

Mechanical Properties

Bending strength

The average values for bending modulus (MOE), strength (MOR), internal bond strength (IB), and internal bond after boiling test are shown in Table 4.

Table 4. Results of Mechanical Properties

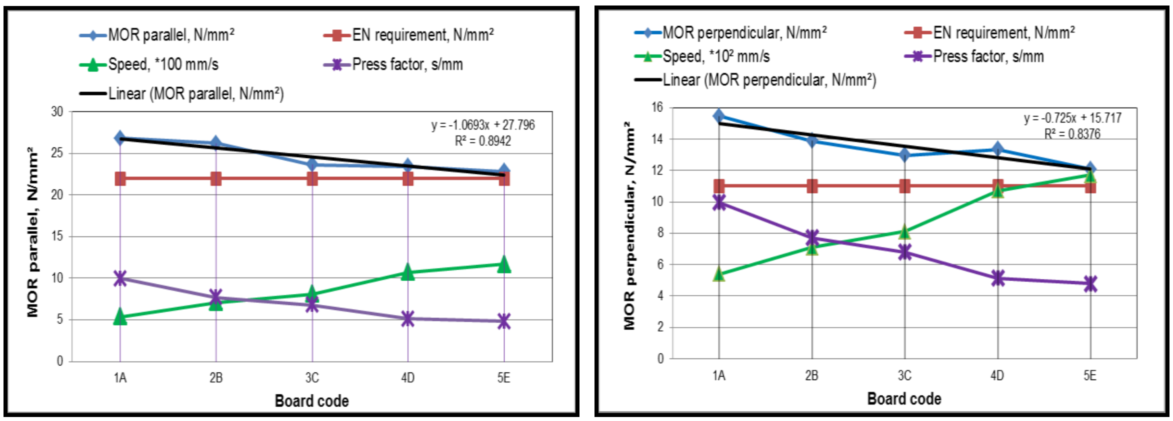
Board code	Board Characteristics					
	MOR parallel[a] N/mm²	MOR perpendicular[b] N/mm²	MOE parallel[a] N/mm²	MOE perpendicular[b] N/mm²	IB N/mm²	IB Boil test N/mm²
	Mean	Mean	Mean	Mean	Mean	Mean
1A	26.8 (4.45)	15.4 (3.17)	4769 (753)	2186 (362)	0.43 (0.08)	0.18 (0.04)
2B	26.2 (5.32)	13.8 (2.53)	4510 (775)	1983 (407)	0.41 (0.12)	0.16 (0.05)
3C	23.6 (5.96)	12.9 (2.58)	4412 (781)	1963 (387)	0.39 (0.06)	0.12 (0.05)
4D	23.4 (4.90)	13.3 (2.54)	4269 (797)	1806 (343)	0.39 (0.08)	0.14 (0.04)
5E	22.8 (4.66)	12.1 (1.92)	3934 (618)	1667 (242)	0.39 (0.04)	0.13 (0.03)
EN[c]	22	11	3500	1400	0.34	0.15

[a] Parallel to length axis of board
[b] Perpendicular to length axis of board
[c] Minimum requirements according to EN 300:2006
Standard deviations are given in parenthesis

MOR and MOE in parallel direction (major axis) varied from 22.8 N/mm^2 to 26.8 N/mm^2 and from 3934 N/mm^2 to 4769 N/mm^2, respectively. There were differences in MOE and MOR along the parallel and perpendicular directions, the lower values being registered for MOR and MOE in perpendicular direction (minor axis) from 12.1 N/mm^2 to 15.4 N/mm^2 and from 1667 N/mm^2 to 2186 N/mm^2, respectively.

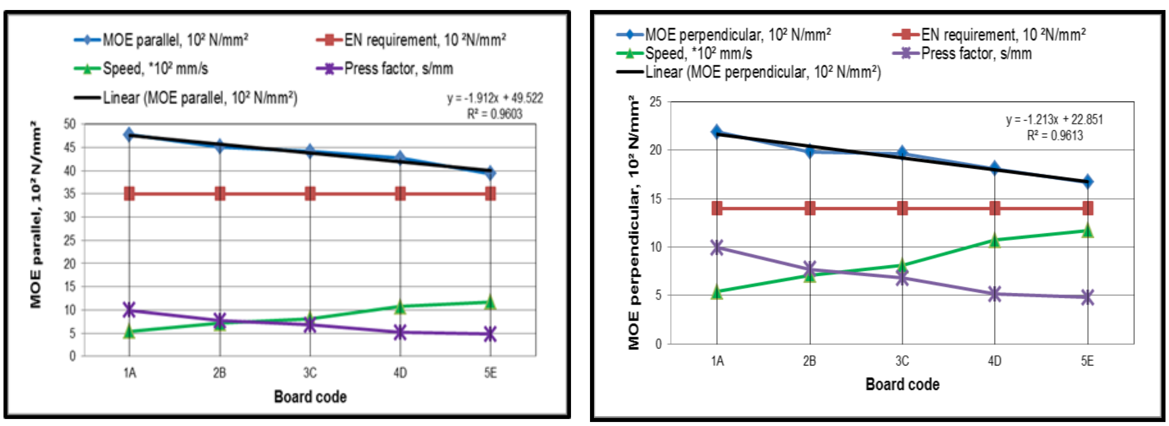
The groups 1A and 2B had the highest MOR and MOE values in both directions, but the ratios of parallel to perpendicular MOR and MOE were rather low (1.73 to 1.89 and 2.18 to 2.24, respectively). The panels from 3C, 4D, and 5E groups had lower MOR and MOE values but similar ratio with 1A and 2B groups. This demonstrated that strands shape and orientation in panels were good, but the panel density was lower compared to panels from the 1A and 2B groups. The results were comparable with those reported by Wang (2004) for MOR and MOE of OSB pine panels, 1.77 and 2.44, respectively. High MOR values may be obtained from the strands with aspect ratio value between 3 and 4 (Nishimura *et al*. 2004), as can be observed also on all tested boards which had a slight higher aspect ratio (strand length divided by its width) of 4.8. The MOR and MOE parallel values are normally double to those across the board. This is an effect of the strand orientation in the face layer (Thoemen *et al.* 2010).

As can be seen from the reported data, for 4D and 5E groups, the mechanical properties decreased with decreasing press factor and increasing speed (Table 1 and Fig. 2, Fig. 3). There was a positive linear correlation between mechanical parameters and press factor (R^2 0.83 to 0.96). Besides high temperatures, the adequate press factor and speed line are needed to achieve rapid cure of the adhesive and provide the mat compaction by wood plasticization. Temperature, moisture content, time, and pressure influence the resin penetration by controlling the resin flow and viscosity of resin (Carvalho *et al*. 2010). A low resin viscosity decreases its capability of uniform wetting of strands; on the other hand a high viscosity resin cannot penetrate the strands. Thus, both situations lead to weak bonds, decreasing the board strength.



A. B.

Fig. 2. Correlations between MOR parallel (A) and perpendicular (B), press factor and speed



A. B.

Fig. 3. Correlations between MOE parallel (A) and perpendicular (B), press factor and speed

Rowell (2005) stated that changes in the board MC have a major effect on mechanical properties, which increase with decreasing MC. These changes in MC are related to OSB/3 exposure under different environment conditions. Increasing MC will negatively influence the board properties, finally leading to reduced board durability.

The MC of boards was measured just after pressing, on four samples conditioned at 20±2 °C and 65±5% relative humidity in order to verify the conformity with standard requirements (EN 300). It might be possible that this was not enough time to help balance moisture content distribution in boards and stresses. With increasing speed it is possible that different areas with different MC may have developed due to non-uniform heating thus influencing the final MC. Therefore not all data are available from production (*e.g.* vertical density profile), which would help in better explanation of the board behavior. The proportion between species used in OSB structure (as shell ratio used) which varied in some limits, might be the responsible for differences in the final MC.

Internal bond

The inner bond quality of boards was evaluated by internal bond strength (IB), determined by tensile strength perpendicular to the board surface. The average value is presented in Table 4. The IB of all boards varied between 0.39 N/mm^2 to 0.43 N/mm^2, the higher values being registered in the case of lower speeds (500 to 700 mm/s) and high press factors (7.5 to 11). All the IB values were slightly above the minimum requirements for OSB/3 (0.34 N/mm^2) according to the EN 300 (2006) standard. The PMDI adhesive used for core proved its performance, resulting in good internal cohesion for all board. Compared to formaldehyde products, MDI resins improve the bond quality by spreading over the strands surface, as well as penetrating into cracks, cell lumens, and even in cell walls (Huntsman 2011).

The requirements for moisture resistance of OSB/3 impose evaluation of internal bond after the boiling test, which should yield a value of 15%. The tested boards didn't fulfill this requirement, excepting the boards from 1A and 2B groups, as is shown in Table 4. Higher compaction and possible deeper penetration of adhesive due to higher press factor may contribute to better behavior to boiling test of these boards compared to those from the other groups.

CONCLUSIONS

1. The physical and mechanical properties strongly depend on the speed line and press factor. Low speed and correspondent high press factor led to an increase in all mechanical properties.
2. There was good linear correlation between press factor and MOR/MOE properties. Doubling of pressing factor and reducing by half of speed line led to increases of MOR/MOE properties up to 24%.
3. Slight differences were found for internal bond strength between board groups, knowing that it depends strongly on the amount of resin applied, which was almost similar for all boards.
4. Thickness swelling and water absorption values varied in small limits between groups, the speed line and the press factor having less effect on these properties.
5. All tested boards met the requirements of EN 300 standard for grade 3 (OSB/3) in terms of mechanical properties, but failed in thickness swell and moisture resistance requirements. Only the boards subjected to high press factor and low speed line passed the boiling test.

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