Effects of Strands Geometry on the Physical and Mechanical Properties of Oriented Strand Boards (OSBs) Made from Black Spruce and Trembling Aspen

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Black spruce is widely used for lumber production in Eastern Canada, and it has the potential to replace trembling aspen and paper birch for oriented strand board (OSB) manufacturing. This study evaluated the bending modulus of elasticity (MOE) and modulus of rupture (MOR), the internal bond (IB), and the thickness swelling (TS) of OSB panels made from black spruce and trembling aspen strands and how they were affected by strand geometry. All the panels met the CSA O437 (1993) standard for class O-2 properties except for the TS. The strand thickness had a significantly negative effect on the bending properties but a significantly positive effect on the IB and TS properties. The strand length had a significantly positive effect on the parallel bending properties but a significantly negative effect on the perpendicular bending properties and the IB, except for the TS. The OSB panels made from aspen obtained better bending properties, while the IB and TS properties were lower than those of the OSB black spruce panels. The results indicate that black spruce strands obtained from the Eastern Canadian softwood lumber industry are suitable for OSB production, but more work is required to reduce the TS.

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Keywords: Strands length; Strands thickness; Physical-mechanical properties; OSB; Black spruce; Trembling aspen

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INTRODUCTION

The Eastern Canadian softwood lumber industry is exploring alternative uses for softwoods' primary processing residues considering the overcapacity of softwood chips traditionally produced for the pulp and paper industry. Trembling aspen is the more standard species used for oriented strand board (OSB) production in Canada. Therefore, the use of softwoods for OSB manufacturing, including black spruce, is not common in Canada. It is known that the physical and mechanical properties of OSB, a multi-layer structural board, mainly depend on the species, the strands geometry, the adhesive, the adhesive content, the hot-pressing time, the hot-pressing temperature, and the closing rate of the press (Winandy and Kamke 2003). The inner structure of this type of strand-based product is formed of many micropores and voids because of the complexity of the strand geometry and the randomness of the strand distribution within the panel (Zhang *et al*. 2005). The strand geometry is an essential factor that affects the panel structure. Therefore, it impacts the panel performance and manufacturing costs (Suchsland and Xu 1989; Marra

1992; Lenth and Kamke 1996; Geimer *et al*. 1999; Dai *et al*. 2007; Li *et al*. 2008, 2009).

As one of the main parameters for strands geometry, the strand length significantly impacts panel performance. Some researchers (Nishimura *et al*. 2001; Barnes 2001; Chirasatitsin *et al*. 2005; Beck *et al*. 2009; Iswanto *et al*. 2019) studied the influence of the strand length on the properties of OSB panels. These studies indicated that the strand length has a significant impact on the bending properties of OSB panels. However, the strand length has no significant effect on other properties, such as the internal bond (IB). Another report (Febrianto *et al*. 2012) analyzed the influence of the strand length on the properties of three-layer OSB and found that it affects the bending properties in the parallel and the perpendicular directions. In addition, the strand length did not influence the thickness swelling (TS). Oriented strand boards made from long strands have better parallel bending properties than those made from short strands because of their better alignment and greater overlap (Suzuki and Takeda 2000; Meyers 2001; Nishimura *et al.* 2004; Chen *et al.* 2008).

Brochmann *et al*. (2004) investigated the influence of the strand thickness on the mechanical properties of OSB panels. It was found that the strand thickness has a marked impact on the IB strength and the TS of OSB panels but no significant effect on their bending properties. Dai *et al*. (2007) indicated that inter-particle contact is an important parameter for panel performance because of its relationship to cohesion between wood particles. The inter-particle contact was strongly influenced by the strand thickness and density. Finer particles resulted in better inter-particle contact. The use of denser wood particles decreased the inter-particle contact because the lower number of particles results in a higher volume of voids and fewer inter-particle contact points. It also indicated that low-density woods are more suitable to produce OSBs than high-density woods. Results from Akrami *et al*. (2014; 2018) showed that fine particles in the core layer of OSBs could significantly reduce the volume of voids in the core layer and adequately increase the inter-particle contact, thus improving the IB and water-resistance properties of the panel.

The specific surface of the strands is also a very important parameter that must be considered in analyzing the performance of wood-based panels (Istrate *et al*. 1965). The specific surface of a given particle depends on its density and its thickness. The specific surface of the strands linearly increases with the decrease in their thickness. Thus, a decrease in the amount of adhesive per unit area of strands at a certain adhesive content (anhydrous wood mass base) reduces the IB.

The main dimensional elements of the wood particles are width, length, and thickness. The ratio of length to thickness, called the slenderness ratio, is an important parameter related to a series of essential characteristics of the panel, such as linear expansion, mechanical properties, TS, and water absorption (Brumbaugh 1960). An increase in the slenderness ratio also increases the bending properties of the panel (Barnes 2001), but it decreases the IB and TS (Brumbaugh. 1960; Sun and Arima 1999; Miyamoto *et al*. 2002). Scott (2001) and Lin and Huang (2004) found a linear decrease in the IB with a higher slenderness ratio, resulting in a higher porosity. Arabi *et al*. (2011a; 2011b) found that the panel density, resin content, and slenderness ratio were directly related to the bending properties of the panel. Meanwhile, the IB decreased with the increase in the slenderness ratio.

The assessment of the feasibility of producing OSB from softwoods is motivated by reducing raw material availability and increasing demand of the OSB industry in Eastern Canada. As black spruce is the most common species used in the Eastern Canadian softwood lumber industry, the evaluation of its potential to replace trembling aspen for OSB manufacturing is meaningful. Thus, the main objective of this project was to characterize the impact of strands geometry on the physical and mechanical properties of OSB made from black spruce and compare it to OSB made from trembling aspen.

EXPERIMENTAL

Materials

Black spruce (*Picea mariana* (Mill.) B.S.P.), with an oven-dried density of 445 kg/m^3, and trembling aspen (*Populus tremuloides* Michx), with an oven-dried density of 424 kg/m^3, were obtained from Arbec Forest Products Inc. (Quebec, Canada) (Jessome 1977). Commercial liquid phenol-formaldehyde adhesive (CL5357) with a solids content of 51% was obtained from LRBG Chemicals Inc. (Longueuil, QC, Canada). The wax emulsion (EW-58A) with a solids content of 58% was obtained from Hexion Canada Inc. (Levis, QC, Canada).

Methods

Manufacturing the OSB panels

Eight black spruce logs and eight trembling aspen logs (3 m long with 25 to 30 cm diameter) were cut into large slabs of 25 mm in thickness with a portable sawmill located at Centre de recherche sur les matériaux renouvelables (CRMR), Université Laval (Quebec City, QC, Canada). The slabs were cut into strands of a predetermined length and thickness by a 12/48 laboratory ring strander (Carmanah Design and Manufacturing Inc., Vancouver, BC, Canada). The strands were conditioned to a moisture content (MC) of 2% to 3% using a laboratory drum drier. The strands width was set at a fixed value of 25 mm considering the slab thickness. The strands were cut to three target lengths of 100, 125, and 150 mm. Three target thicknesses of 0.50, 0.75, and 0.85 mm were used per length. Eighteen types of strands (3 lengths × 3 thicknesses × 2 species) were obtained, representing the various combinations of strand geometry and species. They were removed from the mixture *via* screening to eliminate the variation from the influence of fine particles and small strands. The strands were blended with the liquid phenol-formaldehyde adhesive at 5% content (oven-dry wood mass) and the wax emulsion at 1% content (oven-dry wood mass) using an in-house made drum blender. Water was added to set the MCs of the surface layers and the core layer furnish at 8% and 7%, respectively. The blended strands were placed in a mold using a screening box to align them in the desired direction. The orientation of the surface-layer strands was perpendicular to the core-layer strands. The mass proportion of the surface/core/surface layers was 30:40:30. The final size of the OSB panels was 760 mm × 760 mm × 15 mm (length × width × thickness). The mat was hot pressed to a target density of 600 kg/m^3 at a temperature of 210 °C during a pressing cycle of 355 s (closing + holding + opening time) using a steam injection hot press (Dieffenbacher North America, Windsor, ON, Canada). The hot press had a maximum operating pressure of 9,500 kPa and it was equipped with the PRESSMAN control system developed by the Alberta Research Council (Edmonton, AB, Canada) located at CRMR, Université Laval (Quebec City, QC, Canada). Eighteen types of OSB panels were manufactured, representing various combinations of strand geometries and species (Table 1). There were three replications of each OSB panel type. The pressing process consisted of a one-step closure schedule developed by Wang and Winistorfer (2000) (Table 2). After hot pressing, the panels were conditioned at 20 °C and 65% relative humidity to obtain an equilibrium moisture content (EMC) of 8%. The cutting plan of the produced OSB is shown in Fig. 1.

Table 1. Strands Geometry of the Three-Layer OSB Panels Manufactured at a Target Density of 600 kg/m[2]

Panel Type[1]		Strands Geometry		
		Length (mm)	Thickness (mm)	Slenderness Ratio
S1	A1	100	0.50	200
S2	A2	100	0.75	133
S3	A3	100	0.85	118
S4	A4	125	0.50	250
S5	A5	125	0.75	167
S6	A6	125	0.85	147
S7	A7	150	0.50	300
S8	A8	150	0.75	200
S9	A9	150	0.85	177

[1] S: black spruce; A: trembling aspen
[2] Target density at an EMC of 8%

Table 2. One-step Pressing Schedule

Schedule	Time (s)
Total closing time (From mat thickness to panel thickness)	23
Hold at final position (100% of panel thickness)	272
Total opening time	60
Open to intermediate position A (101.5% of final position)	10
Open to intermediate position B (103% of final position)	10
Open to intermediate position C (104% of final position)	10
Open to intermediate position D (106% of final position)	10
Open to intermediate position E (109% of final position)	10
Open to intermediate position F (110% of final position)	10

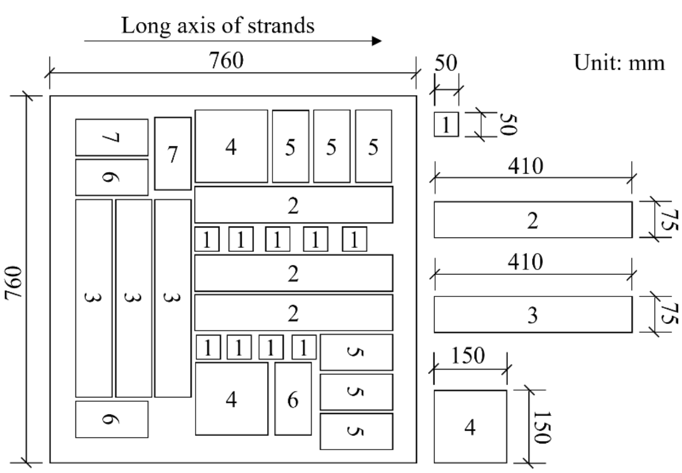


Fig. 1. Cutting scheme of the samples from the produced OSB: (1) vertical density profile and internal bond strength; (2) parallel bending modulus of elasticity and modulus of rupture; (3) perpendicular bending modulus of elasticity and modulus of rupture; (4) thickness swelling.

Measurement of the vertical density profile

The vertical density profiles (VDP) of the OSB panels were determined using a XQMS (QDP-01X; Quintek Measurement Systems Inc., Knoxville, TN, USA) beam densitometer with a reading increment of 0.02 mm. Nine samples of 50 mm × 50 mm (length × width) were used for each OSB panel.

Measurement of the mechanical and physical properties

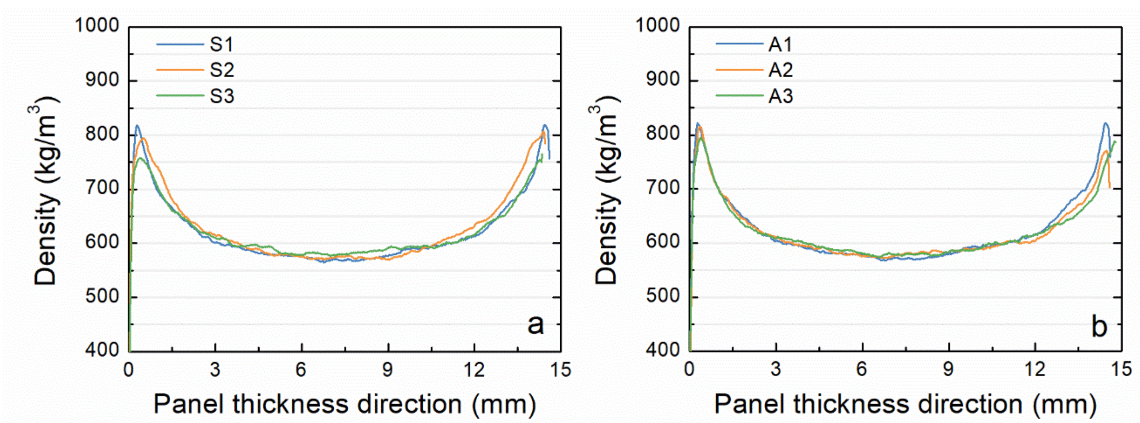
All mechanical and physical properties in this study were measured according to the CSA O437 (1993) standard. The bending modulus of rupture (MOR) and modulus of elasticity (MOE) in the directions parallel (par) and perpendicular (per) to the surface-layer strands were tested using an MTS tension and compression testing machine (MTS QTest/5; MTS Systems Corporation, MN, USA) with a measuring range of 5 kN to 50 kN. The test sample width was 75 mm. The sample length was 24 times the nominal panel thickness (15 mm) plus 50 mm for a total of 410 mm. Six samples were prepared for each OSB panel. The internal bond (IB) strength was also measured using an MTS QTest/5 instrument. Six samples of 50 mm × 50 mm (length × width) were prepared for each OSB panel. Two samples of 150 mm × 150 mm (length × width) were prepared for each OSB panel to test the thickness swelling (TS) after 24 h of immersion. The samples were conditioned following clause 3.1.6 of CSA O437.1.1.

Statistical analysis

The physical and mechanical properties of the OSB samples were analyzed by three-way analysis of variance (ANOVA) using IBM SPSS version 25 (IBM, Armonk, NY, USA). The test of normality for each property and each type of panel was performed. The significant differences between the measured mean values were determined using Bonferroni's multiple-comparisons test at a 0.05 level of probability as affected by three factors (species, strand length, and thickness) and their interaction.

RESULTS AND DISCUSSION

The mean VDPs of the OSB panels made from black spruce (S1 to S9) and trembling aspen (A1 to A9) are presented in Fig. 2.



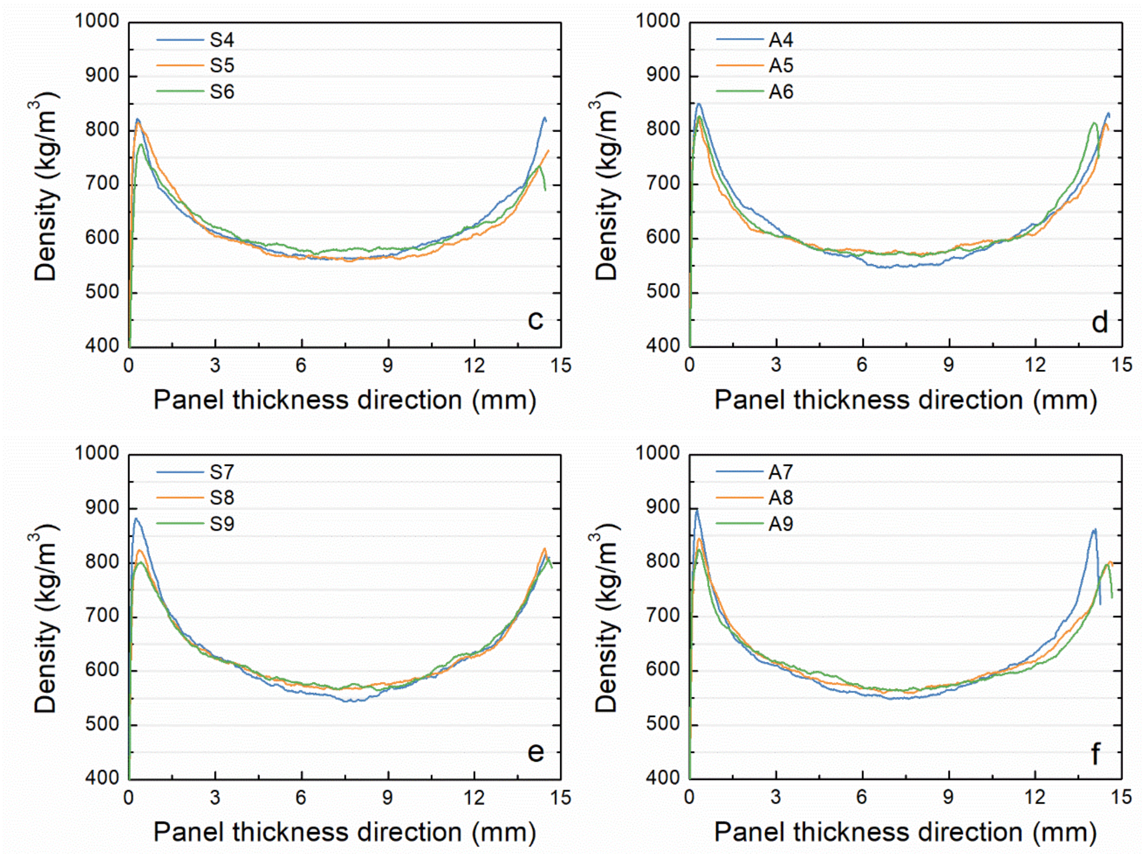


Fig. 2. The effect of strand length and strand thickness on the mean vertical density profile of OSB panels made from black spruce and trembling aspen with a) and b) 100 mm, c) and d) 125 mm, e and f) 150 mm long strands, respectively

The core layer of the OSB panels had a lower density than the surface layers, as shown by the typical M-shaped VDPs, as also reported by other researchers (Wang and Cooper 2005; Painter *et al*. 2006; Jin *et al*. 2009). Figures 2a, 2c, and 2e show that the OSB samples made from the 0.50 mm thick black spruce strands (S1, S4, and S7) had a relatively steeper VDP than those made from the 0.75 mm (S2, S5, and S8) and 0.85 mm thick (S3, S6, and S9) strands for the three strands length levels. The VDP of the samples made from the thicker strands showed a lower surface density and a higher and flatter core density compared to those from the thinner strands. At the same strands thickness level, the sample made from the 100 mm long strands (S1, S2, and S3) showed less difference between the surface and core density than those made from the 125 mm (S4, S5, and S6) and 150 mm (S7, S8, and S9) long strands. Although the samples made from the short strands had slightly lower surface density and higher core density, the shape of the density profile did not change with an increase in the strand length. The samples made from the trembling aspen strands (A1 to A9) showed similar tendencies with the changes in the strand length and thickness (Figs. 2b, 2d, 2f). In general, the samples made from trembling aspen showed more difference between the surface and core densities than those made from black spruce.

Table 3 shows that all the studied properties were significantly affected by the strand thickness (C) for both species. Most of the studied properties were affected by the strand length (B) except for the TS. Most of the studied properties were affected by species (A) except the perpendicular MOR and MOE. No properties were significantly affected by interactions between the species (A) and strand length (B) except for the perpendicular MOE. No properties were significantly affected by interactions between the species (A) and strand thickness (C), between the strand length (B) and strand thickness (C), and between the species (A), strand length (B), and strand thickness (C).

Table 3. ANOVA Results (*P*-value) on the Effects of Species, Strand Length, Strand Thickness, and their Interactions on Selected Properties of OSB

Source of Variance	P-value					
	MORpar	MORper	MOEpar	MOEper	IB	TS
Species (A)	0.020	0.609	<0.001	0.229	0.025	<0.001
Strand length (B)	<0.001	<0.001	<0.001	<0.001	0.008	0.219
Strand thickness (C)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
A*B	0.591	0.907	0.985	0.049	0.974	0.976
A*C	0.587	0.683	0.688	0.801	0.817	0.415
B*C	0.729	0.392	0.146	0.912	0.848	0.974
A*B*C	0.978	0.840	0.945	0.947	0.953	0.973

MOR: modulus of rupture; MOE: modulus of elasticity; IB: internal bond; TS: thickness swelling; par: parallel; per: perpendicular.
Significant difference, α = 0.05.

Figure 3 shows the results obtained for the mean bending MOE of the OSB panels made from nine combinations of black spruce strand thickness and strand length (S1 to S9).

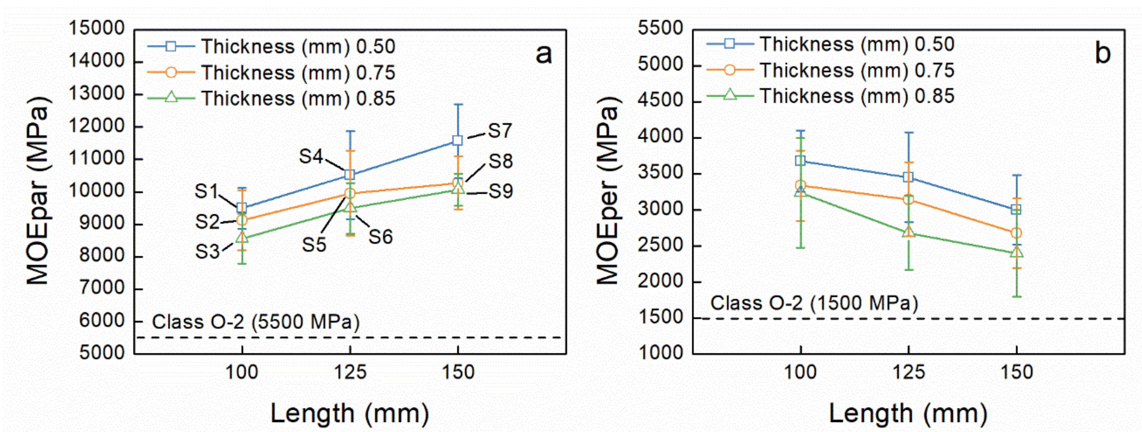


Fig. 3. The effect of the strand length and strand thickness on the a) MOEpar and b) MOEper values of the boards made from black spruce. The horizontal dashed lines represent the CSA O437 (1993) minimum MOEpar and MOEper values for class O-2.

Figure 3a shows that the mean MOEpar values of the panels showed an upward trend as the strand length and thickness increased and decreased, respectively. However, the mean MOEper values of the panels show a decreasing trend with an increase in the strand length (Fig. 3b). As the strand thickness increased, the MOEpar and MOEper of the panels tended to decrease at the three different strands length levels. The OSB panels made from the 150 mm long strands (S7 to S9) showed higher mean MOEpar and lower mean MOEper values ranging from 10,070 to 11,560 MPa and 2,400 to 3,002 MPa, respectively. As expected, the OSB panels made from the 100 mm long strands (S1 to S3) showed lower mean MOEpar values and higher mean MOEper values, ranging from 8,560 to 9,490 MPa and 3,240 to 3,680 MPa, respectively. The MOEpar and MOEper of the panels made from trembling aspen (A1 to A9) showed similar tendencies as for the black spruce panels following variations in the strand length and thickness (Fig. 4). The panels made from the 150 mm long strands (A7 to A9) had higher mean MOEpar and lower mean MOEper values, ranging from 10,610 to 12,690 MPa (Fig. 4a) and 2,550 MPa to 3,240 MPa (Fig. 4b), respectively. The lower mean MOEpar and the higher mean MOEper values were found in the panels made from the 100 mm long strands (A1 to A3), which ranged from 9,180 to 10,600 MPa (Fig. 4a) and 2,830 to 3,480 MPa (Fig. 4b), respectively.

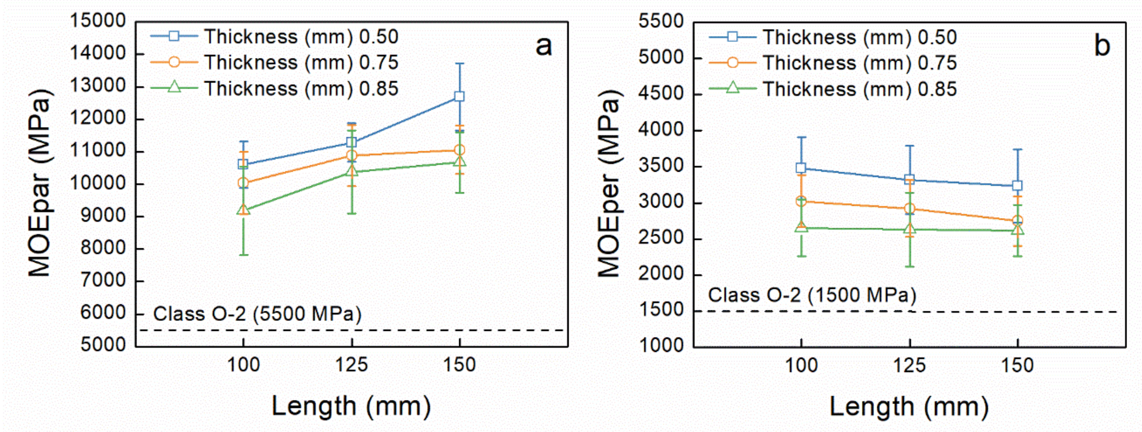


Fig. 4. The effect of the strand length and strand thickness on the a) MOEpar and b) MOEper values of the boards made from trembling aspen. The horizontal dashed lines represent the CSA (1993) minimum MOEpar and MOEper values for class O-2.

As was the case for the MOEpar and MOEper values, the MORpar and MORper of the panels showed similar trends with variations in the strand length and strand thickness (Figs. 5 and 6).

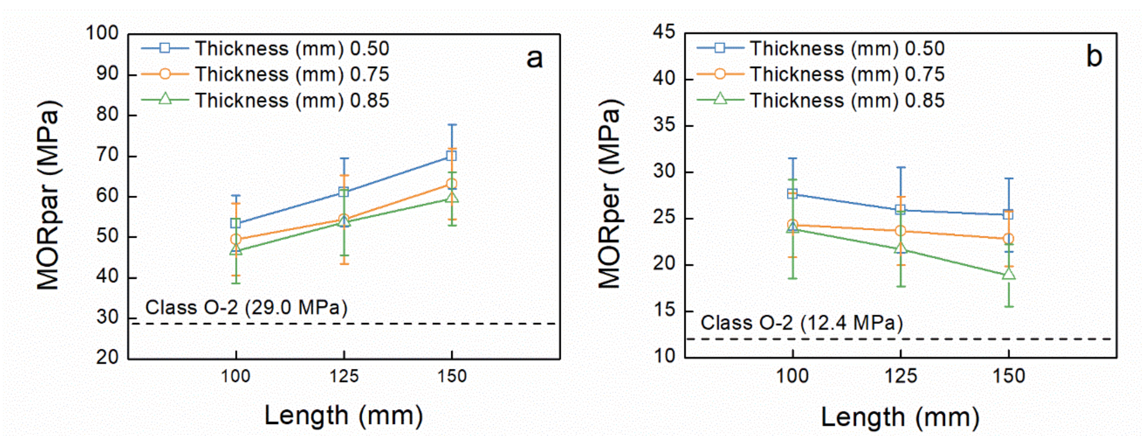


Fig. 5. The effect of the strand length and strand thickness on the a) MORpar and b) MORper values of the boards made from black spruce. The horizontal dashed lines represent the CSA O437 (1993) minimum MORpar and MORper values for class O-2.

For the OSB panels made from black spruce, the higher mean MORpar and lower mean MORper values that ranged from 59.5 to 69.9 MPa (Fig. 5a) and 18.9 to 25.4 MPa (Fig. 5b), respectively, were found in the panels made from the 150 mm long strands (S7 to S9). The OSB panels made from the 100 mm long strands (S1 to S3) represented the lower mean MORpar and the higher mean MORper, ranging from 46.6 to 53.4 MPa (Fig. 5a) and 23.9 to 27.6 MPa (Fig. 5b), respectively. For the OSB panels made from trembling aspen (Fig. 6), the higher mean MORpar and lower mean MORper values ranged from 58.8

to 70.9 MPa (Fig. 6a) and 18.1 to 24.3 MPa (Fig. 6b), respectively (A7 to A9). The lower mean MORpar and higher mean MORper values were found in the panels made from the 100 mm long strands (A1 to A3), ranging from 52.2 MPa to 57.4 MPa (Fig. 6a) and 22.5 MPa to 29.8 MPa (Fig. 6b), respectively. The mean values obtained for the MOE and MOR values of all types of OSB panels were higher than those prescribed by the CSA O437.0 (1993) standard.

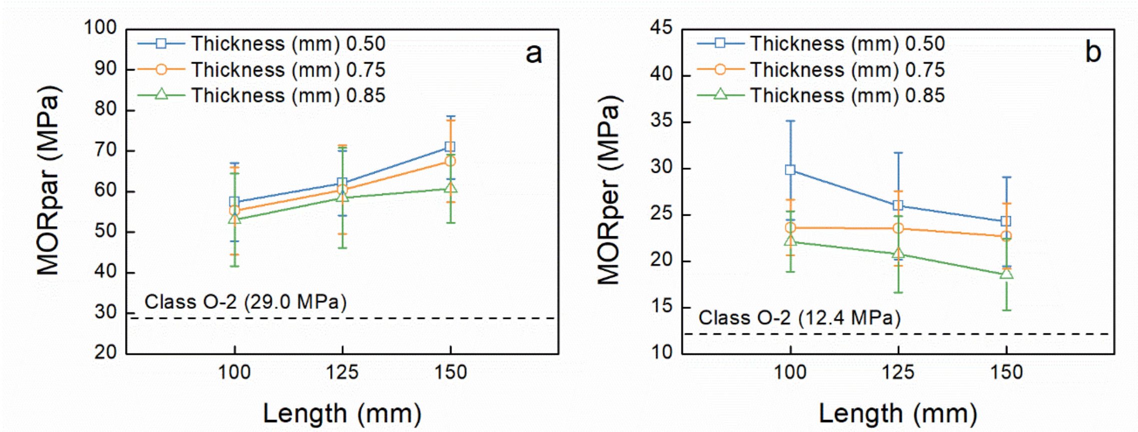


Fig. 6. The effect of the strand length and strand thickness on the a) MORpar and b) MORper values of the boards made from trembling aspen. The horizontal dashed lines represent the CSA O437 (1993) minimum MORpar and MORper values for class O-2.

The bending properties of OSB panels are influenced mainly by the surface layers, as mentioned by Deomano and Zink-Sharp (2004). More specifically, a longer strand length can increase the overlap area between the strands, resulting in better stress transfer among the strands and improved parallel bending properties (Suchsland 1968; Nishimura *et al*. 2001; Barnes 2001; Chirasatitsin *et al*. 2005; Beck *et al*. 2009; Febrianto *et al*. 2012). Conversely, a longer strand length decreases the MOEper and MORper values because of strand length's positive effect on the strand orientation (Suzuki and Takeda 2000; Meyers 2001; Nishimura *et al*. 2004; Chen *et al*. 2008). The OSB panels made from thick strands resulted in lower mean MOE and MOR values at a given strand length. One of the important reasons for this is that an increase in the strand thickness results in a greater voids volume outside the strands (Mirski *et al*. 2016). In addition, thicker strands result in a lower number of individual strands and therefore a lower overlapping surface between the strands. The panels made from low-density aspen strands presented higher parallel bending strength and stiffness properties compared to the OSB's from high-density black spruce strands, which can be explained by a higher inter-particle contact surface. A given surface area of low-density wood strands occupies a higher volume than that of high-density wood strands. Therefore, low-density wood strands compacted during hot-pressing increases inter-particle contact surface because of the greater number of particles and the higher compression rate (Stegmann and Durst 1965; Deomano and Zink-Sharp 2004).

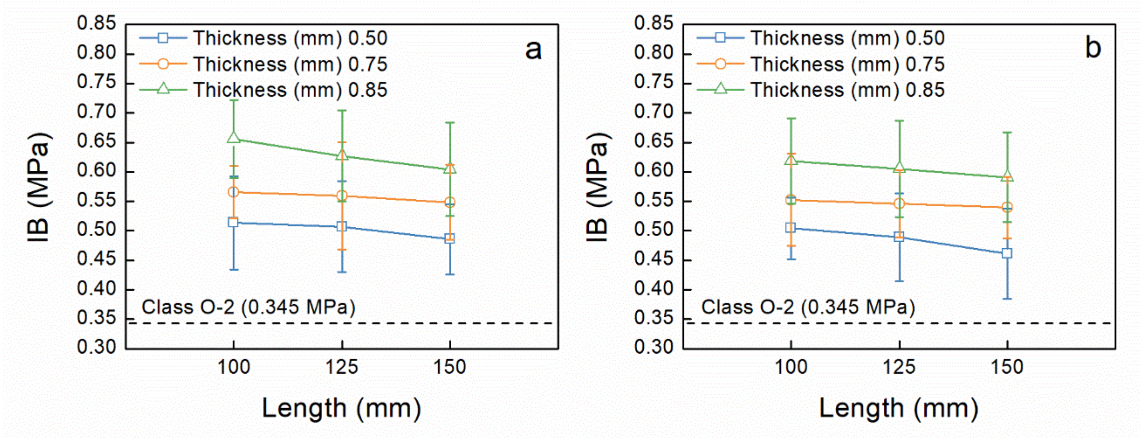


Fig. 7. The effect of the strand length and strand thickness on the IB values of the boards made from a) black spruce and b) trembling aspen. The horizontal dashed lines represent the CSA O437 (1993) minimum IB values for class O-2.

Figure 7 represents the results of the IB strength tests for the OSB panels made from the black spruce and trembling aspen strands. The OSB panels made from the longer strands tended to have slightly lower IB strength properties at a given strand thickness. This is due to the longer strand resulting in a different density distribution between the surface and core layers and increasing internal defects (Suchsland 1968). On the contrary, the mean IB values of the panels showed an upward trend as the strand thickness increased at a given strand length. The surface area of the strands decreased as the strand thickness increased. This means that the amount of adhesive per strand unit area significantly increases for constant adhesive content, thus increasing the IB value (Medved *et al*. 2021). However, findings by Xu and Steiner (1995) and Dai *et al*. (2007) showed that thicker wood strands involve a lower number of strands, which creates a greater void volume and fewer inter-strand contacts in the panels' core structure. For the panels made from black spruce (Fig. 7a), the stronger OSB panels obtained for the parallel bending properties (longer and thinner strands) had weaker IB properties, with values ranging from 0.486 MPa to 0.604 MPa for the 150 mm long strands (S7 to S9). For the panels made from trembling aspen (Fig. 7b), the lower IB strength values ranged from 0.461 to 0.591 MPa for the 150 mm long strands (A7 to A9). For the panels made from aspen strands, heat transfer by conduction to the core layer of the mat was quicker because of the higher compaction and therefore higher density of the surface layers, which resulted in a faster cure of the adhesive in the core layer. In addition, the higher compaction of the surface layers results in lower compaction of the core layer, which contributes to keeping the core-layer density low (Srivaro *et al*. 2021). Therefore, OSB panels with low-density aspen strands exhibit a lower IB strength compared to those of higher-density black spruce strands. The mean values obtained for the IB strength of all types of OSB panels were higher than those prescribed by the CSA O437 (1993) class O-2 standard.

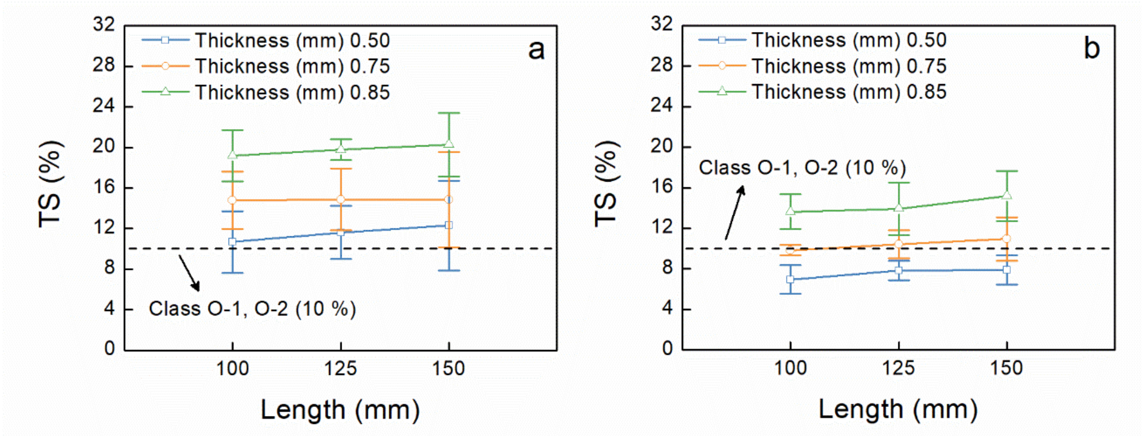


Fig. 8. The effect of the strand length and strand thickness on the TS properties after 24 h of immersion in water of boards made from a) black spruce and b) trembling aspen. The horizontal dashed lines represent the CSA O437 (1993) maximum TS values for class O-1 and O-2.

Oriented strand board is a sandwich material, and it has the property of swelling by absorbing water due to its low density and loose structure (Wang and Winistorfer 2000). Figure 8 shows the mean TS values of the OSB panels made from strands of different geometries. The OSB panels that were made from the longer strands showed slightly higher TS values at a given strand thickness level. Meanwhile, the mean TS values of the panels increased with as the strand thickness increased at the same strand length level. For the OSB panels made from black spruce, the higher mean TS values were found in the panels made from 0.85 mm thick strands (S3, S6, and S9), ranging from 19.2% to 20.3% (Fig. 8a). The lower mean TS values were found in the panels made from 0.50 mm thick strands (S1, S4, and S7), ranging from 10.7% to 12.3% (Fig. 8a). For the OSB panels made from trembling aspen, the higher mean TS values were also found in those made from 0.85 mm thick strands (A3, A6, and A9), ranging from 13.6% to 15.2% (Fig. 8b). The OSB panels made from 0.50 mm thick strands (A1, A4, and A7) had lower TS values, ranging from 7.0% to 7.9% (Fig. 8b). Except for the trembling aspen OSB panels made from 0.5 mm thick strands, all panels had higher TS values than the CSA O437 (1993) class O-1 and O-2 standards. Previous work has shown that large voids in the structure can act as a water reservoir and passage (Li *et al*. 2016). The use of thicker wood strands involves a lower number of strands, which results in a greater void volume and fewer inter-strand contacts within the panel (Dai *et al*. 2007). Thus, the OSB panels made from thick strands showed an obvious potential for higher water absorption than those made from thin strands. Trembling aspen is a diffuse-porous hardwood species with a low density, a homogeneous cell structure, and a high volume of vessels in its structure. It can be compressed uniformly compared to black spruce, which has a relatively high density, a non-uniform cell structure, and high-density variation within its growth rings (Wang and Winistorfer 2000). Thus, it is likely that trembling aspen OSB panels exhibited a weaker springback effect during water immersion, and that this accounts for the lower TS values.

CONCLUSIONS

1. Strand thickness significantly affected all the studied properties of the oriented strandboard (OSB) panels. The strand length also significantly impacted most of the

studied properties except for the thickness swelling (TS). The species significantly impacted most of the studied properties except for the modulus of elasticity (MOEper) and modulus of rupture (MORper). The interaction between species and strand length had no significant effect on the studied properties except for the MOEper. No studied properties were significantly affected by interactions between the species and strand thickness, between the strand length and strand thickness, and between the species, strand length, and strand thickness.

2. The overall results of the OSB properties for the black spruce and trembling aspen met the CSA O437 (1993) class O-2 standard, with the exception of the TS properties. The bending properties of the aspen OSB panels were higher than those of the black spruce OSB panels. The internal bond (IB) and TS properties of the aspen OSB panels were lower than those of the black spruce OSB panels. The TS was notably higher for the black spruce OSB panels compared to the trembling aspen OSB panels.
3. The parallel bending properties of the OSB panels increased as the strand length increased but decreased as the strand thickness increased. The perpendicular bending properties of the OSB panels decreased as the strand length and strand thickness increased. The IB strength of the OSB panels decreased as the strand length increased but increased as the strand thickness increased. The TS properties of the OSB panels increased as the strand length and thickness increased.

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REFERENCES CITED

Akrami, A., and Laleicke, P. F. (2018). “Densification, screw holding strength, and Brinell hardness of European beech and poplar oriented strand boards,” *Wood Material Science & Engineering* 13(4), 236-240. DOI: 10.1080/17480272.2017.1358764

Akrami, A., Fruehwald, A., and Barbu, M. C. (2014). “The effect of fine strands in core layer on physical and mechanical properties of oriented strand boards (OSB) made of beech (*Fagus sylvatica*) and poplar (*Populus tremula*),” *European Journal of Wood and Wood Products* 72(4), 521-525. DOI: 10.1007/s00107-014-0802-z

Arabi, M., Faezipour, M., and Gholizadeh, H. (2011a). “Reducing resin content and board density without adversely affecting the mechanical properties of strand board through controlling particle size,” *Journal of Forestry Research* 22(4), 659. DOI: 10.1007/s11676-011-0207-3

Arabi, M., Faezipour, M., Layeghi, M., and Enayati, A. A. (2011b). “Interaction analysis between slenderness ratio and resin content on mechanical properties of particleboard,” *Journal of Forestry Research* 22(3), 461. DOI: 10.1007/s11676-011-0188-2

Barnes, D. (2001). “A model of the effect of strand length and strand thickness on the strength properties of oriented wood composites,” *Forest Products Journal* 51(2), 36-

46.
Beck, K., Cloutier, A., Salenikovich, A., and Beauregard, R. (2009). "Effect of strand geometry and wood species on strandboard mechanical properties," *Wood and Fiber Science* 41(3), 267-278.
Brochmann, J., Edwardson, C., and Shmulsky, R. (2004). "Influence of resin type and flake thickness on properties of OSB," *Forest Products Journal* 54(3), 51-55.
Brumbaugh, J. (1960). "Effect of flake dimensions on properties of particle boards," *Forest Products Journal* 10(5), 243-6.
Chen, S., Du, C., and Wellwood, R. (2008). "Analysis of strand characteristics and alignment of commercial OSB panels," *Forest Products Journal* 58(6), 94-98.
Chirasatitsin, S., Prasertsan, S., Wisutmethangoon, W., and Kyokong, B. (2005). "Mechanical properties of rubberwood oriented strand lumber (OSL): The effect of strand length," *Songklanakarin Journal of Science and Technology* 27(5), 1047-1055.
CSA O437 (1993). "Standards on OSB and waferboard," Canadian Standards Association, Toronto, Canada.
Dai, C., Yu, C., and Zhou, C. (2007). "Theoretical modeling of bonding characteristics and performance of wood composites. Part I. Inter-element contact," *Wood and Fiber Science* 39(1), 48-55.
Deomano, E. C., and Zink-Sharp, A. (2004). "Bending properties of wood flakes of three southern species," *Wood and Fiber Science* 36(4), 493-499.
Febrianto, F., Sahroni, Hidayat, W., Bakar, E. S., Kwon, G.-J., Kwon, J.-H., Hong, S.-I., and Kim, N.-H. (2012). "Properties of oriented strand board made from Betung bamboo (*Dendrocalamus asper* (Schultes. f) Backer ex Heyne)," *Wood Science and Technology* 46(1-3), 53-62. DOI: 10.1007/s00226-010-0385-8
Geimer, R. L., Evans, J. W., and Setiabudi, D. (1999). *Flake Furnish Characterization: Modeling Board Properties with Geometric Descriptors* (Report No. FPL-RP-577), U.S. Department of Agriculture Forest Products Laboratory, Madison, WI, USA.
Istrate, V., Filipescu, G., and Stefu, C. (1965). "The influence of chip dimension on the consumption of glue and on the quality of particle board," *Industria Lemnului* 4, 133-137.
Iswanto, A. H., Idris, M., and Sucipto, T. (2019). "Effect of bamboo strand length on oriented strand board," *IOP Conference Series: Earth and Environmental Science* 260, 012039. DOI: 10.1088/1755-1315/260/1/012039
Jessome, A. P. (1977). *Strength and Related Properties of Woods Grown in Canada*, Eastern Forest Products Laboratory, Ottawa, ON, Canada.
Jin, J., Dai, C., Hsu, W. E., and Yu, C. (2009). "Properties of strand boards with uniform and conventional vertical density profiles," *Wood Science and Technology* 43(7-8), 559. DOI: 10.1007/s00226-009-0248-3
Lenth, C. A., and Kamke, F. A. (1996). "Investigations of flakeboard mat consolidation. Part I. Characterizing the cellular structure," *Wood and Fiber Science* 28(2), 153-167.
Li, P., Dai, C., and Wang, S. (2009). "A simulation of void variation in wood-strand composites during consolidation," 63(3), 357-361. DOI: 10.1515/HF.2009.044
Li, P., Wang, S., Chen, S., and Wang, F. (2008). "A three-dimensional solid model for OSB mat," *Forest Products Journal* 58(1), 53-58.
Li, W., Van den Bulcke, J., De Schryver, T., and Van Acker, J. (2016). "Investigating water transport in MDF and OSB using a gantry-based X-ray CT scanning system," *Wood Science and Technology* 50(6), 1197-1211. DOI: 10.1007/s00226-016-0855-8

Lin, H. C., and Huang, J. C. (2004). “Using single image multi-processing analysis techniques to estimate the internal bond strength of strand board,” *Taiwan Journal of Forest Science* 19(2), 109-117.

Marra, A. A. (1992). *Technology of Wood Bonding: Principles in Practice*, Springer, New York, NY, USA.

Medved, S., and Grudnik, J. (2021). “Influence of resin content on the surface covered with adhesive,” *International Journal of Adhesion and Adhesives* 104, article no. 102698. DOI: 10.1016/j.ijadhadh.2020.102698

Meyers, K. L. (2001). *Impact of Strand Geometry and Orientation on Mechanical Properties of Strand Composites,* Master’s Thesis, Washington State University, Pullman, WA, USA.

Mirski, R., Dziurka, D., and Derkowski, A. (2016). “Properties of oriented strand boards with external layers made of non-strand chips,” *BioResources* 11(4), 8344-8354. DOI: 10.15376/biores.11.4.8344-8354

Miyamoto, K., Nakahara, S., and Suzuki, S. (2002). “Effect of particle shape on linear expansion of strand board,” *Journal of Wood Science* 48(3), 185-190. DOI: 10.1007/BF00771365

Moslemi, A. A. (1974). *Particleboard: Volume 1: Materials* Southern Illinois University Press, Carbondale, IL, USA.

Nishimura, T., Amin, J., and Ansell, M. P. (2004). “Image analysis and bending properties of model OSB panels as a function of strand distribution, shape and size,” *Wood Science and Technology* 38(4), 297-309. DOI: 10.1007/s00226-003-0219-z

Nishimura, T., Ansell, M. P., and Ando, N. (2001). “The relationship between the arrangement of wood strands at the surface of OSB and the modulus of rupture determined by image analysis,” *Wood Science and Technology* 35(6), 555-562. DOI: 10.1007/s002260100118

Painter, G., Budman, H., and Pritzker, M. (2006). “Prediction of oriented strand board properties from mat formation and compression operating conditions. Part 1. Horizontal density distribution and vertical density profile,” *Wood Science and Technology* 40(2), 139-158. DOI: 10.1007/s00226-005-0044-7

Scott, K. A. (2001). *Economic Feasibility of Implementing a Resin Distribution Measurement System for MDF Fiber*, Master’s Thesis, Virginia Tech, Blacksburg, VA, USA.

Srivaro, S., Lim, H., Li, M., Jantawee, S., and Tomad, J. (2021). “Effect of compression ratio and original wood density on pressing characteristics and physical and mechanical properties of thermally compressed coconut wood,” *Construction and Building Materials* 299, article no. 124272. DOI: 10.1016/j.conbuildmat.2021.124272

Stegmann, G., and Durst, J. (1965). *Beech Pressboard*, U.S. Department of Agriculture Forest Products Laboratory, Madison, WI, USA.

Suchsland, O. (1968). “Strand board from southern pine,” *Southern Lumberman* 15, 139-144.

Suchsland, O., and Xu, H. (1989). “A simulation of the horizontal density distribution in a flakeboard,” *Forest Products Journal*, 39(5), 29-33

Sun, Y.-G, and Arima, T. (1999). “Structural mechanics of wood composite materials II: Ultrasonic propagation mechanism and internal bonding of strand board,” *Journal of Wood Science* 45(3), 221-226. DOI: 10.1007/BF01177729

Suzuki, S., and Takeda, K. (2000). "Production and properties of Japanese oriented strand board I: Effect of strand length and orientation on strength properties of sugi oriented strand board," *Journal of Wood Science* 46(4), 289-295. DOI: 10.1007/BF00766219

Wang, J. Y., and Cooper, P. A. (2005). "Vertical density profiles in thermally compressed balsam fir wood," *Forest Products Journal* 55(5), 65-68.

Wang, S., and Winistorfer, P. M. (2000). "The effect of species and species distribution on the layer characteristics of OSB," *Forest Products Journal* 50(4), 37-44.

Winandy, J. E., and Kamke, F. A. (2003). *Fundamentals of Composite Processing. Proceedings of a Workshop* (Report No. FPL-GTR-149), U.S. Department of Agriculture Forest Products Laboratory, Madison, WI, USA.

Xu, W., and Steiner, R. P. (1995). "A statistical characterization of the horizontal density distribution in flakeboard," *Wood and Fiber Science* 27(2), 160-167.

Zhang, B., Wu, Q., Wang, L., and Han, G. (2005). "The influence of in-plane density variation on engineering properties of oriented strandboard: A finite element simulation," in: *Proceedings of McMat 2005, the 2005 Joint ASCE/ASME/SES Conference on Mechanics and Materials*, Baton Rouge, LA, USA, paper 257.

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