EFFECT OF STRAND GEOMETRY AND WOOD SPECIES ON STRANDBOARD MECHANICAL PROPERTIES

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Abstract. This study compared the performance of strandboards made from trembling aspen, a low-density hardwood species, with strandboards made from paper birch, a medium-density hardwood species. Strands were cut into three different lengths (78, 105, and 142 mm) and two thicknesses (0.55 and 0.75 mm) to compare the impact of species, strand geometry, specific surface, and slenderness ratio. Internal bond (IB), modulus of elasticity (MOE), and modulus of rupture (MOR) for flatwise and edgewise bending, compressive strength, and stiffness were all determined. Both species performed equally well in IB (0.73 MPa for both species combined). The highest MOE and MOR values in flatwise and edgewise bending were obtained for long, thin strands and were significantly lower for birch than for aspen panels (flatwise: 13.6 GPa and 99.2 MPa for aspen and 12.1 GPa and 85.5 MPa for birch; edgewise: 13.5 GPa and 66.3 MPa for aspen and 13.2 GPa and 65.7 MPa for birch). Short aspen strands resulted in the highest compressive properties, slightly higher than those of short birch strands (aspen: compressive strength 10.4 MPa and stiffness 1.22 GPa; birch: 10.8 MPa and 2.25 GPa, respectively). Strand length must therefore be a compromise between the need for high bending properties provided by long strands and the need for high compressive properties provided by short strands.

Keywords: Oriented strand lumber, flexural properties, compressive properties, internal bond, paper birch, trembling aspen.

INTRODUCTION

Competition for wood supplies and market share stimulates the oriented strandboard (OSB) industry to produce better, more economic products made from alternative raw material (UN 2007). Value-added products made from underutilized species could be an interesting addition to the production range of OSB manufacturers. Value-added products such as moisture-resistant panels for subflooring or longer sheathing panels could be developed from OSB panels engineered for these specific applications. Another option would be to produce value-added engineered wood products based on OSB technology using existing OSB production facilities.

Oriented strand lumber (OSL) is a structural composite utilized as framing material in wood construction. The manufacturing process is very

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similar to that of OSB: wood strands are bound with an exterior-type adhesive in a multiopening hot press (Barnes 2000; Chirasatitsin et al 2005). Strands are primarily oriented along the length of the member. The thickness of OSL available on the market varies 45 – 190 mm. Even with a similar production process, most OSB mills cannot produce OSL in their facilities because their presses are not designed for such thick mats. One possible solution would be to develop an OSL-type composite made from thinner, face-laminated panels instead of one thick panel. Weight and Yadama (2008a, 2008b) utilized a similar approach to produce a laminated-strand veneer composite. This new material could be produced with a species such as trembling aspen (*Populus tremuloides*). The OSB industry in Canada is already well adapted to aspen, but raw material availability is limited. Available underutilized species such as paper birch (*Betula papyrifera*) in eastern Canada could be utilized more intensively for manufacturing conventional OSB- and OSL-type composites for structural applications.

Beck et al (2009) determined production parameters and mechanical properties of OSB panels produced from trembling aspen and paper birch with a near-uniform vertical density profile. By keeping the specific surface (surface-to-mass ratio) of the paper birch and trembling aspen strands nearly constant, similar internal bond and bending properties of the tested panels were achieved. The only exception was the modulus of elasticity (MOE) in flatwise bending, in which panels made from aspen performed better than those made from birch.

Generally, it can be stated that particle geometry is one of the main factors influencing the strength and performance of wood composites (Marra 1992). Therefore, to further improve the bending properties of the composite material, geometrical parameters other than strand thickness must be investigated. Increasing strand length improves the bending properties of oriented strand products (Barnes 2001). This is from increased strand overlap resulting in better stress transfer through adhesive joints (Suchsland 1968) and improved orientation resulting from longer strands (Meyers 2001).

Strand length is not the only important factor; the relationship between strand length and strand thickness (slenderness ratio) also plays a key role. A study conducted by Post (1958) concluded that bending strength is fairly well correlated to the length-to-thickness ratio of the particles and constantly increases up to a ratio of at least 300. Thinner strands at a given length produce stronger panels from more intimate contact between strands and fewer voids (Dai et al 2007). Thicker strands introduce stress riser effects from large discontinuities at the end of the strands (Marra 1992). Barnes (1988) states that increasing strand length and decreasing strand thickness—ie, increasing the slenderness ratio—decreases the angle through which stress is transferred from one strand to the next and results in an increase in strength. Wang and Lam (1999) developed quadratic regression models to relate bending modulus of rupture (MOR) and MOE of oriented flakeboards to slenderness ratio, surface orientation, and panel density. They concluded that for strand lengths of 50 – 100 mm at a thickness of 0.6 mm, the optimum slenderness ratio was 133. Weight and Yadama (2008a) concluded that a slenderness ratio of 430 is optimal for the production of a laminated strand veneer composite.

The overall objective of this study was to develop a concept for a new engineered wood product consisting of laminated thin OSL-type panels. This article presents results demonstrating the effect of strand geometry on the mechanical performance of strandboard made from trembling aspen and paper birch.

MATERIALS AND METHODS

Panel Fabrication

Approximately 20 logs of trembling aspen and paper birch were obtained from private forestland in the Québec City area. Green logs were debarked and cut into disks of three lengths: 78 mm (short), 105 mm (medium), and 142 mm (long), with each disk length corresponding to a specific strand length. The oven-dry density, determined according to ISO 3131 (ISO 1975), was 459 kg/m^3 for aspen and 624 kg/m^3 for birch, both being slightly higher than the average values for the species (trembling aspen: 424 kg/m^3, paper birch: 588 kg/m^3) according to Jessome (1977). The disks were stored in a freezer and thawed before stranding. The strands were cut to two target thicknesses of 0.55 mm (thin) and 0.75 mm (thick) (Table 1) using a laboratory-scale CAE strander. Strand width, which was not controlled, ranged 9 – 60 mm. The strands were dried to 2 – 4% MC and screened to remove fines. A mix of liquid and powder phenol–formaldehyde adhesive was applied to the furnish at 7% per oven-dry wood weight. The panels were pressed at the Université Laval wood composites laboratory in Québec City using a hot press with an 864-mm square platen at 202°C. The target panel size was 762 × 762 × 15 mm. Based on industrial chosen target oven-dry panel density was 650 kg/m^3. A total of 36 panels (2 species × 2 nominal strand thicknesses × 3 strand lengths × 3 replications) were produced, all with strands aligned in one direction using a laboratory-sized forming device to produce an OSL-type strandboard. Vane spacing for the forming device was 40 mm with a free fall height of 50 – 100 mm. A three-step closing pressing schedule was utilized based on the one developed by Wang et al (2000). First, mats were quickly pressed from the starting position to the first intermediate position (120% of target panel thickness). The press was held in that position before closing down to the second intermediate position (110% of target panel thickness). Next, the press was closed further and held at the final board thickness. It was then opened slowly to the intermediate positions (101.5, 103, and 110%) before being opened completely (Table 2). After fabrication, panels were stored in a conditioning room at 20 ± 3°C and 65 ± 5% RH for 1 – 7 da, resulting in moisture contents of 4 – 6% MC (ASTM D 4442 Method A; ASTM 2008a).

Table 1 summarizes panel fabrication parameters, the resulting specific surface values, and the corresponding slenderness ratios. The specific surface is calculated as (Moslemi 1974):

$$S_S = \frac{2}{t \cdot \rho} \tag{1}$$

where S_s is the specific surface (m^2/kg), t is the strand thickness (m), and ρ is the oven-dry wood density (kg/m^3). The slenderness ratio is calculated as (Moslemi 1974):

$$S_R = \frac{\ell}{t} \tag{2}$$

where S_R is the slenderness ratio, ℓ is the strand length (mm), and t is the strand thickness (mm).

Table 1. *Panel fabrication parameters.*

	Oven-dry wood density (ρ; kg/m^3)	Strand thickness (t; mm)	Strand length (ℓ; mm)	Target panel density (kg/m^3)	Strand specific surface (S_S; m^2/kg)	Strand slenderness ratio (S_R; mm/mm)	Name
Trembling aspen	459	0.49 (17.5)[a]	78	650	8.8	159	AS5
		0.53 (8.1)	105		8.3	198	AM5
		0.45 (15.1)	142		9.8	316	AL5
		0.75 (10.1)	78	650	5.8	104	AS7
		0.71 (7.7)	105		6.2	148	AM7
		0.65 (8.1)	142		6.6	215	AL7
Paper birch	624	0.46 (19.5)	78	650	7.0	170	BS5
		0.47 (15.6)	105		6.8	223	BM5
		0.43 (16.3)	142		7.4	330	BL5
		0.75 (10.7)	78	650	4.3	104	BS7
		0.71 (11.2)	105		4.5	148	BM7
		0.72 (8.7)	142		4.5	200	BL7

[a] Coefficient of variation (%).

Table 2. *Three-step closing pressing procedure.*

Species		Aspen	Paper birch
Starting press position (mm)		122	122
First closure step	Closing rate (mm/s)	13.6	11.3
	Duration (s)	5	6
	Closing rate (mm/s)	5.0	4.2
	Duration (s)	6	6
	Closing rate (mm/s)	2.0	0.5
	Duration (s)	1	8
	Closing rate (mm/s)	—	0.4
	Duration (s)		7
	Closing rate to intermediate position (120% of panel thickness; mm/s)	2.1	0.4
	Duration (s)	2	10
Hold at intermediate position (s)		35	25
Second closure step	Closing rate to intermediate position (110% of panel thickness; mm/s)	0.150	0.075
Hold at intermediate position (s)		30	20
Third closure step	Closing rate to final position (100% of panel thickness; mm/s)	0.150	0.075
Total closing time (s)		107	130
Hold at final position (s)		193	170
Opening sequence	Open to intermediate position (101.5% of final position; mm/s)	0.015	0.046
	Open to intermediate position (103% of final position; mm/s)	0.017	0.050
	Open to intermediate position (110% of final position; mm/s)	0.034	0.102
	Open to starting position (mm/s)	12.1	12.1
Total press cycle time (s)		375	335

Testing

Vertical density profile. Six 50 × 50-mm specimens per panel were tested using a QMS density profiler (Model QDP-01X) to measure density at 0.04-mm increments.

Internal bond. The vertical density profile specimens were utilized for internal bond (IB) tests according to ASTM D 1037 (ASTM 2008b).

Flatwise bending. MOR and MOE in flatwise bending parallel to strand orientation were determined according to ASTM D 1037 (ASTM 2008b). Two 76 × 480-mm specimens per panel were tested at a 360-mm span.

Edgewise bending. To determine MOR and MOE in edgewise bending parallel to strand orientation, ASTM D 5456 (ASTM 2008c) and ASTM 198 (ASTM 2008d) bending test procedures were adapted. Specimens were loaded at third points using a span-to-depth ratio of 18, and deformation was measured at the neutral axis using a yoke. Two 15 × 30 × 600-mm specimens per panel were tested at a 540-mm span. A schematic of the test setup is provided in Fig 1.

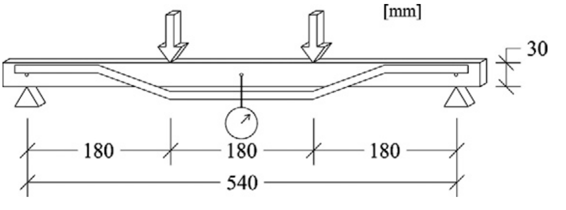

Figure 1. Test setup for 4-point edgewise bending tests.

Compression parallel to panel surface. The compressive strength and MOE perpendicular to strand orientation were determined according to ASTM D 1037 (ASTM 2008b). To give specimens lateral stability, two panel thicknesses were face-laminated using an epoxy resin. Four 25 × 102-mm specimens were tested per panel.

RESULTS AND DISCUSSION

Vertical Density Profile

Average density profiles for aspen and birch panels are shown in Fig 2. The chosen pressing schedule resulted in a near-uniform density

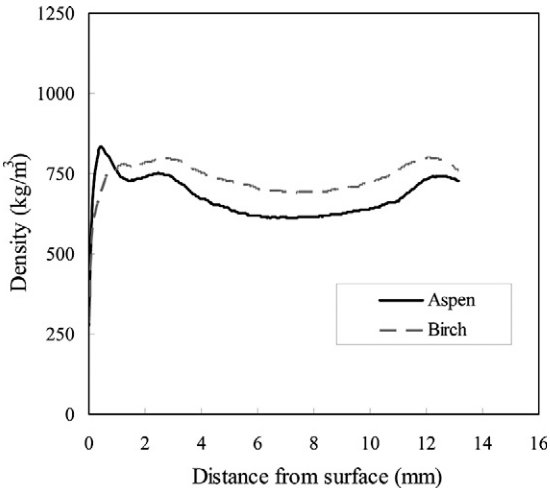

Figure 2. Averaged vertical density profiles for aspen and birch panels (N = 99).

profile throughout the thickness of the birch panels with slightly higher densities at the surface. The surface densities of aspen panels were significantly higher than those of the core.

Internal Bond

Results of the IB tests are presented in Fig 3. Analysis of variance (ANOVA), with specimen density considered as a covariable, showed none of the parameters tested to have a significant impact (α = 0.05) on the IB strength of aspen and birch panels. This means that no significant difference was found between aspen and birch IB specimens for all strand thicknesses and lengths considered, which could be explained by the high resin content. The average IB strength obtained for both species combined

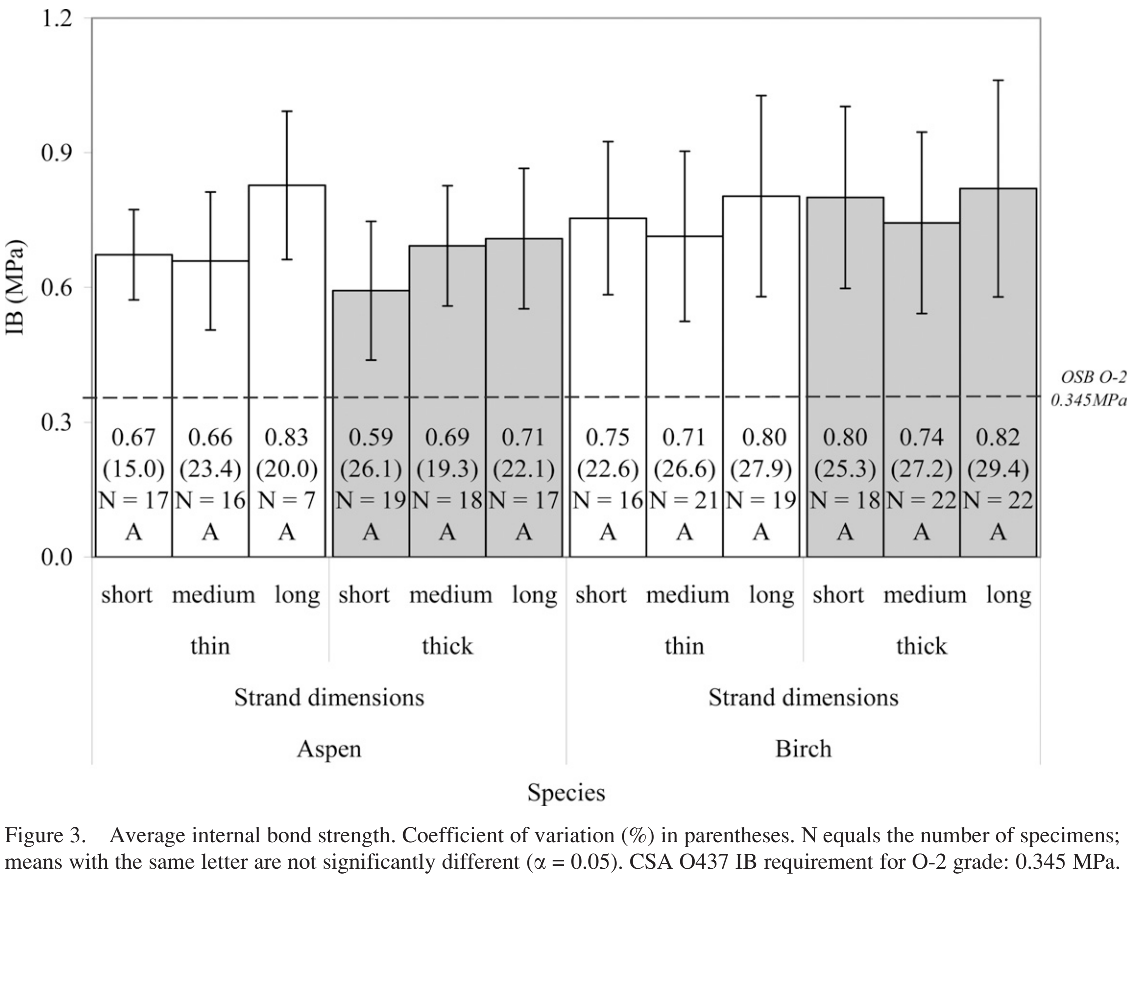

Figure 3. Average internal bond strength. Coefficient of variation (%) in parentheses. N equals the number of specimens; means with the same letter are not significantly different (α = 0.05). CSA O437 IB requirement for O-2 grade: 0.345 MPa.

was 0.73 MPa, well above the requirements of CSA-O437 (CSA 1993) for O-2 grade OSB (0.345 MPa). IB specimens in which failure was caused by folded strands were excluded from the analysis.

Flatwise Bending

Results of the flatwise bending tests are shown in Fig 4. ANOVA showed species, strand length, and strand thickness to have a significant impact on panel MOR and MOE at a significance level of $\alpha = 0.05$. No interactions were significant (Table 3). Aspen panels performed better than birch panels. This can be explained by the higher surface density of aspen panels, which enhances flexural behavior, and their higher compaction ratio (ratio of panel to wood density). According to Rice (1984), a higher compaction ratio increases bending MOR and MOE values for flakeboard. Longer strands resulted in better properties than shorter strands as a result of better alignment among longer strands (Meyers 2001; Chen et al 2008) and increased overlap length (Suchsland 1968). Thinner strands resulted in increased bending properties because of more intimate interstrand contact, more uniform mat formation from a higher number of strands, and significantly reduced void volume, especially around strand edges (Dai et al 2007).

Statistical analysis showed that bending properties improved significantly when the slenderness ratio was increased. Results of a linear regression based on the complete set of results obtained for aspen and birch are summarized in Fig 5. They show that to have comparable

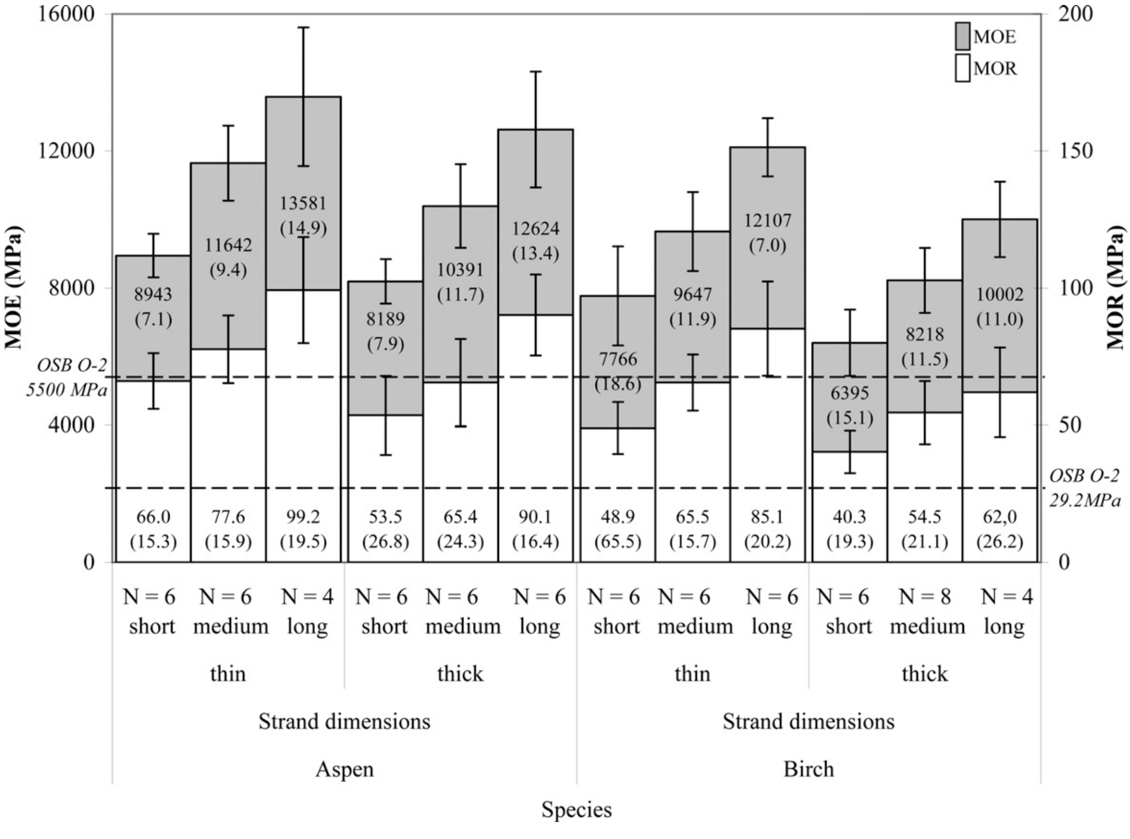

Figure 4. Average flatwise bending properties. Coefficient of variation (%) in parentheses. CSA-O437 requirement for O-2 grade: modulus of rupture = 29.0 MPa; modulus of elasticity = 5500 MPa.

bending properties for aspen and birch panels, birch strands must have a higher slenderness ratio, which can be obtained using thinner strands at a given length.

Table 3. *Analysis of variance results for modulus of rupture (MOR) and modulus of elasticity (MOE) in flatwise bending*.

	Source	df	F value	Prob > F
MOR	Spec	1	30.55	<0.0001
	Thick	1	19.92	0.0001
	Length	2	33.94	<0.0001
	Spec*thick	1	0.44	0.5112
	Spec*length	2	1.22	0.3111
	Thick*length	2	0.56	0.5771
	Spec*thick*length	2	1.16	0.3308
MOE	Spec	1	33.13	<0.0001
	Thick	1	16.44	0.0004
	Length	2	51.56	<0.0001
	Spec*thick	1	1.09	0.3066
	Spec*length	2	0.41	0.6709
	Thick*length	2	0.22	0.8044
	Spec*thick*length	2	0.23	0.7957

A comparison of all specimens showed species to have an influence on bending properties. However, statistical analysis of specimens with similar specific surfaces alone—ie, thick aspen strands and thin birch strands—showed no significant difference between the two species. In this case, only strand length had a significant impact. An ANOVA performed with strand length and specific surface as variables showed both to have a significant impact on flatwise bending without interaction. A higher specific surface resulted in increased bending properties.

The highest average MOR achieved was 99.2 MPa for long, thin aspen strands, and the lowest average MOR was 40.3 MPa for short, thick birch strands, well above the CSA-O437 requirements for OSB (29.0 MPa for the O-2 grade). The highest average MOE achieved was 13.6 GPa for long, thin aspen strands and the lowest was 6.4 GPa for short, thick birch strands, well above the

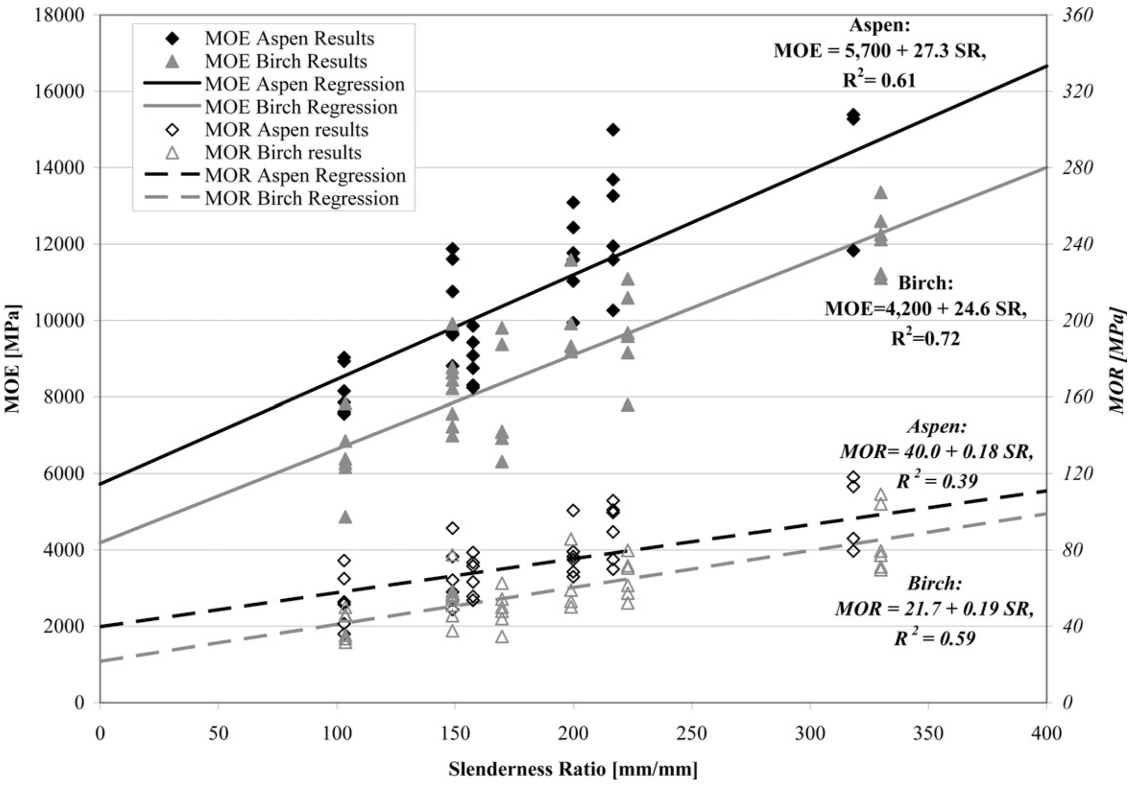

Figure 5. Flatwise modulus of elasticity and modulus of rupture results versus slenderness ratio (SR).

CSA-O437 (CSA 1993) requirements for OSB (5.5 GPa for the O-2 grade). TimberStrand®, a commercial laminated strand lumber (LSL) produced by Weyerhaeuser, has a flatwise MOE of 9.7 GPa and a specified flatwise bending strength of 24.2 MPa (iLevel 2008). The fifth percentile at 75% confidence level (characteristic values) after conversion from the standard load duration to short-term test (dividing by 0.8) is 30.3 MPa. Weight and Yadama (2008a) achieved a MOE of 10.2 GPa and a MOR of 79.1 MPa. All flatwise bending specimens failed in rupture on the tension side.

Edgewise Bending

Results of the edgewise bending tests are given in Fig 6 and Table 4. Specimen density had a significant impact ($\alpha = 0.05$) on the edgewise bending properties and was therefore considered as a covariable in the ANOVA. Statistical analysis showed species, strand length, and strand thickness to have a significant impact ($\alpha = 0.05$) on the edgewise flexural properties. Aspen panels outperformed birch panels, which can be

Table 4. *Analysis of variance results for modulus of rupture (MOR) and modulus of elasticity (MOE) in edgewise bending.*

	Source	df	F value	Prob > F
MOR	Spec	1	26.37	<0.0001
	Thick	1	22.38	<0.0001
	Length	2	18.39	<0.0001
	Spec*thick	1	5.31	0.0303
	Spec*length	2	0.84	0.4434
	Thick*length	2	1.04	0.3672
	Spec*thick*length	2	1.61	0.2217
MOE	Spec	1	38.82	<0.0001
	Thick	1	43.73	<0.0001
	Length	2	131.49	<0.0001
	Spec*thick	1	4.19	0.0512
	Spec*length	2	1.05	0.3642
	Thick*length	2	0.34	0.7138
	Spec*thick*length	2	2.58	0.0961

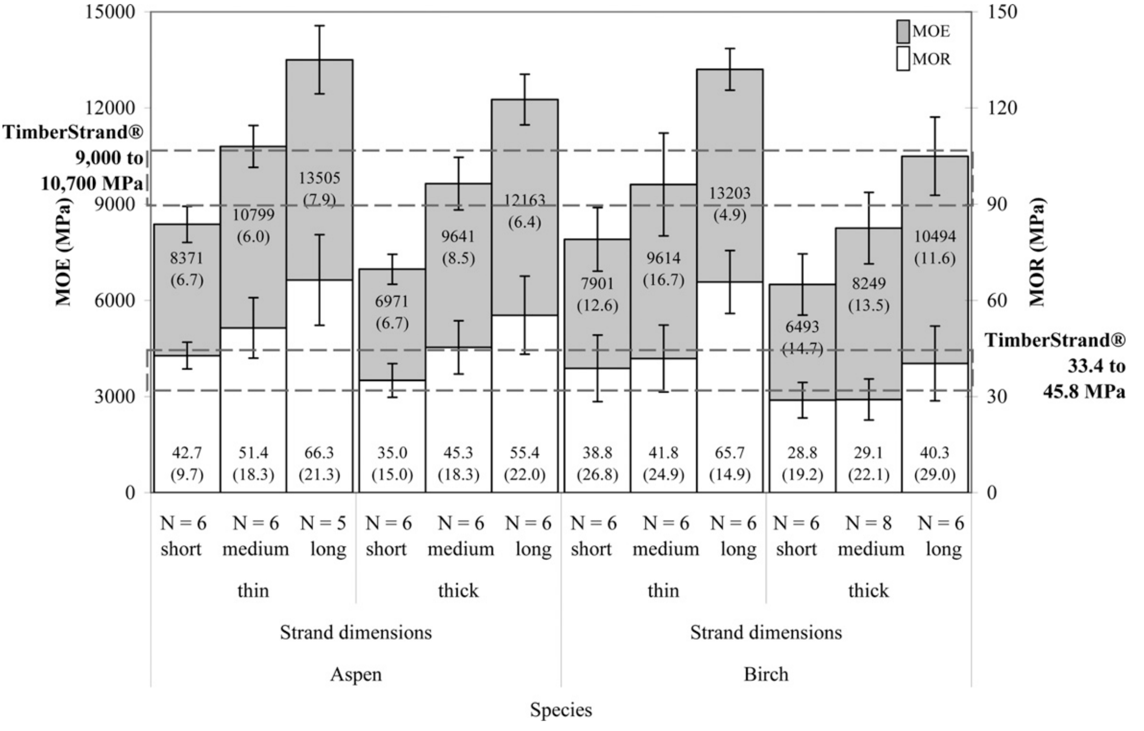

Figure 6. Average edgewise bending properties. Coefficient of variation (%) in parentheses. TimberStrand® modulus of elasticity values range from 9.0 GPa to 10.7 GPa; modulus of rupture (characteristic) values range from 33.4 MPa to 45.8 MPa (iLevel 2008).

explained by their higher compaction ratio (Rice 1984). Bending properties improved when longer and thinner strands were utilized. Although no literature is available on the edgewise bending of strandboards, it can be assumed that the reasons for the better performance of specimens made from longer and thinner strands are the same as for flatwise bending: better alignment, more intimate interstrand contact, and fewer voids. The only significant interaction obtained was between species and strand thickness for MOR. The MOR of birch panels with thick strands was significantly lower than that of birch panels with thin strands and aspen panels with thin or thick strands (Table 4), which means that the effect of strand thickness varies between species. The use of thick strands cut from a dense species lowers the contact surface between strands, which results in decreased mechanical properties (Dai et al 2007).

Whereas increasing the slenderness ratio resulted in improved edgewise bending properties comparable to flatwise bending, specimen density also had a significant impact. The results of linear regression based on the complete set of results obtained for aspen and birch are given in Fig 7. Results obtained in edgewise bending show that to have comparable panel properties, birch panels must be produced at a higher panel density or from strands with a higher slenderness ratio than aspen strands, ie thinner birch strands at a constant length.

Species had a significant impact on bending properties when comparing all specimens. Statistical analysis performed only on the specimens of similar specific surface—ie, thick aspen strands and thin birch strands—showed no significant difference between bending properties for the two species. In this case, only strand length had a significant impact. Both strand length and specific

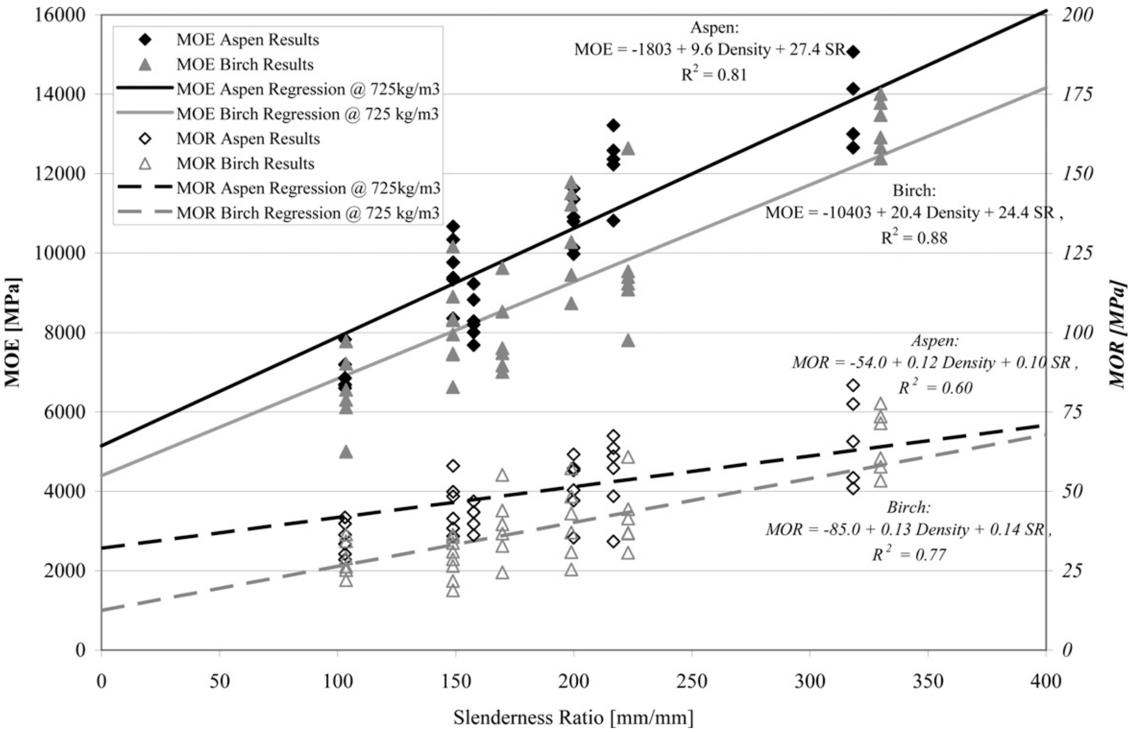

Figure 7. Edgewise modulus of elasticity and modulus of rupture results versus slenderness ratio. Regression lines are shown for a specimen density of 725 kg/m^3.

surface had a significant impact, but no interaction was found between them based on ANOVA. Higher specific surfaces resulted in increased bending properties.

The highest average MOR and MOE were 66.3 MPa and 13.5 GPa, respectively, for long, thin aspen strands, and the lowest average MOR and MOE were 28.8 MPa and 6.5 GPa for short, thick birch strands. The MOE values obtained were similar and even superior to those for commercial strand products and solid structural lumber; MOE values ranged 9.0 – 10.7 GPa (iLevel 2008) for TimberStrand® LSL and spruce–pine–fir dimension lumber of select structural quality has an MOE of 8.5 GPa (CSA 2005).

The specified strength of TimberStrand® LSL in bending varies between 21.6 and 29.6 MPa for 1.3E and 1.55E grades, respectively. After converting these values from the standard load duration to short-term test and adjusting for beam depth (multiplying by $[305/30]^{0.092}$) (iLevel 2008), the fifth percentiles at 75% confidence level (characteristic values) would be 33.4 and 45.8 MPa, respectively. Beams with long, thin strands are therefore likely to offer similar performance to commercial strand products, whereas those with short, thick strands do not meet the target performance level. However, this conclusion needs to be verified with full-size tests.

Compression

Test results are shown in Fig 8. Specimen density had a significant impact ($\alpha = 0.05$) and was therefore considered a covariable in the ANOVA. Statistical analysis showed species and strand length to have a significant ($\alpha = 0.05$) impact on the compressive properties of the panels (Table 5). Aspen panels performed better than birch panels, and shorter strands resulted in better properties than longer strands. Short strands do not align well, resulting in a higher percentage of strands oriented parallel to the testing direction. No interactions were significant (Table 5). The highest compressive strength and MOE were 14.5 and 2852 MPa, respectively, for short aspen strands. TimberStrand® has specified compressive strength values ranging from 8.6 – 10.0 MPa (iLevel 2008). Spruce–pine–fir dimension lumber of Select Structural quality has a strength of 5.3 MPa (CSA 2005).

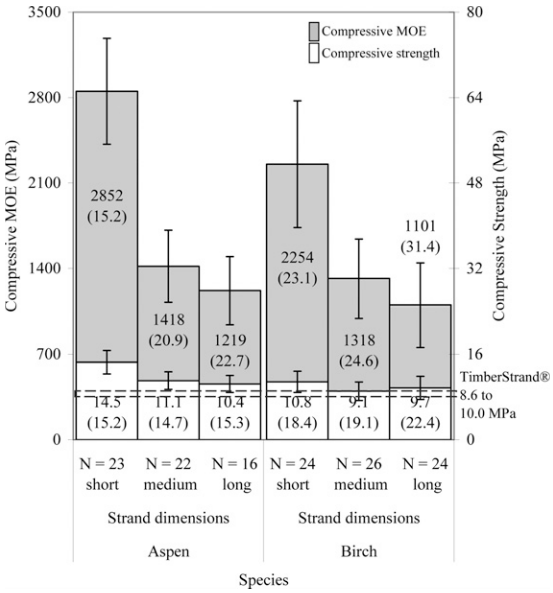

Figure 8. Average compressive properties. Coefficient of variation (%) in parentheses. TimberStrand® specified compressive strength values range from 8.6 MPa to 10.0 MPa (iLevel 2008).

Table 5. *Analysis of variance results for compressive strength and stiffness.*

	Source	df	F value	Prob > F
Strength	Spec	1	110.68	<0.0001
	Thick	1	0.77	0.386
	Length	2	69.62	<0.0001
	Spec*thick	1	1.45	0.2375
	Spec*length	2	3.23	0.0544
	Thick*length	2	0.17	0.8435
	Spec*thick*length	2	3.05	0.0633
Stiffness	Spec	1	19.71	<0.0001
	Thick	1	0.08	0.7766
	Length	2	141.42	<0.0001
	Spec*thick	1	1.04	0.3159
	Spec*length	2	3.08	0.0618
	Thick*length	2	1.19	0.3182
	Spec*thick*length	2	1.21	0.3121

CONCLUSIONS

The main objective of this study was to determine the effect of strand geometry on the mechanical performance of an OSL product prototype with a uniform vertical density profile made from trembling aspen or paper birch. The prototype will be utilized for a new engineered wood product consisting of laminated thin OSL-type panels. Vertical density profiles showed that profiles with near-uniform cores and slightly pronounced face densities can be achieved using a three-step press closing procedure. This was demonstrated more successfully for birch than for aspen.

Strand geometry and species had no significant effect on IB, although they did have a significant impact on flatwise and edgewise bending properties. Generally, aspen panels had better bending properties than birch panels, and longer, thinner strands resulted in higher MOR and MOE. Slenderness ratio had a significant effect on bending properties. A higher slenderness ratio improved MOR and MOE values. Similar bending properties for aspen and birch panels were achieved by adjusting strand thickness to keep the specific surface of the strands constant. For flatwise bending, the highest average MOR and MOE were achieved for long, thin aspen strands (99.2 and 13.6 GPa, respectively).

The highest edgewise bending properties (MOR of 66.3 MPa and MOE of 13.5 GPa)— obtained for panels made from long, thin aspen strands—put the prototype within the required range to compete with similar engineered wood products.

Strand length and species had a significant effect on compressive strength parallel to the panel surface and perpendicular to strand orientation. Aspen panels performed better than birch panels, and shorter strands resulted in better properties than longer strands. The product can be utilized in edgewise applications (such as beams, headers, or columns) in which both bending properties in strand orientation and compressive properties perpendicular to strand orientation are of great importance. Strand length must therefore be a compromise between the need for high bending properties provided by long strands and the need for high compressive properties provided by short strands.

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