SELECTED PROPERTIES OF WOOD STRAND AND ORIENTED STRANDBOARD FROM SMALL-DIAMETER SOUTHERN PINE TREES[1]

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ABSTRACT

Thermal and mechanical properties of southern pine and willow strands and properties of southern pine oriented strandboard (OSB) from small-diameter logs were investigated in this study. The effects of density and species group on tensile strength, dynamic moduli, and thermal stability of wood strands, and of strand quality (i.e., wood fines) on three-layer OSB properties were analyzed.

Strand tensile strength and dynamic storage moduli (E′) increased with the increase of strand density. A large variation in both tensile strength and E′ values was observed for southern pine, while willow strands showed much smaller variability. The dynamic moduli (E′) of strands decreased with increase of temperature in the range of 25° to 200°C. Small loss modulus (E″) peaks were observed over the temperature range studied. The strands with higher densities had higher E″. Thermogravimetric analysis results revealed that high-density strands were thermally more stable than low-density strands.

Three-layer OSB made of small-diameter southern pine trees showed satisfactory strength and dimensional stability properties. As the fines loading levels increased, linear expansion (LE) along the parallel direction decreased, while the LE value along the perpendicular direction and thickness swelling increased. With increased fines levels, the internal bond strength showed an increasing trend up to the 20% fines level, and bending strength and modulus varied little in the parallel direction and slightly decreased in the perpendicular direction.

Keywords: Southern pine, small diameter, strand, OSB, property, fines.

INTRODUCTION

Silvicultural treatments such as thinnings and stand improvements promote increased growth, size, and value of the remaining trees and help reduce hazardous flammable bio-mass from the forest. The treatment would be more economical if there were viable markets for the removed material. Due to the recent slowdown in the pulp and paper industry and restricted logging on federal forest land, there is an overstocking of small-diameter pine trees in the southern United States. Forest managers have identified forest

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stands overstocked with small-diameter trees as a critical forest health issue. Overstocked stands are subject to attack by insects and disease, and the risk of destruction by wild fire as a result of the heavy fuel load (Wolfe 2000). There is a need for removing and utilizing these materials to capture more value from the forest and to reduce fire hazards. One way to help recover the cost of thinning is value-added structural uses of the small-diameter round timber (Wolfe 2000). Strand-type structural wood composites such as oriented strandboard (OSB) provide an excellent opportunity for this abundant resource.

For strand-based structural composites such as OSB, panel strength largely depends on the mechanical properties of individual strands (Rowell and Banks 1987; Lee and Wu 2003). Price (1975) investigated the tensile properties of sweetgum in association with hot-pressing. The result showed that tensile properties of pressed sweetgum strands in the face layer increased, and diminished in the core layer due to vertical pressure variation during pressing. Extensive studies on strand property were conducted at the USDA Forest Products Laboratory (Geimer et al. 1985). In their study, two levels of pressing temperature were used, and the higher temperature showed a greater effect on the properties of Douglas-fir strands. Strand properties have been used to predict strength properties of structural wood composite materials (Barnes 2000 and 2001; Lee and Wu 2003).

Temperatures used for processing wood-based composites significantly influence physical, structural, and chemical properties of the materials. Thermo-gravimetric analysis (TGA) and dynamic mechanical analysis (DMA) have been widely used to characterize the thermo-chemical and thermo-mechanical properties of lignocellulosic materials (Backman 2001). In a previous study, dynamic mechanical behavior of Scots pine in radial and tangential directions was investigated with DMA at 1 Hz frequency (Backman 2001). It was found that wood along the radial direction had a higher elastic modulus and lower loss factor (tanδ) at temperatures between −120°C and 80°C, compared with the tangential direction. Investigations in another study also reported property differences in radial and tangential directions with dynamic mechanical measurements on water-swollen softwood (Japanese cypress) in a temperature range between 10°C and 95°C (Furuta et al. 1997). A loss factor peak was observed at 80°C for the tangential direction and 95°C for the radial direction. Salmen (1984) measured dynamic mechanical properties of water-saturated Norway spruce both longitudinally and transversely at 10 Hz and determined the glass transition temperature (Tg) for lignin to be about 100°C. However, all of the previous research was done using wood samples with large thickness (e.g., more than 1.5 mm). Very limited information is available on the study of dynamical properties of thin strands (less than 1 mm) for strand-based composites.

Juvenile wood has properties that are significantly different from mature wood. A summary of the properties of juvenile wood was published by Bendtsen (1978). Research by Pearson and Gilmore (1971) demonstrated that juvenile wood had substantially lower mechanical properties than mature wood. The low strength and stiffness values of juvenile wood are a major concern in composite manufacturing. Kretschmann et al. (1993) investigated the implications of southern pine juvenile wood on structural performance of laminated veneer lumber (LVL). LVL made of various proportions of juvenile and mature veneer was tested in flatwise and edgewise bending, and in tension. Results of the study showed that the strength and stiffness of LVL decreased with increased juvenile wood content.

For strand composite manufacturing, the flaking of small-diameter juvenile wood usually leads to a large amount of fines (i.e., small wood particles). Use of wood fines can help reduce raw material cost for OSB production. However, the fines change internal mat structure and influence panel properties (Barnes 2000). The structural composite industry faces common problems on how to generate flakes with a minimum amount of fines, and how to best utilize them in the furnish (EWRF 2001). Thus, it is of practical significance to understand the effect of varying amounts of fines on final board properties.

This study was aimed at providing a better understanding of the properties of small-diameter southern pine materials and their use for strand-based composite manufacturing. The specific objectives were to investigate strand properties (i.e., tensile strength, dynamic modulus, and thermal stability) and panel performance of OSB from small-diameter southern pine logs as influenced by fines contents.

MATERIALS AND METHODS

Log selection and strand preparation

Small-diameter southern pine (*Pinus spp.*) logs (7–15 cm) were obtained from a local chip mill in southern Louisiana. The materials were tops of trees removed from the forest as part of silvicultural treatments. Each log was debarked and then sawn into 15-cm-long sections, which were soaked in water prior to flaking. A CAE 915-mm disc flaker was used to produce 15-cm-long and 0.1-cm-thick strands. For comparison of strand properties, strands from willow (*Salix spp.*) were prepared by flaking 2.54-cm-thick boards into strands of the same thickness. Willow is a low-density hardwood species with relatively uniform texture (USDA Forest Products Laboratory 1999), and has been used to make mixed hardwood OSB in the South. All strands were kiln-dried to about 3% moisture content (MC) and screened to separate fines. To provide sufficient amount of fines for panel manufacturing, a small tree chipper was used to chip larger southern pine strands into fines.

Strand property testing

Tensile strength testing.—Sixty large strands without apparent surface cracks from each material type (i.e., southern pine and willow) were randomly selected and conditioned at 20°C and 65% relative humidity. They were cut to 10-cm-long samples with varying width (12 to 15 mm). The samples were notched at the center to ensure the breakage in the middle of sample during tensile testing. All samples were tested according to the ASTM D 1037 (ASTM 1998) using an INSTRON machine at a loading speed of 4 mm/min.

Dynamic mechanical analysis.—Sixty specimens of 40 × 10 × 0.5–1.0 (thickness) mm for each material type were prepared for DMA. They were separated into four groups according to strand density (i.e., A: <0.41 g/cm^3; B: 0.41–0.50 g/cm^3; C: 0.51–0.60 g/cm^3; D: >0.60 g/cm^3). All samples were conditioned at 25°C and 65% relative humidity for two weeks prior to testing. Each specimen was mounted in a TA Q-800 dynamic mechanical analyzer in a single cantilever mode. Clamps were attached at both ends at room temperature with a torque force of 0.1 Nm. Test runs were made at a constant temperature of 25°C and a varying temperature from 25°C to 200°C with a heating rate of 2°C/min using 1 Hz frequency. Information on storage modulus (E′), loss modulus (E″), and loss factor (tanδ) was collected for each sample.

Thermo-gravimetric analysis.—TGA specimens were prepared from different density groups of the selected DMA test samples. They were separately ground to pass through a 20-mesh screen and oven-dried at 80°C for 24 h. Thermo-gravimetric analysis was carried out using a TA Q 50 analyzer. An approximately 5-mg sample was used for each test, and the test was carried out under a nitrogen atmosphere at a heating rate of 20°C/min over a temperature range of 50 to 500°C. Initial weight loss temperature, extrapolated onset temperature, maximum weight loss temperature, and residual weight for each sample were recorded.

Board fabrication and testing

OSB with controlled alignment level was manufactured using phenol-formaldehyde (PF) resin in combination with wax. The experimental variables are shown in Table 1. Three-layer boards were made with large flakes in the face layer and varied amount of fines uniformly distributed in the core layer. The fines contents in the core layer were 0, 10, 20, 30, and 45% based on the total flake weight in the panel. All three-

TABLE 1. *Experimental variables for panel manufacturing.*

Experimental variables	Panel manufacturing conditions
Panel size	570 × 500 × 12 mm
Density	0.70 g/cm^3
Fines content	0, 10, 20, 30, 45%
Resin and amount	PF 4%
Panel structure	3-layer
Replication	Two for each condition

layer panels (570 × 500 × 12 mm) were constructed with a face and core flake weight ratio (i.e., shelling ratio) of 55 to 45 (i.e., 1.22). The PF resin and wax were sprayed onto strands inside a blender at 4% and 1% loading levels, respectively, based on the oven-dry weight of the strands. Mats were manually formed using a specially designed forming box to control the strand alignment level. The formed mats were loaded into a press and hot-pressed to the target thickness at a temperature of 190°C for 4 min. Two replicates were used for each condition, and a total of 10 boards were manufactured. The panels were trimmed and conditioned for two weeks under room conditions before testing.

Flake alignment angles were measured from board surfaces by randomly selecting 150 flakes on each side of the board. This was done by first taking a digital image of each of the two surfaces for a given board. A line parallel to the long dimension of each selected flake was drawn on the board surface using sigma-scan software®. The slope of the line was calculated and converted to the angle data. The alignment angle of each strand was measured from −90 to 90° with 0° set as the principal machine direction. Strand alignment was described by percent alignment (PA) proposed by Geimer (1976). Density profile through the thickness of the specimen (50 × 50 mm) was evaluated using a Quintek Density Profile QDP-01X. The maximum, average, and minimum densities for each board were recorded. Six replicates were used, and the result was averaged for each group.

The properties tested include linear expansion (LE), modulus of elasticity (MOE), modulus of rupture (MOR), thickness swelling (TS), and internal bond (IB). Tests were conducted according to the ASTM Standard D1037 (ASTM 1998). Eight samples (4 parallel and 4 perpendicular) of 288 × 74 mm were prepared for LE test. Two holes 245 mm apart were drilled along the long dimension of each specimen. A small rivet (1.0 mm in diameter) with crossed hairline on the top, dipped in epoxy glue, was plugged into each of the two holes. All specimens were initially oven-dried for 24 h, and then vacuum-pressure-soaked in the water at 20°C for 3 h (1h vacuum at 0.1 MPa and 2 h at 0.7 MPa pressure). LE was evaluated by measuring the reference distance between the two rivets before and after water-soaking. Two samples from each board, 343 × 74 mm, were cut along each of the two principal directions for static bending test (i.e., MOE and MOR). They were labeled according to board type and orientation (parallel or perpendicular). Tests in the dry condition were conducted in a three-point bending mode over an effective span of 288 mm at a loading speed of 5.88 mm/min. TS tests were carried out on four specimens of 147 × 147 mm at each condition after being soaked in water for 24 h at 20°C (ASTM 1998). Six specimens of 50 × 50 mm for each condition were tested for IB strength at a testing speed of 0.98 mm/min.

Statistical analysis

Regression analysis was performed to express the relationships between tensile strength and strand density, between dynamic modulus and strand density, and between dynamic modulus and temperature. Statistical comparisons (i.e., t-test at the 5% confidence level) were done to investigate the effects of fines levels on the properties of OSB panels. Finally, nonlinear regression models were established to describe the correlations between LE and fines level, and between TS and fines level.

RESULTS AND DISCUSSION

Strand property

Tensile strength.—Tensile strength data of southern pine strands in different density groups in comparison with those of willow are summarized in Table 2. The average tensile strength

TABLE 2. *Summary of tensile strength properties of strands.*[a]

Material type	Density group[b]	Moisture content (%)	Sample thickness (mm)	Tensile strength (MPa)
Southern Pine	A	10.30	0.67 (0.11)	31.73 (13.08)
	B	10.30	0.55 (0.14)	42.41 (9.56)
	C	10.30	0.60 (0.19)	55.33 (22.55)
	D	10.30	0.51 (0.07)	75.03 (36.43)
Willow	0.38 (0.04)	10.30	0.79 (0.08)	31.28 (7.44)

[a] The results are averages and standard deviations (in parentheses) from the mean values of 60 randomly chosen strand samples.
[b] Density group (g/cm^3): A: <0.41; B: 0.41–0.50; C: 0.51–0.60; D: >0.60.

values for four density groups are 32, 42, 55, and 75 MPa for A (<0.41 g/cm^3), B (0.41–0.50 g/cm^3), C (0.51–0.60 g/cm^3), and D (>0.60g/cm^3), respectively. It is clearly seen that higher density groups had higher tensile strength values. The average tensile strength of group D was over twice higher than that of the group A, showing a large strand property variability.

The data of tensile strength were plotted as a function of strand density to show the relationship between tensile strength and density for both southern pine and willow (Fig. 1a). For both types of strands, tensile strength had an increasing trend with the increase of strand density. Unlike the data of willow strands, which are crowded in a narrow range, southern pine strands showed a wide spread of the tensile strength. A linear fit between tensile strength and strand density for both species led to the following relationships:

$$TS_{SP} = 168.13 * \rho - 33.14 \quad r^2 = 0.62 \qquad (1)$$

$$TS_{WL} = 115.81 * \rho - 12.30 \quad r^2 = 0.34 \qquad (2)$$

where, TS_{SP} and TS_{WL} are the tensile strengths (MPa) for southern pine and willow, respectively; ρ is strand density (g/cm^3). As shown, a good linear regression relationship between tensile strength and specimen density was obtained for southern pine, but there is a less linear dependence for willow. These relationships can be conveniently used to predict the tensile strength of strands to aid the OSB manufacturing and property optimization process.

Figure 1b shows the distributions of tensile strength for southern pine and willow strands. The overall distribution for southern pine strands was close to a normal distribution with a mean of 48.90 MPa and a standard deviation of 19.93 MPa. This observation agreed well with the results of an earlier work by Wu et al. (2005), where the average tensile strength of southern pine veneers (0.38 cm thick) was 49.98 MPa with a standard deviation of 19.12 MPa. Compared to willow with a mean value of 31.28 MPa and a standard deviation of 7.44 MPa, southern pine showed a higher tensile strength and a large

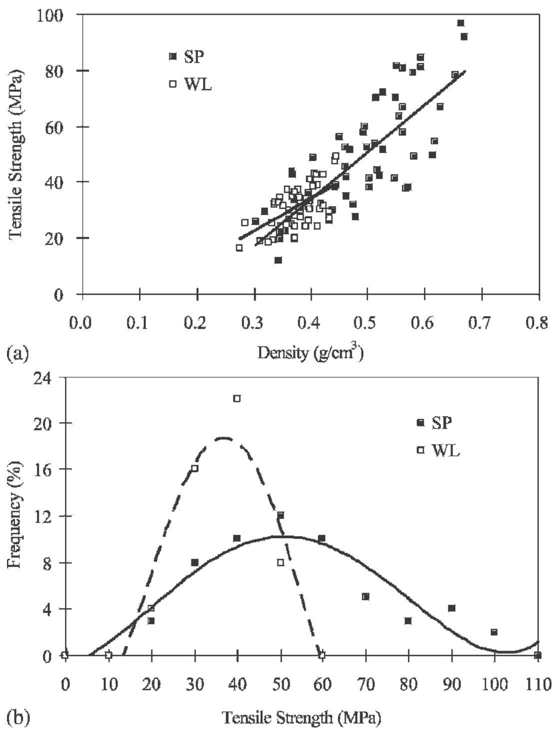

FIG. 1. Tensile strength of wood strands. a) relationship between tensile strength and strand density with lines showing regression fit, and b) the distribution of tensile strength. SP-southern pine and WL-willow.

TABLE 3. *Summary of DMA results on wood strands.*[a]

Material type	Density group[b] (g/cm^3)	Specimen Width (mm)	Specimen Thickness (mm)	Storage modulus (GPa)	Loss modulus (GPa)	tanδ
Southern Pine	A	8.26	0.69	3.53	0.089	0.026
		(0.26)	(0.16)	(0.74)	(0.01)	(0.01)
	B	8.66	0.67	5.69	0.161	0.028
		(0.53)	(0.09)	(0.81)	(0.05)	(0.01)
	C	9.34	0.63	7.23	0.192	0.027
		(0.57)	(0.07)	(1.26)	(0.06)	(0.01)
	D	9.00	0.59	10.00	0.242	0.025
		(0.55)	(0.12)	(1.48)	(0.05)	(0.01)
Willow	0.40	9.41	0.80	3.91	0.115	0.030
	(0.03)	(0.18)	(0.04)	(0.94)	(0.06)	(0.01)

[a] The results are given as averages and standard deviations (in parentheses).
[b] Density group (g/cm^3): A: <0.41; B: 0.41 – 0.50; C: 0.51 – 0.60; D: >0.60.

r variability. The distribution strongly indicated a significant variation in mechanical properties of small-diameter southern pine materials.

Dynamic modulus at room temperature.—Dynamic mechanical properties of southern pine strands in comparison with willow flakes are summarized in Table 3. There was a clear difference in storage (E′) and loss modulus (E″) among different density groups. At 25°C, the E′ value of group D averaged 10.00 GPa and the value of group A averaged 3.53 GPa. The average E′ value of group D was nearly three times higher than group A. The reason for the large difference in modulus among different density groups may be related to actual cell structure. It was observed that high-density strands were mostly from latewood and low-density stands from earlywood. Latewood tracheids have thicker cell walls than earlywood tracheids. The thick cell wall gives higher stiffness for high-density strands and therefore a higher modulus compared with low-density strands (Backman 2001).

Figure 2a shows a comparison of storage moduli of small-diameter southern pine and willow strands as a function of specimen density. There is a linear relationship between storage modulus and strand density as shown by the following equations:

$$E'_{SP} = 20.182 * \rho - 3.506 \qquad r^2 = 0.82 \qquad (3)$$

$$E'_{WL} = 30.176 * \rho - 8.078 \qquad r^2 = 0.66 \qquad (4)$$

where E'_{SP} and E'_{WL} are the storage modulus (GPa) for southern pine and willow, respectively; and ρ is strand density (g/cm^3). The cor-

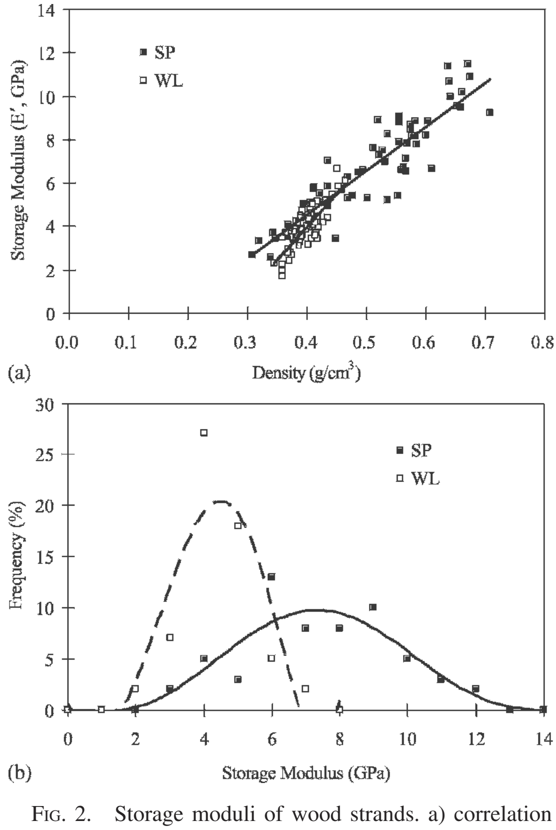

FIG. 2. Storage moduli of wood strands. a) correlation between storage modulus (E′) and strand density, and b) the distribution of storage modulus. SP-southern pine and WL-willow.

relation coefficients are reasonably high, especially for southern pine materials.

A nearly normal distribution of storage modulus for southern pine strands was obtained with a mean of 6.84 MPa and standard deviation of 2.26 MPa (Fig. 2b). This result was close to the tensile modulus of the same species (Wu et al. 2006), where the average value was 8.60 MPa with a standard deviation of 3.31 MPa. The storage modulus of willow was averaged at 3.91 MPa with a standard deviation of 0.94MPa. Compared to willow, southern pine strands showed a wide variation in storage modulus due to the significant difference in densities of the tested specimens.

Effect of temperature on dynamic modulus.—Figure 3 shows the effect of temperature on dynamic moduli of southern pine strands in different density groups in comparison with willow strands. A decreasing trend in storage moduli (E′) over the temperature range was observed, and no major transition was detected (Fig. 3a). When wood is subjected to heating, chemical bonds in wood begin to cleave at 100°C, and water, carbon dioxides, and traces of organic degradation products are formed between 100°C and 200°C (Shafizadeh 1985; LeVan 1989). In the constituents of wood, hemicelluloses generally show a lower thermal stability than cellulose, presumably due to their lack of crystallinity. Lignin degrades over a wider temperature range than carbohydrates due to its high structural diversity (Alen et al. 1996). The reduction of stiffness of the samples would be due to the softening of lignin and slight pyrolytic degradation of hemicellulose at higher temperatures (Elder 1990; Alen et al. 2002). Similar to the DMA results at room temperature, a significant increase in the E′ values at an elevated temperature level is clearly seen with the strands in higher density groups. Statistical regression analysis showed rather good linear relationships between temperature and storage modulus for southern pine samples in different density groups:

$$E'_A = -0.004T + 3.296 \qquad r^2 = 0.99 \qquad (5)$$

$$E'_B = -0.007T + 5.191 \qquad r^2 = 0.99 \qquad (6)$$

$$E'_C = -0.010T + 7.377 \qquad r^2 = 0.99 \qquad (7)$$

$$E'_D = -0.013T + 10.091 \qquad r^2 = 0.99 \qquad (8)$$

where E'_A, E'_B, E'_C, and E'_D are storage moduli (GPa) for density groups of A, B, C, and D, respectively; T is temperature (°C). For every 10 degree of temperature increase, E'_A, E'_B, E'_C, and E'_D decreased by about 40, 70, 100, and 130 MPa, respectively. Higher density group decreased at relatively higher rates.

Loss moduli (E″) spectra of southern pine and willow strands are presented in Fig. 3b. For southern pine, very slight loss modulus peaks are observed around 50°C. This seems to be the

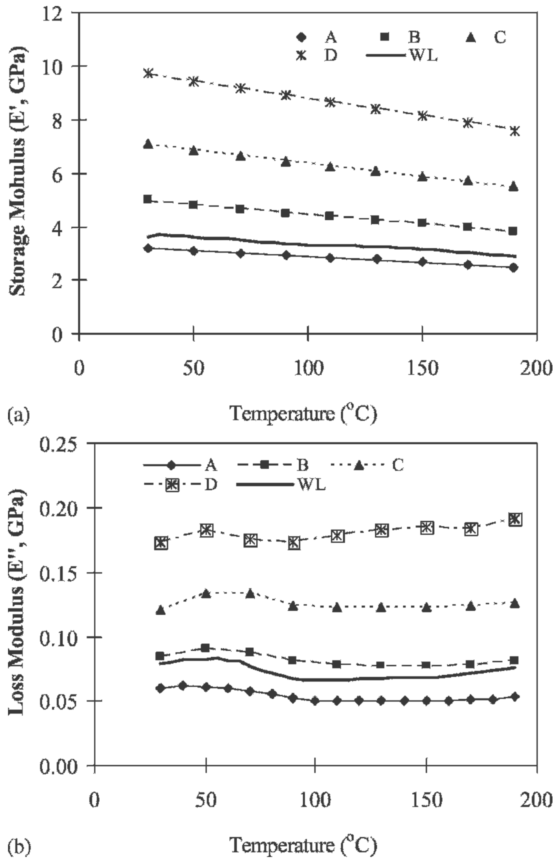

FIG. 3. The storage modulus (E′) and loss modulus (E″) of southern pine (SP: A, B, C, and D) and willow (WL) strands as a function of temperature.

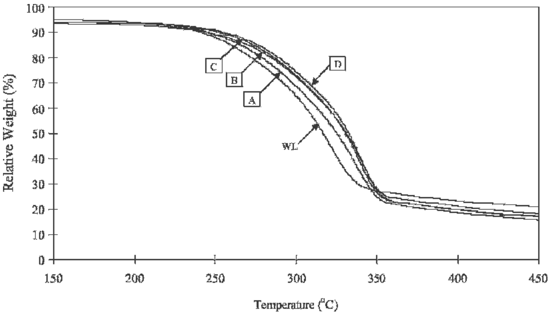

FIG. 4. TGA diagrams of southern pine samples of different density groups (SP: A, B, C, and D) as compared to willow (WL).

transition point for lignin. Little change in the intensity (i.e., height of the peak) of a transition is observed for all density groups. The southern pine strands with higher density had higher E″. The E′ and E″ spectra of willow appear between A and B groups, reflecting the fact that the density of willow is between A and B groups.

Strand thermal stability.—Figure 4 shows TGA diagrams of southern pine samples of different density groups in comparison with willow in the temperature range of 150° to 450°C. TGA data (Fig. 4 and Table 4) showed that the temperatures for the initial weight loss and extrapolated onsets of high-density groups were higher than low-density groups. This result indicates that low-density southern pine samples are slightly less thermally stable than high-density specimens. It is clearly seen that the initial weight loss and extrapolated onset temperatures of willow samples were lower than southern pine samples, indicating that southern pine of all density groups had more stable thermal properties than willow. The lower thermal stability of willow could be due to the higher extractives content (Bakker et al. 2004).

Panel properties

Panel properties of three-layer southern pine OSB at various fines levels in the core layer are summarized in Table 5 with statistical ranking on various properties. Percentage alignment of the strands varied from 63% to 70%. The cumulative distributions of alignment angles for the boards with different fines contents are shown in Fig. 5a. Typical strand alignment distribution curves are shown for all panels. About 85% to 90% flakes of panels were aligned within −30 to 30 degrees from the panel's principal direction, indicating a good control of strand orientation in the mat-forming process. Typical density profiles across panel thickness at various fines content levels are shown in Fig. 5b. In general, the density profiles of all boards had M-shapes, the common density gradient of boards from the vertical variation of pressure, temperature, and moisture of hot-pressing (Kelly 1977). It seems that density gradients increased with increased fines contents in the core layer. The density profile of a board is highly dependent upon the particle configuration (Kelly 1977). The boards with 45% fines had no large strands in the core layer, showing the largest strand shape differential between face and core layers. The boards with no fines or lower fines had more uniform mat structures along the panel thickness direction.

Mechanical properties of OSB as a function of fines levels in the core layer are plotted in Fig. 6. Generally, MOE and MOR varied little in the

TABLE 4. *Summary of TGA results of wood strands.*

Material type	Density group[b] (g/cm^3)	Initial weight loss temp (°C)	Extrapolated onset temp[a] (°C)	Maximum weight loss temp (°C)	Residual weight (%)
Southern Pine	A	188	286	350	14.44
	B	191	298	353	15.52
	C	196	299	356	15.57
	D	206	303	361	16.69
Willow	0.40	182	273	340	19.40

[a] Extrapolated onset temperature is the intersection point of two lines drawn tangent to the two linear regions of the TGA curve.
[b] Density group (g/cm^3): A: <0.41; B: 0.41–0.50; C: 0.51–0.60; D: >0.60.

TABLE 5. *Summary of panel properties of three-layer OSB from small-diameter southern pine logs.*[a]

Fines level (%)	PA (%)	Parallel Density (g/cm^3)	Parallel MOR (MPa)	Parallel MOE (GPa)	Parallel Density (g/cm^3)	Parallel LE (%)	Perpendicular Density (g/cm^3)	Perpendicular MOR (MPa)	Perpendicular MOE (GPa)	Perpendicular Density (g/cm^3)	Perpendicular LE (%)	IB Density (g/cm^3)	IB (MPa)	TS Density (g/cm^3)	TS (%)
0	68.43	0.77	49.21a	9.75a	0.78	0.21a	0.79	27.21a	3.22a	0.83	0.32c	0.83	0.55b	0.78	22.31b
	(2.92)	(0.01)	(1.41)	(1.36)	(0.07)	(0.03)	(0.01)	(0.83)	(0.09)	(0.02)	(0.04)	(0.06)	(0.28)	(0.04)	(1.80)
10	67.36	0.71	47.10a	8.18c	0.78	0.19ab	0.83	22.07abc	2.90ab	0.79	0.28c	0.77	0.43ab	0.80	27.22ab
	(8.21)	(0.01)	(1.36)	(0.02)	(0.00)	(0.03)	(0.02)	(0.39)	(0.21)	(0.01)	(0.01)	(0.07)	(0.18)	(0.00)	(1.94)
20	63.02	0.75	53.31a	9.48ab	0.77	0.17ab	0.81	23.79ab	2.70bc	0.80	0.40c	0.85	0.49a	0.74	29.26a
	(5.48)	(0.00)	(3.12)	(0.23)	(0.01)	(0.02)	(0.03)	(1.56)	(0.17)	(0.01)	(0.13)	(0.10)	(0.16)	(0.02)	(1.29)
30	66.02	0.72	47.14a	8.57bc	0.74	0.14b	0.81	18.76bc	2.70bc	0.74	0.60b	0.78	0.63a	0.72	30.40ab
	(4.96)	(0.01)	(1.80)	(0.87)	(0.03)	(0.01)	(0.00)	(1.07)	(0.05)	(0.00)	(0.03)	(0.06)	(0.16)	(0.04)	(2.27)
45	69.94	0.69	51.59a	9.10abc	0.73	0.07c	0.81	15.34c	2.50c	0.76	0.90a	0.76	0.52ab	0.72	31.76ab
	(3.69)	(0.02)	(0.13)	(0.15)	(0.04)	(0.02)	(0.03)	(5.41)	(0.11)	(0.03)	(0.09)	(0.07)	(0.08)	(0.01)	(0.75)

[a] PA represents the average value of percent alignment of the strands from both sides of the panel.
Data listed are means and standard deviations in parentheses.
Thickness swelling (TS) was measured at positions 24.5 mm from the sample edge.
The same letter for each property denotes no significant difference at the 5 percent confidence level.

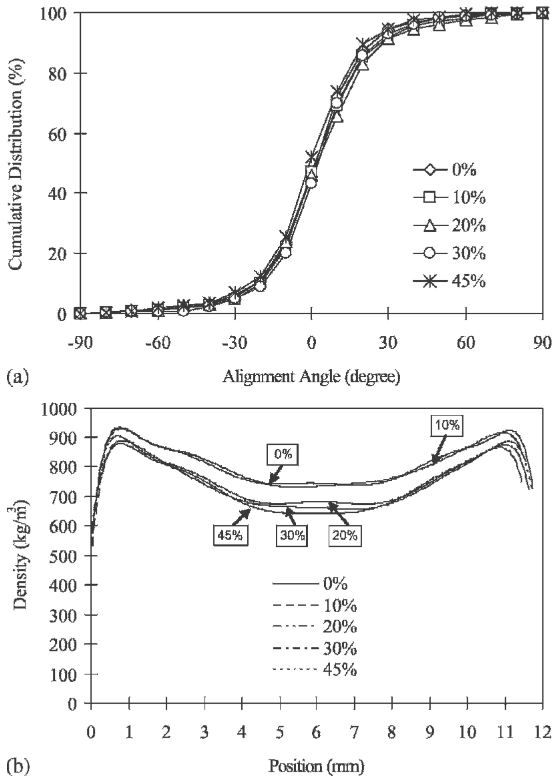

FIG. 5. Cumulative distribution of flake alignment angles (a) and density profile across panel thickness (b) at various fines loading levels for southern pine OSB.

parallel direction and slightly decreased in the perpendicular direction as fines in the core layer increased (Fig. 6a and b). This is due to the fact that the bending properties are mainly controlled by the face layer properties where only large flakes were used for all panels in this study. For all fines loading levels, both MOE and MOR of OSB met the current industrial standards of commercial OSB CSA 0437 (parallel: MOE 5.5 GPa, MOR 29.0 MPa; perpendicular: MOE 1.5 GPa, MOR 12.4 MPa) (Smulski 1997). IB strength was improved somewhat as fines increased to the 20% level (Fig. 6c), indicating that fines can be used to fill the voids in the core layer where the density was low. IB values showed no further increase for boards with 30% fines content, and even decreased as fines further increased to 45% (i.e., pure fines in the core). This was probably due to a poorer bonding from less resin coverage on the surfaces of

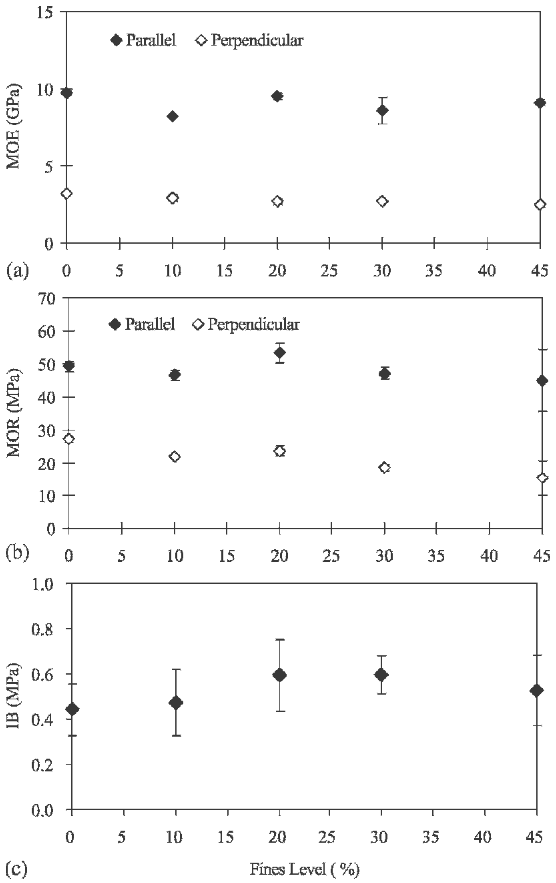

FIG. 6. Mechanical properties of southern pine OSB as a function of fines level. a) modulus of elasticity (MOE), b) modulus of rupture (MOR), and c) internal bond (IB). Vertical lines through the symbols represent the standard deviation from the mean value.

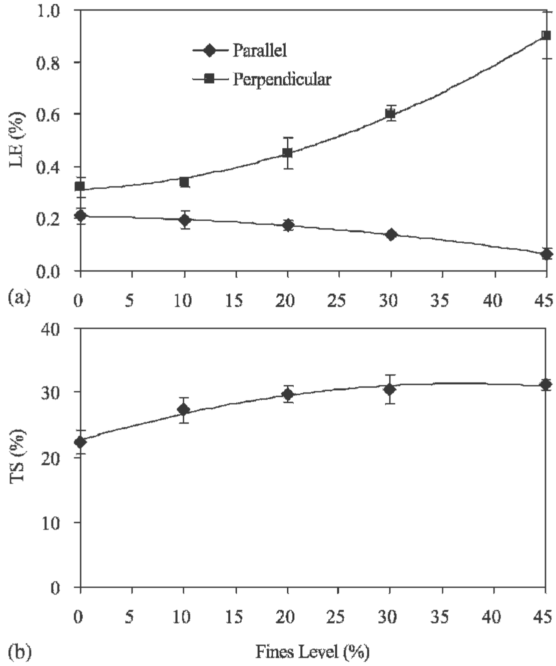

FIG. 7. Physical properties of southern pine OSB as a function of fines level. a) linear expansion (LE), and b) thickness swelling (TS). Vertical lines through the symbols represent the standard deviation from the mean value.

wood fines at higher fines loading levels. Thus, using high levels of wood fines in the core layer can lead to decreased IB strength without using high resin loading levels. In addition, a large variability of IB data at a given fines level was also observed. This observation could be related to the large density variation in small-diameter southern pine strands, which resulted in different compression in the board and in-plane density variation. The average IB strength for boards at all fines contents well exceeded the standard value (0.345 MPa).

Figure 7 shows dimensional stability properties of boards as a function of fines. Perpendicular LE increased and parallel LE decreased significantly with the increase of fines content (Table 5). Thus, fines in the core layer can cause a poor balance of LE values along the two principal directions. The perpendicular LE well exceeded the current industrial standards of commercial OSB (0.50%) at high fines loading levels, while the parallel LE for all fines levels was lower than the standard value (0.35%). TS increased significantly as fines increased up to the 30% level. The increased TS values were due to the increased water absorption of panels resulting from the larger surface area of small wood particles. A further increase of fines to the 45% level showed no increase in TS values. This could be related to the considerable thickness springback of boards after it was released from hot-pressing, which was reflected by lower overall panel density as shown in Table 5.

A nonlinear regression analysis was performed to establish the following relationships between LE/TS (%) and fines level (FL, %):

$$LE_{\perp} = 0.0003FL^2 + 0.0018FL + 0.312 \quad r^2 = 0.99 \tag{9}$$

$$LE_{//} = -0.00005FL^2 + 0.0007FL + 0.209 \quad r^2 = 0.99 \tag{10}$$

$$TS = -0.0064FL^2 + 0.4722FL + 22.615 \quad r^2 = 0.98 \tag{11}$$

The above equations adequately describe the LE-FL and TS-FL relationships as shown by the high correlation coefficients of all regression models.

SUMMARY AND CONCLUSIONS

Properties of southern pine and willow strands and OSB from small-diameter southern pine logs were investigated in this study. The results of strand properties showed that both tensile strength and dynamic moduli were highly correlated with strand density. Strands with higher density had higher tensile strength and storage modulus (E′). Compared to willow, a large variation in tensile strength and E′ was observed for southern pine. E′ showed a decreasing trend with the increase of temperature in the selected temperature range, indicating reduced stiffness at higher temperature. Slight loss modulus (E″) peaks are observed for all tested samples, but no considerable change in the intensity of transition for strands with different densities. The correlations of tensile strength/strand density, storage modulus/strand density, and storage modulus/temperature can be expressed by linear regression analysis. Thermo-gravimetric analysis showed that southern pine strands with higher densities had higher thermal stability than low-density strands.

The test results of three-layer OSB showed panels made of small-diameter trees had satisfactory strength and dimensional stability performances. Fines levels had varying effects on the panel properties. With increased fines contents, IB strength showed an increasing trend up to the 20% fines levels ; the bending strength and stiffness varied little in the parallel direction and slightly decreased in the perpendicular direction. Nonlinear regression models were established to describe the relationships between linear expansion or thickness swelling and fines level. Increased fines in the core layer led to increased thickness swelling and a poor balance of linear expansion between parallel and perpendicular directions.

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