Forest Management on Mechanical Properties of Oriented Strand Board

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Abstract

The goal of this study was to integrate forest management practice with the mechanical properties of oriented strand board (OSB). Modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond strength (IBS) were determined from OSB panels made from control, thinned, and fertilized trees. Different trends were associated with growth ring counts and heights of the feedstock trees. The mechanical properties were not dependent on the density profiles. MOE and IBS from the different forest managed trees were strongly correlated with different anatomical structures. However, the MOR of panels made trees from different forest management schemes was not strongly correlated with any anatomical structures but was strongly correlated with MOE.

Oriented strand board (OSB) is used as a panel building material. The demand for OSB increases mainly owing to the good mechanical properties and efficient utilization of woody biomass. Most of the feedstock for OSB is from the trees under different forest management schemes. Properties of wood are highly influenced by forest management activities such as fertilization, thinning, pruning, site, and harvesting age, but to what degree and in what manner have yet to be broadly determined. As a result, there is a vital link missing between environmentally sustainable forest management and efficient creation of building construction materials.

Previous studies proposed that density and density profile were assumed to be key indicators to predict mechanical properties of OSB. However, the relationship between density–density profile and the mechanical properties of OSB from previous studies (Wang and Winistorfer 2000, Steidl et al. 2003) does not appear to be strongly dependent. Rather, material properties of wood appear to be related with its structure (Jeong et al. 2009). When OSB was fabricated with wood strands from differently managed forests, mechanical properties of OSB would be expected to be different due to the fact that forest management altered the wood structure (Jeong et al. 2010; Jeong and Zink-Sharp 2012, 2013). Larson et al. (2001) said that ‘‘to understand how wood is formed and how wood quality varies, one must first understand how trees grow.’’

To optimize the desired properties and sustainability of wood resources, a link between forest management practices and quality of bio-based composites must be established. The current study results identify and trace trends that, if certain forest management activities continue, could improve properties of end products. These analyses identify areas where adverse impacts could be minimized through targeted utilization. Based on this research, forest management and processing industries focused on systematic forest management activities could lead to more efficient and cost-effective bio-based composites.

The effects of thinning and fertilization on anatomical structure of loblolly pine and the correlation between the anatomical properties were analyzed previously (Jeong et al. 2010; Jeong and Zink-Sharp 2012, 2013). Ring width, latewood percentage, density, fiber length, cell wall thickness, and cell diameter were measured at sampling heights of 0.5 to 1.5 m, 1.5 to 4.0 m, and 4.0 to 7.0 m. With increment of growth ring number, density, fiber length, and latewood percentage, the ratio of cell wall thickness to cell diameter from the control, thinned, and fertilized trees increased, but ring width decreased. With increment of height, densities from all trees decreased regardless of forest management plan. Latewood percentage from the control and fertilized trees decreased as height increased, whereas latewood percentage from the thinned tree increased. Earlywood and latewood fiber length from the control, thinned, and fertilized trees increased as height increased, except for latewood fiber length from the control.

The thinning and fertilization effects on the mechanical properties of wood strands were analyzed by correlating anatomical structure (Jeong and Zink-Sharp 2012, 2013). Regardless of forest management plan, modulus of elasticity (MOE) and ultimate tensile strength (UTS) increased as growth ring number increased. MOE and UTS from the

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control tree increased as height increased. MOE and UTS from thinned tree increased as height increased from 0.5 to 1.5 m to 1.5 to 4.0 m, but MOE and UTS decreased as height increased from 1.5 to 4.0 m to 4.0 to 7.0 m. MOE and UTS from the fertilized tree decreased as height increased. An inconsistent relationship between specific gravity and the mechanical properties for the forest management plans was found. To investigate a more reliable indicator to predict the mechanical properties, correlations between wood structures and the mechanical properties were analyzed.

Previous studies have investigated the effects of juvenile wood on mechanical properties of wood-based materials. Composite boards made from juvenile wood had similar mechanical properties (MOE, modulus of rupture [MOR], and internal bond strength [IBS]) to boards made from mature wood (Pugel et al. 1990, Larson et al. 2001). However, the compaction ratio was higher in boards made from juvenile wood compared with boards made from mature wood to achieve the same mechanical properties. From another study (Pugel et al. 1989), a detrimental effect of juvenile wood on MOE was found, whereas MOR was positively related with juvenile wood. IBS was not significantly influenced by two different loblolly pine flake types.

IBS of commercial OSB, made of different species and a different combination of phenol-formaldehyde and methylenebis (4-phenyl isocyanate) resins for face and core, was compared (Wasnewski 1989). The results showed that IBS was related not to the density but rather to the different species. The effects of green pruning and moderately thinned loblolly pine strands on mechanical and physical properties of particleboard were analyzed (Wang et al. 2004). While the IBS and MOR from the two different forest managed trees were not significantly different, the MOE was significantly different.

Although some information about the effect of feedstock on mechanical properties of OSB is available, the previous studies do not link the feedstock properties to the mechanical properties of OSB. The goal of this study was to integrate forest management practices with the mechanical properties of OSB. To achieve the goal, a system approach linked the results from previous studies (Jeong and Zink-Sharp 2012, 2013; Jeong 2013) that encompassed the information of anatomical structure from different forest managed trees associated with height and growth ring numbers to OSB mechanical properties of the current study.

Materials and Methods

Strand generation

Loblolly pine trees (*Pinus taeda*) under different forest management schemes (control, thinned, and fertilized trees) were cut at different sampling heights of 0.5 to 1.5 m, 1.5 to 4.0 m, and 4.0 to 7.0 m. The control tree was 23 years old and had undergone no forest management. The thinned tree was 28 years old. The thinning practice had occurred at 8 and 22 years. The fertilized tree was 9 years old. Fertilizer had been applied during the first 4 years. Detailed information on forest management and the anatomical characteristics is available from the previous study (Jeong and Zink-Sharp 2012, 2013). The same trees and stems from the previous study (Jeong and Zink-Sharp 2012, 2013; Jeong 2013) were used to fabricate oriented strand panels. From loblolly pine stems at different heights, wood blocks measuring 140.0 by 140.0 by 25.4 mm were prepared to generate wood strands. After wood blocks were marked to identify the forest management scheme, growth ring number, and height, all blocks were vacuum soaked in water for 24 hours to minimize the surface checking. The strands were generated using a laboratory flaker. The strands were 140.0 mm long, 25.4 mm wide, and 0.76 mm thick. The strands were dried to 6 percent moisture content before blending.

Blending and mat formation

A rotary blender was used to mix strands with liquid phenol-formaldehyde resin (50% solid content). Resin was applied using a spinning disk atomizer. Each blender load provided 2,725 g of flakes for one board. The total blend time was about 8 minutes. The resonated strands were formed into a 610.0 by 510.0-mm mat after passing through an orienting screen. The screen device had oriented metal plates and a motor to agitate the metal plates to directionally orient the strands. The OSB had one layer in which the strands were designed to have the longitudinal-radial plane parallel to the surface of the OSB. A laboratory mat forming device with an oil-sprayed metal plate was placed under the screen to form a mat. Each board contained 2,807 g of resinated strands to achieve a target density of 640 kg/m^3.

Hot pressing

The mat was placed on the hot platen press and compressed to a final thickness of 12.5 mm at a platen temperature of 195°C for 7 minutes. The press cycle consisted of a closing time of 30 seconds with a target thickness of 420 seconds and a degas time of 40 seconds. The platen temperature and press cycle were chosen to ensure full cure of the resin within the core. The finished boards were stored at ambient conditions until the boards were cut into samples for mechanical testing.

Mechanical properties of OSB from different forest management schemes

The boards were trimmed to dimensions of 500 by 450 mm, and mechanical testing samples were prepared from each board. From each board, a minimum of seven density profile specimens, four bending specimens, and seven internal bond specimens were prepared in accordance with ASTM D1037 (ASTM International 2004). Table 1 shows the testing arrangement, including density of strands and sample size for density profile, MOE, MOR, and IBS from different forest management schemes; height; and growth ring number.

To measure the density profile of a board, 50.8 by 50.8-mm blocks were cut across the center of the board. The vertical density profile was scanned using a commercial densitometer (QMS Density Profile System QDP-01X). After the density profile was measured, the same 50.8 by 50.8-mm blocks were used to measure IBS. The same cross section of two steel blocks was bonded using hot-melt glue. The IBS test was conducted at a loading rate of 0.8 mm/mm/min. The bending specimens were cut to the dimension of 76.2 by 360.0 mm from each board. A bending test was conducted at 6 mm/min with a 300-mm span.

Statistical analysis

Hierarchical linear regression models were used to integrate the forest management with board properties. A

Table 1.—Test arrangements and sample size for differently managed trees at three different sampling heights.[a]

Forest management scheme	Height (m)	Growth ring no.	SG of board	Boards	MOE	MOR	IBS	Density
Control	0.5–1.5	4–9	0.69 (19.30)	2	8	8	14	14
		13–15	0.73 (15.85)	2	8	8	14	14
	1.5– 4.0	7–9	0.72 (15.25)	2	8	8	14	14
	4.0–7.0	3–5	0.69 (4.08)	2	8	8	14	14
		6–8	0.63 (28.33)	2	8	8	14	14
Thinned	0.5–1.5	5–7	0.72 (14.04)	2	8	8	14	14
		8–9	0.81 (9.79)	2	8	8	14	14
		11–13	0.85 (7.36)	2	8	8	14	14
	1.5–4.0	4–6	0.60 (12.86)	2	8	8	14	14
		7–9	0.76 (13.91)	2	8	8	14	14
		11–14	0.86 (15.69)	2	8	8	14	14
	4.0–7.0	5–7	0.70 (13.81)	2	8	8	14	14
		8–10	0.64 (14.34)	2	8	8	14	14
		11–15	0.66 (18.22)	2	8	8	14	14
Fertilized	0.5–1.5	4–5	0.77 (18.73)	2	8	8	14	14
		7–9	0.77 (21.35)	2	8	8	14	14
	1.5–4.0	7–9	0.71 (15.29)	2	8	8	14	14
	4.0–7.0	4–6	0.76 (9.44)	2	8	8	14	14

[a] SG = specific gravity; MOE = modulus of elasticity; MOR = modulus of rupture; IBS = internal bond strength.

similar scheme was applied to analyze the hierarchically structured data (Jeong and Zink-Sharp 2012, 2013; Jeong 2013). The anatomical properties, including ring width, latewood percentage, strand density, earlywood and latewood fiber length, tangential earlywood and latewood cell wall thickness, tangential earlywood and latewood cell wall diameter, radial earlywood and latewood cell diameter, and radial earlywood and latewood cell wall thickness associated with forest management, were analyzed in terms of how the anatomical properties influenced the specific mechanical properties of OSB. The growth ring position and height effects on OSB properties were also analyzed.

Results and Discussion

MOE, MOR, and IBS of OSB from different forest managed trees

Figures 1 and 2 show the MOE and MOR of OSB from different management plans at different growth ring numbers and tree heights. With increment of growth ring number, MOE and MOR of OSB from the control tree did not change at 0.5 to 1.5 m, but the MOE increased and the MOR decreased at 4.0 to 7.0 m. The MOE and MOR of OSB from the fertilized tree at 0.5 to 1.5 m increased with increment of growth ring numbers. Considering the time (growth ring numbers 1 to 4) when fertilizer was applied to the feedstock tree (Jeong and Zink-Sharp 2012), MOE and MOR may be reduced by fertilization. Likewise, considering the time (growth ring number 8) when thinning was applied to the feedstock tree (Jeong and Zink-Sharp 2013), MOE and MOR of OSB from the thinned tree may decrease by thinning associated with growth ring number, except for the MOR at 0.5 to 1.5 m. Comparing OSB properties from differently managed trees, there was no consistent trend for MOE and MOR with height.

Figure 3 shows the IBS of OSB made of strands from different forest managed trees at different growth ring numbers and heights. With increment of growth ring number, IBS of OSB from the control tree tended to show a small decrement, but IBS of OSB from the fertilized tree increased. IBS of OSB from the thinned tree showed inconsistent trends with growth ring numbers. With increment of height, IBS of OSB from the control tree increased, whereas the IBS from the thinned tree decreased. IBS of OSB from the fertilized tree did not show a consistent trend with increment of height. The results of IBS of OSB from different forest managed trees indicated that the IBS was different by different forest management schemes and height.

Direct comparison between density profile and mechanical properties of OSB

From Table 2, the density profile of the control OSB from the two different growth ring numbers was distinctively different at a height of 0.5 to 1.5 m, but MOE and MOR of OSB from the two growth ring numbers were not different (Figs. 1 and 2). Although the trends of MOE of OSB made of strands from the thinned tree at a height of 0.5 to 1.5 m followed the trends of the density profiles, the rest of MOE and MOR from the thinned tree did not agree with peak density value through different heights and growth ring numbers. Comparing peak density value of OSB from the fertilized tree from two growth ring numbers at a height of 0.5 to 1.5 m, higher peak density was found from the OSB made of strands from growth ring numbers 4 to 5. However, lower MOE and MOR values from the fertilized tree were found at growth ring numbers 4 to 5 compared with the MOE and MOR at growth ring numbers 7 to 9. From the results, it can be concluded that MOE and MOR values from different forest managed trees were not dependent on the trends of the density profiles.

Comparing peak density values from OSB made of strands from different forest managed trees at a height of 0.5 to 1.5 m, the highest peak density of OSB made of strands from the thinned tree was found, whereas the highest MOE and MOR of OSB made of strands from the fertilized tree were found. The lowest peak density was found from the OSB from the control tree, whereas the lowest MOE was found from the thinned tree and the lowest MOR from the

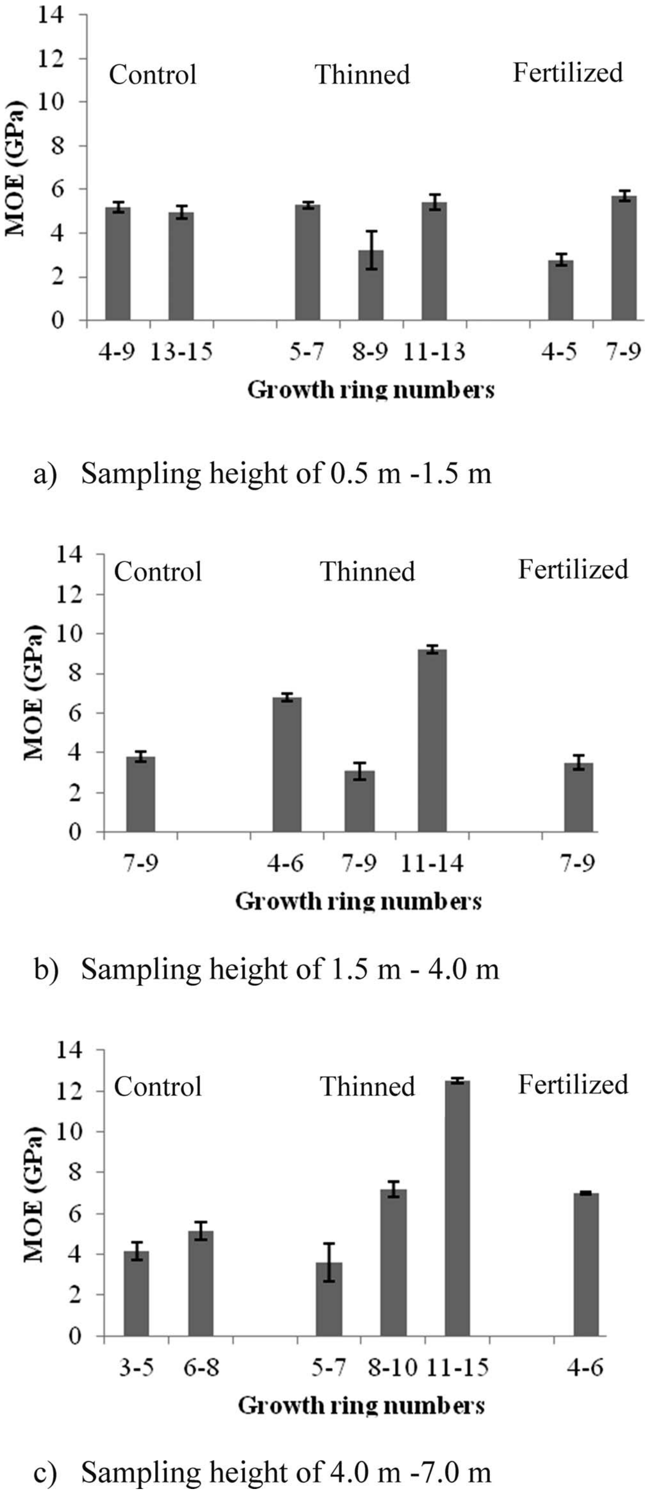

Figure 1.—Modulus of elasticity (MOE) of oriented strand board from different forest managed trees at different growth ring numbers and heights.

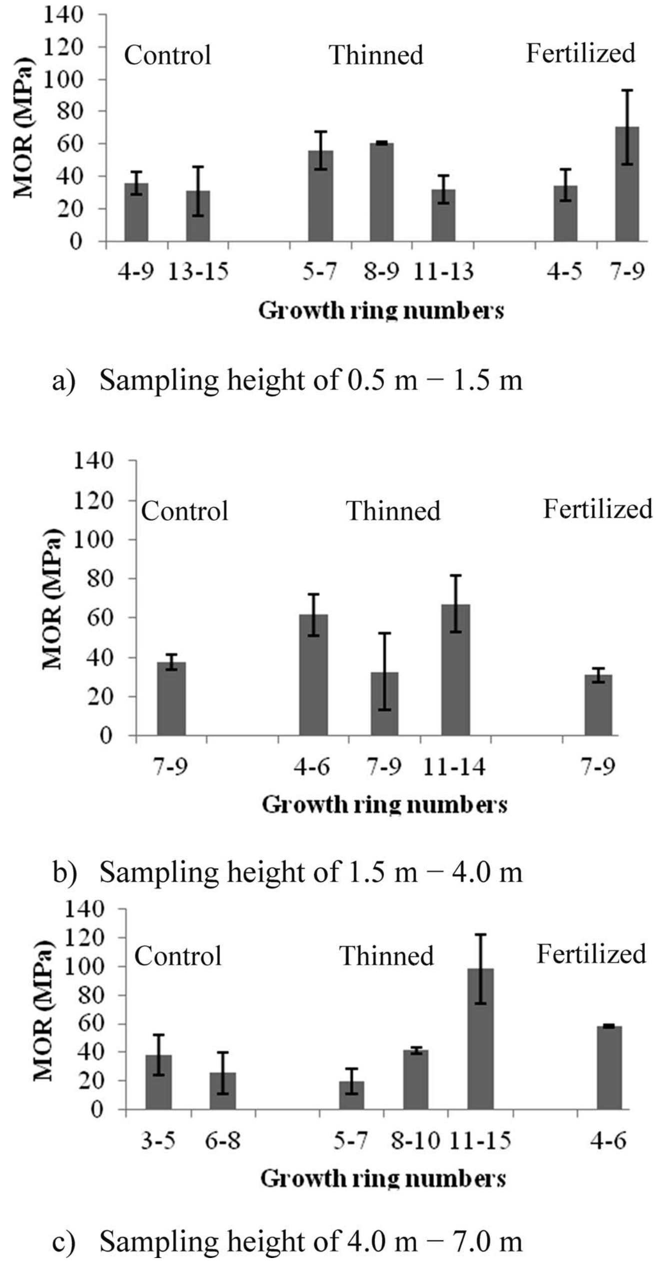

Figure 2.—Modulus of rupture (MOR) of oriented strand board from different forest managed trees at different growth ring numbers and heights.

control tree. Additional disagreement between the peak density and the MOE and MOR was found from the OSB at different heights. The lowest peak density of OSB from the fertilized tree was found at a height of 1.5 to 4.0 m, whereas the lowest MOE was found from the thinned tree. At a height of 4.0 to 7.0 m, the lowest peak density of OSB from the control tree was found, whereas the lowest MOE and MOR were found from the thinned tree.

Comparing the OSB from the control tree at a height of 0.5 to 1.5 m, the core density of OSB made of strands from growth ring numbers 13 to 15 was higher (Table 2), but a lower IBS was observed (Fig. 3). Comparing the OSB from the thinned tree at a height of 0.5 to 1.5 m, in contrast to the core density value, the highest IBS was found from the OSB made of strands at growth ring numbers 5 to 7, and the lowest IBS was found from the OSB at growth ring numbers 11 to 13. Disagreement in the relationship between the core density and IBS of OSB from the fertilized tree was also found. From the direct comparison between the core density and IBS of OSB, IBS of OSB from different forest managed trees did not agree with the core density value.

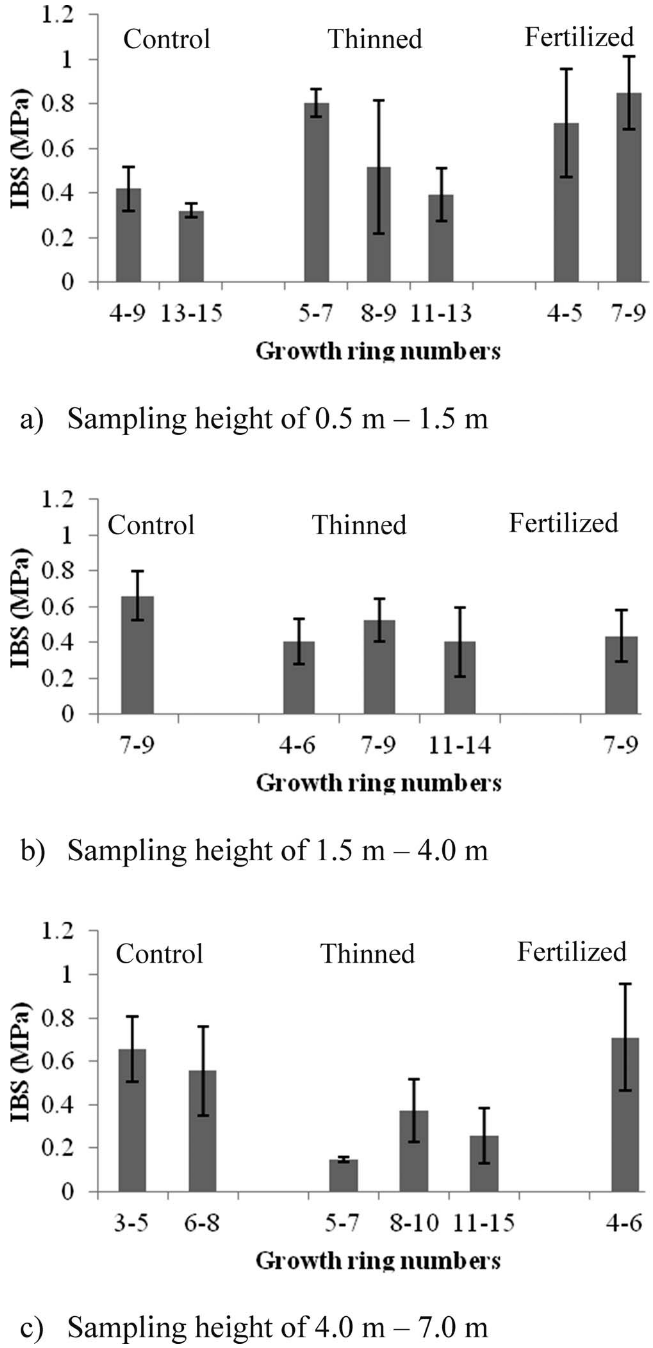

Figure 3.—Internal bond strength (IBS) of oriented strand board from different forest managed trees at different growth ring numbers and heights.

Correlation between anatomical structures and mechanical properties of OSB

Table 3 shows the correlation between mechanical properties and predictor variables, showing only the Spearman rank correlation coefficients above 0.6. MOE from the control tree was positively correlated with tangential earlywood cell diameter and tangential latewood cell wall thickness. Considering the cutting direction used to create strands and the way strands are stacked in OSB, tangential cell dimension was perpendicular to the surface plane. The increment of tangential cell dimension creates the reinforcement to the loading perpendicular to the surface and less displacement parallel to the loading direction. Therefore, MOE could be increased by reinforcement of tangential cell dimension (Papka and Kyriakides 1994, Andrews et al. 2001).

MOE of OSB from the thinned tree was highly correlated with many anatomical properties. As with the correlation between the MOE of OSB from the control tree and anatomical properties, the tangential latewood cell wall thickness and the tangential earlywood cell diameter showed strong correlation with the MOE of OSB from the thinned tree as well. In addition to these two anatomical structures, the earlywood and latewood fiber length, the tangential latewood cell diameter, and the latewood percentage were positively correlated with the MOE, whereas the ring width was negatively correlated with the MOE of OSB. Longer fiber length may act as a reinforcement in the lower bottom area of the OSB where tension stress occurs. Stiffness of latewood is much higher than that of earlywood (Jeong et al. 2009). Therefore, a larger latewood portion should increase the MOE. However, larger ring width normally occurs in the juvenile wood portion where the stiffness of wood is lower rather than in the mature wood portion (Andrews et al. 2001, Jeong et al. 2010). Consequently, larger ring width decreases the MOE.

The MOE of OSB from the fertilized tree was negatively correlated with the radial earlywood cell wall thickness, the tangential earlywood cell wall thickness, and the radial earlywood cell diameter. If the earlywood portion is significantly higher than the latewood portion in a given amount of volume, the MOE decreases owing to the lower stiffness of earlywood (Andrews et al. 2001, Jeong et al. 2009). The feedstock tree used for the fabrication of the OSB showed that the latewood cell wall thickness decreased, whereas the earlywood cell diameter increased by fertilization (Jeong and Zink-Sharp 2012).

MOR of OSB from different forest managed trees did not show strong correlation with any anatomical properties. The highest correlation from the control tree was found between the MOR of the OSB and earlywood fiber length (0.59). The highest correlation from the thinned tree was found between the MOR of the OSB and the tangential latewood cell diameter (0.58). The highest correlation from the fertilized tree was found between the MOR of the OSB and the earlywood fiber length (0.33). MOR is calculated from the peak load associated with moment term and given section modulus. MOR value is most likely determined from failure induced by stress concentration where the weakest area is exposed to mixed stress conditions within OSB under bending. Therefore, compared with the MOE, a direct involvement of anatomical structure in determination of the MOR is rather weak. Although strong correlation between anatomical structure and MOR of OSB from different forest managed trees was not found, the MOR from different forest managed trees showed strong correlation with the MOE. The prediction of the MOR could be based on the MOE values (Geimer et al. 1999, Jin et al. 2009).

The IBS from the control tree was negatively correlated with the tangential earlywood cell wall thickness, the tangential earlywood cell diameter, and the average strand density. Increment of tangential earlywood cell diameter creates a larger weak zone to fracture when the pulling force is applied (Ford and Gibson 1998), which resulted in lower IBS of OSB. Cellular structural damage in the form of

Table 2.—The highest and lowest peak and core density values and corresponding growth ring ranges at given heights for oriented strand board made of strands from differently managed trees.

Height (m)	Forest management scheme	Peak density (g/cm^3)		Core density (g/cm^3)	
		Highest	Lowest	Highest	Lowest
0.5–1.5	Control	1.03 (13–15)	0.84 (4–9)	0.56 (13–15)	0.55 (4–9)
	Thinned	1.08 (11–13)	0.98 (8–9)	0.69 (11–13)	0.59 (5–7)
	Fertilized	1.07 (4–5)	0.95 (7–9)	0.64 (4–5)	0.62 (7–9)
1.5–4.0	Control	1.03 (7–9)	NA[a]	0.60 (7–9)	NA
	Thinned	1.06 (11–14)	0.77 (4–6)	0.77 (11–14)	0.44 (4–6)
	Fertilized	0.87 (7–9)	NA	0.56 (7–9)	NA
4.0–7.0	Control	0.98 (3–5)	0.85 (6–8)	0.52 (3–5)	0.46 (6–8)
	Thinned	1.00 (5–7)	0.74 (8–10)	0.55 (11–15)	0.47 (5–7)
	Fertilized	1.00 (4–6)	NA	0.57 (4–6)	NA

[a] NA = not available.

Table 3.—Spearman rank correlation coefficients (r) between mechanical properties of oriented strand board and anatomical properties.[a]

MOE	*r*	MOR	*r*	IBS	*r*
Control					
Tangential earlywood cell diameter	0.68	MOE	0.63	Tangential earlywood cell wall thickness	−0.74
Tangential latewood cell wall thickness	0.61	Earlywood fiber length	0.59	Tangential earlywood cell diameter	−0.67
				Average strand density	−0.64
Thinned					
Tangential latewood cell wall thickness	0.86	MOE	0.83	Radial earlywood cell diameter	−0.82
Earlywood fiber length	0.83	Tangential latewood cell diameter	0.58	Tangential latewood cell diameter	−0.75
Tangential latewood cell diameter	0.82	Tangential earlywood cell diameter	0.57	Radial latewood cell diameter	0.74
Latewood fiber length	0.79	Tangential latewood cell wall thickness	0.56	Latewood fiber length	−0.70
Tangential earlywood cell diameter	0.77			Earlywood fiber length	−0.68
Latewood percentage	0.69			Tangential earlywood cell diameter	−0.68
Ring width	−0.67			Tangential latewood cell wall thickness	−0.65
Fertilized					
Radial earlywood cell wall thickness	−0.79	MOE	0.73	Radial earlywood cell wall thickness	−0.64
Tangential earlywood cell wall thickness	−0.62	IBS	0.59	Radial earlywood cell diameter	−0.60
Radial earlywood cell diameter	−0.60	Earlywood fiber length	0.33		

[a] MOE = modulus of elasticity; MOR = modulus of rupture; IBS = internal bond strength.

buckling, shearing, and bending failure, most frequently found in the earlywood zones, was caused by compression from the latewood areas of adjacent flakes (Papka and Kyriakides 1994). The difference in resistance to compression of earlywood and latewood, combined with the abrupt transition in density between these two zones, results in considerable stresses on earlywood tracheids.

The IBS from the thinned tree was negatively correlated with many anatomical properties. It was interesting to see that the radial latewood cell diameter was positively correlated with the IBS, whereas the tangential latewood cell diameter was negatively correlated with the IBS. It can be speculated that the IBS of the OSB made of strands from the thinned tree is related to the compression direction to the cell orientation in the strands. Strands were designed to have the longitudinal-radial plane parallel to the surface of OSB. Therefore, tangential latewood cell walls are exposed to the adhesion with other strands, whereas radial latewood cell walls are faced perpendicular to the adhesion plane. Increment of radial cell diameter increases the adhesion area, while increment of tangential latewood cell diameter creates a larger weak zone to be fractured when cells are compressed by hot press, which results in lower IBS.

The mechanism of reduction of the IBS from the thinned tree by increment of earlywood cell diameter can be explained similarly from the relationship between earlywood cell diameter and the IBS from the control tree. The increment of tangential latewood cell wall thickness may create the reduction of the adhesive penetration. The increment of fiber length reduces the contact area between fibers given space in the strands, which may decrease the IBS. As was seen from the correlation between the IBS and anatomical structure from the control and thinned trees, earlywood cell dimensions were negatively correlated with IBS of OSB from the fertilized tree. The IBS from the fertilized tree increased as growth ring number increased owing to the fact that the latewood portion increased after fertilization (Jeong and Zink-Sharp 2012).

Bending and IBS of OSB from different forest managed trees were strongly correlated with different anatomical structures. However, density profile was not found to be a reliable predictor for the mechanical properties of OSB from different forest managed trees. A significant modeling effort may be required for more quantitative information about the influence of anatomical structure on mechanical properties of OSB, which deserves future study.

Conclusions

The MOE and MOR of OSB from the control tree were not different by growth ring number. In general, the MOE and MOR were decreased by thinning and were increased by fertilization. With increment of growth ring number, the IBS of OSB from the control tree decreased, but the IBS of OSB from the fertilized tree increased. The IBS of OSB from the thinned tree increased except for the sampling height of 0.5 to 1.5 m. There was no consistent trend between the effects of tree height on MOE, MOR, and IBS of OSB from different forest managed trees.

From the direct comparison, the MOE, MOR, and IBS were not dependent on the density profile. It was found that different anatomical structures were highly correlated with different mechanical properties of OSB from differently managed trees. Therefore, to utilize wood resources more efficiently and produce reliable OSB, specific forest management regimes should be implemented for the targeted anatomical structures of feedstock trees.

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