EFFECT OF PANEL DENSITY ON MAJOR PROPERTIES OF ORIENTED STRANDBOARD

*Siguo Chen**
Adjunct Professor
Zhejiang Forestry University
Lin'an Hangzhou, China, 311300
and
Senior Scientist and Program Manager
Forest Products Business Unit
Alberta Innovates-Technology Futures
Edmonton, Alberta, Canada T6N 1E4

Chungui Du
Associate Professor
School of Engineering, Zhejiang Forestry University
Lin'an Hangzhou, China, 311300

Robert Wellwood
Manager
Forest Products Business Unit
Alberta Innovates-Technology Futures
Edmonton, Alberta, Canada T6N 1E4

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Abstract. An extensive experimental study was carried out to systematically investigate the influence of panel density on oriented strandboard (OSB) properties. Nine sets of 711 × 711 × 11.1-mm aspen OSB panels with a target density varying 449-705 kg/m^3 were manufactured. The panels were tested for major properties, including modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength (IB), water absorption (WA), and thickness swell (TS) after 24-h soaking and rolling shear strength (RS). The results indicated that, in general, panel density positively affected the properties of the OSB panels. Effects of panel density on parallel MOR and MOE, IB, and RS were nonlinear and could be described with convex quadratic curves. TS and WA linearly decreased with increasing panel density.

Keywords: OSB, panel density, pilot plant experiment, physical and mechanical properties.

INTRODUCTION

Previous studies have indicated that density affects physical and mechanical properties of oriented strandboard (OSB). Lee and Stephens (1988) evaluated seven types of composite boards, including OSB, and found that edgewise shear strength was linearly related to density for most board types. In a study on layer thickness swell (TS), Xu and Winistorfer (1995a) demonstrated that the layer TS was positively linearly correlated to layer density. Wang et al (2003) compared properties of commercial aspen, pine, and mixed hardwood OSB products. They observed that layer TS generally matched well with vertical density profile (VDP). However, within a species, their data did not show consistent relationships among water absorption (WA), total TS, and panel density. They also tested modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond strength (IB) of panels made of the three species. Only the hardwood OSB panels displayed a meaningful correlation of MOR, MOE, and IB with the panel density. Brochmann et al (2004) reported that density was highly significant in determining TS values of OSB, and density

* Corresponding author: Siguo.Chen@albertainnovates.ca

accounted for a large amount of variability among IB tests. Using an X-ray system to scan panels to determine horizontal panel density, Wang et al (2007) stated that localized density had a significant effect on most fastener holding capacity for OSB. In a recent publication, Jin et al (2009) tested randomly oriented strandboards with both uniform and conventional VDP. Their results indicated that IB, MOR, MOE, and WA were well correlated with board density, whereas the relationship between TS and density was less certain.

Much of the existing literature on effects of density on OSB properties has been devoted to comparisons between different products or between thin layers of different densities of the same panel. Few studies have been conducted for a wide density range with small intervals on a same product. Test results based on commercial OSB products of different densities sampled from different mills may be inconclusive because of variations in other production parameters such as resin and strand geometry.

A better understanding of the effect of panel density on physical and mechanical properties of OSB could help researchers and producers determine the appropriate density levels to achieve desired product properties without overconsumption of raw material. The objective of this study was to investigate relationships between major properties of OSB and panel density by carrying out a systematic and extensive pilot plant experiment. Nine sets of 3-layer oriented panels with densities ranging 449-705 kg/m^3 were manufactured using aspen strands. The panel properties tested in this study were MOR, MOE, IB, WA, TS, and rolling (interlaminar) shear strength (RS).

MATERIALS AND METHODS

Panel Manufacturing

Commercial aspen strands with nominal 108-mm length and 0.69-mm thickness variable were procured from a local OSB mill. Strand width varied; approximately 80% were 9-19.5 mm. To minimize the influence of nonuniformity of fines distribution in the furnish, the strands were screened using a 4.76-mm deck screen at the Alberta Research Council wood composite panel pilot plant to separate fines (defined as material passing through the screen) from strands. The panels were made with 10% fines and 90% strands.

Nine target panel densities of 449-705 kg/m^3 at 32-kg/m^3 intervals were fabricated. There were 3 replicate panels for each density level and a total of 27 pieces of 711 $\times$ 711 $\times$ 11.1-mm panels. The face/core weight ratio was 60/40. The face material was blended with 3.0% (solids) liquid phenol-formaldehyde resin and the core material with 2.0% isocyanate resin. Slack wax was added at 1.2% (solids) to both face and core materials. The target furnish moisture contents were 7.0 and 4.5% for face layer and core layers, respectively.

All mats were formed by hand in a forming box with a vane orienter of 25-mm spacing. The formed mats were pressed into panels using a hot press with a platen temperature of 205°C for 180 s. The pressed panels were hot-stacked inside an insulated box for approximately 15 h.

Panel Testing

All pressed panels were kept in a conditioning room for 3 wk at 65% RH and 20°C before testing according to CSA O437.1-93 (CSA 1993). Because of a shortage of panel area, a smaller specimen size (75 $\times$ 220 mm) was used in the RS test. The numbers of test specimens per panel for MOE/MOR in each direction, IB, TS/WA (24-h soaking), and RS in each direction were 3, 6, 2, and 3, respectively. One parallel and one perpendicular bending specimen from the 673-kg/m^3 density group were excluded from the testing because of delaminations observed after cutting. Therefore, the total numbers of test specimens for each property were:

MOE/MOR parallel: $3 \times 27\text{-}1 = 80$
MOE/MOR perpendicular: $3 \times 27\text{-}1 = 80$
IB: $6 \times 27 = 162$
TS/WA: $2 \times 27 = 54$

RS parallel: 3 × 27 = 81
RS perpendicular: 3 × 27 = 81

Two of the six IB specimens were also measured for VDP.

RESULTS AND DISCUSSION

Average Values of Each Density Group

In Table 1 are the average property values of the specimens for each density group and their coefficients of variation. The target and actual average densities from the three replicate panels of each density group are also included. It was noted that the properties generally improved as the average density increased with the exception of parallel MOR and MOE. The group average values of parallel MOR and MOE attained their highest levels when the target density reached 641 kg/m^3. A further increase in density resulted in a clear decrease in parallel MOE and, to a lesser degree, parallel MOR. Although the properties benefitted from higher panel density, increasing density means increased manufacturing cost. Panel properties can also be improved by increasing resin content or by using better strands. It is therefore important to understand how the property values change at different levels of panel density. This information would help OSB producers to make knowledge-based decisions on balancing density, resin, and other parameters to achieve the required property values at the lowest cost. A regression analysis was carried out for each property in the following steps.

Vertical Density Profile

VDP in OSB is typically characterized by high-density surface and low-density core layers. The formation of such a profile is the combined result of gradients of temperature, moisture content, and pressure in the strand furnish during pressing. Representative VDPs are displayed in Fig 1. To avoid overcrowded curves, only the VDP from every other density group is presented. It is evident that the profile became steeper (greater difference between face and core) as the average panel density increased. Also, there is a general trend for the density peaks within the face layers to move inward with decreasing average density.

Table 1. Average property values of the tested specimens for each density group and their coefficients of variation.[a]

Density (kg/m^3)										
Target	Actual	$MOR_{\parallel}$ (MPa)	$MOR_{\perp}$ (MPa)	$MOE_{\parallel}$ (MPa)	$MOE_{\perp}$ (MPa)	IB (MPa)	WA (%)	TS (%)	$RS_{\parallel}$ (MPa)	$RS_{\perp}$ (MPa)
449	456	14.6	9.7	4000	1500	0.14	53.2	22.2	0.38	0.46
		(21.8)[b]	(16.6)	(13.0)	(23.2)	(38.6)	(11.2)	(7.6)	(19.8)	(22.1)
481	475	16.1	12.5	4200	1800	0.183	45.8	19.3	0.52	0.67
		(18.5)	(29.1)	(17.8)	(22.6)	(31.7)	(6.9)	(7.4)	(15.2)	(23.0)
513	505	23.4	13.2	5300	1800	0.234	42.5	18.7	0.65	0.69
		(25.5)	(21.4)	(12.9)	(15.6)	(35.1)	(8.3)	(9.4)	(11.8)	(14.2)
545	543	29.7	16.7	6400	1900	0.307	37.3	17.8	0.79	0.9
		(24.0)	(13.1)	(20.5)	(9.9)	(30.4)	(4.6)	(9.4)	(17.4)	(10.3)
577	575	32.8	18.4	7000	2300	0.354	42.9	20.6	0.79	0.96
		(13.5)	(25.3)	(14.5)	(19.2)	(19.5)	(6.9)	(4.6)	(13.2)	(15.1)
609	602	33.3	22.7	7200	2800	0.333	37.0	19.5	0.8	0.98
		(18.6)	(20.3)	(16.8)	(11.0)	(24.6)	(7.9)	(4.7)	(14.0)	(13.7)
641	631	42.1	21.5	8000	2500	0.428	33.0	17.2	1.01	1.01
		(14.4)	(15.0)	(7.5)	(11.8)	(23.8)	(10.4)	(7.6)	(7.6)	(10.5)
673	673	41.4	23.8	7700	3100	0.443	30.0	15.7	0.98	1.24
		(17.1)	(19.6)	(11.4)	(13.1)	(12.1)	(6.8)	(5.1)	(15.8)	(12.6)
705	707	40.8	25.7	7300	3100	0.412	26.0	14.5	1.1	1.14
		(16.5)	(24.6)	(7.7)	(14.2)	(24.1)	(6.4)	(6.2)	(9.8)	(8.0)

[a] The target and the actual average densities from the three replicate panels of each density group are also included.
[b] Coefficients of variation (%) in parentheses. Each number is the average of test specimens.
$\parallel$= parallel; $\perp$= perpendicular.
MOR, modulus of rupture; MOE, modulus of elasticity; IB, internal bond; WA, water adsorption; TS, thickness swelling; RS, rolling shear.

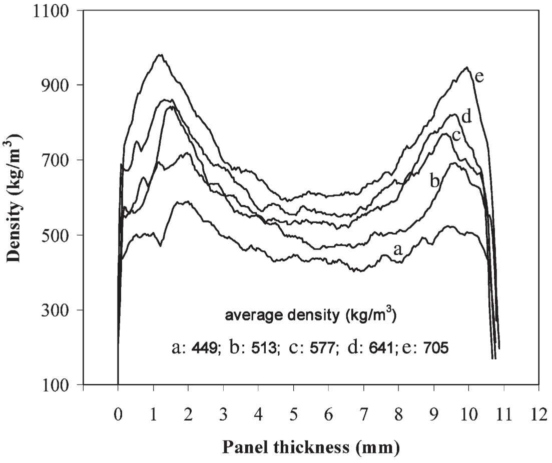

Figure 1. Representative vertical density profiles of panels with 5 target density levels: 449, 513, 577, 641, and 705 kg/m^3.

VDP has been recognized by many researchers as one of the influential factors affecting most of the physical and mechanical properties of OSB (Xu 1999; Gu et al 2005; Jin et al 2009). It is generally believed that a pronounced VDP is beneficial for MOR and MOE and that a flatter VDP would result in greater dimensional stability and IB.

Because panel density affects VDP, this could complicate the effect of density on panel properties in that VDP has an impact on panel properties for the same panel density.

Average Values of Each Panel

More detailed analysis of the relationships between panel properties and density was carried out by plotting the average property value and its corresponding average density of the specimens cut from each panel (Figs 2-7).

Bending strength and stiffness. The relationships between the parallel bending properties and density were best described with quadratic regression curves (Figs 2-3). Both parallel MOR and MOE values increased with increasing panel density, but the increase gradually slowed as density continued to increase. The parallel MOR curve leveled off when density reached approximately 690 kg/m^3, whereas the parallel MOE curve reached its highest value and started to drop when density was approximately 660 kg/m^3. It has been suggested that wood cell wall damage may occur at excessive densification (Dai et al 2002). However, as shown in Figs 2 and 3, perpendicular MOR and MOE increased linearly

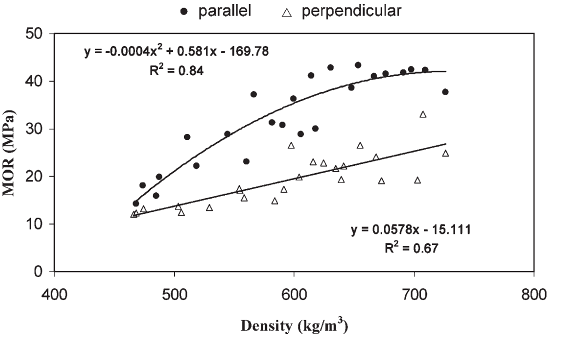

Figure 2. Correlation between panel average modulus of rupture and density.

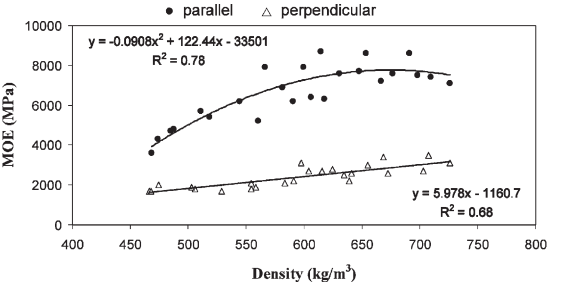

Figure 3. Correlation between panel average modulus of elasticity and density.

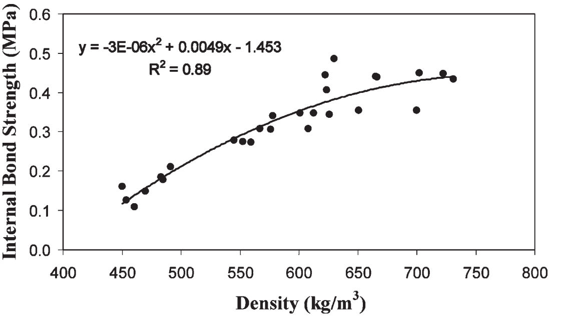

Figure 4. Correlation between panel average internal bond strength and density.

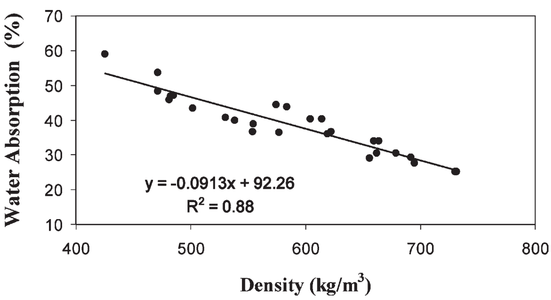

Figure 5. Correlation between panel average 24-h water absorption and density.

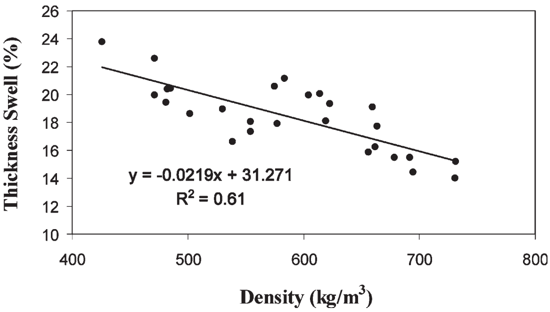

Figure 6. Correlation between panel average 24-h thickness swell and density.

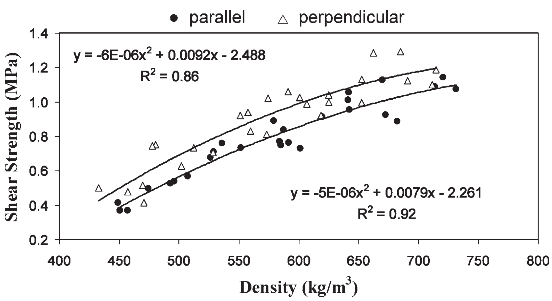

Figure 7. Correlation between panel average rolling shear (interlaminar) strength and density.

with increasing density over the entire density range, indicating that cell wall damage may not be an adequate or complete explanation. The fact that most wood cells have their long directions parallel to the grain and OSB strands are generally cut parallel to the grain may be attributable to the difference of parallel and perpendicular bending properties in response to high densification.

OSB is primarily used as construction sheathing, and bending resistance is one of the most important mechanical properties. There have been studies showing greater bending properties resulting from higher density strandboards, especially randomly oriented boards (Hiziroglu 2009; Jin et al 2009). However, limited published data are available for comparison with this study regarding the density effect on bending properties of OSB over an extensive range of panel density.

Internal bond strength. The correlation between IB and density was nonlinear and can also be described with a quadratic regression curve (Fig 4). When a higher density mat is pressed, a greater degree of interstrand contact during the consolidation enables more effective formation of bond lines, resulting in a higher IB strength. Jin et al (2009) obtained a similar IB-density nonlinear relationship from their randomly oriented boards with a uniform VDP. A reasonable explanation was provided regarding the nonlinearity: a faster development of interstrand contact at lower mat densities than at higher mat densities during the pressing process.

Although linear and other nonlinear relationships have been reported (Dai et al 2008; Jin et al 2009), IB generally increases monotonically with increasing density. The degree of correlation between IB and panel density varies, and this may be the result of, at least in part, differences in VDP. Specimens subjected to IB testing tend to fail within the low-density core layer. Panels with the same average density but different core densities from a difference in VDP would cause IB variation. Other production variables such as strand geometry, fines, and resin distribution may also contribute to IB variability. Xu and Winistorfer (1995b) tested IB of thin layers sawn from an OSB specimen; although a positive correlation between IB and density was obtained, the range of R^2 was only 0.20-0.25.

Water absorption and thickness swell. Both WA and TS linearly decreased with increasing density (Figs 5 and 6). However, the correlation between TS and density was not as strong as those for MOR, MOE, IB, and WA. Moisture-induced TS is often a limiting factor for OSB application. A large number of studies have been carried out in attempts to determine optimal product and process parameters to reduce TS. Various research results regarding the influence of density on TS have been reported, but some are contradictory. For instance, Liu and McNatt (1991) conditioned laboratory-made aspen flakeboards at 80% RH for 71 da and found no definite relationship between TS and density. Wu and Piao (1999) demonstrated that the TS rate, TS/WA, increased with increasing specimen density. Geimer (1982) studied TS of flakeboards subjected to a series of RH and vacuum-pressure soak conditions. He pointed out that at any one level of moisture content, TS was greatest in the highest density boards. However, at any one level of environment exposure, TS was less in the high-density boards.

Winistorfer and Xu (1996) investigated the behavior of layer TS of OSB and found that TS increased proportionally with the layer density. They therefore suggested that efforts to improve dimensional stability should be focused on stabilizing the high-density surface layers. Using an optical technique to determine layer TS, Wang and Winistorfer (2003) showed that TS of OSB was dominated by high-density surface layers throughout the 24-h soak cycle. In research on TS of OSB under long-term cyclic RH, Wu and Lee (2002) developed a model to predict TS. They found that the predicted TS distribution across panel thickness followed the distribution of EMC more closely than VDP. In a comparative study of commercial OSB products, Wang et al (2003) and Gu et al (2005) demonstrated that layer TS distributions resembled the VDP, suggesting that TS is positively related to density. However, no positive correlation between the average panel density and the total TS was evident.

The relationship among TS, WA, and density appears to be fairly complex. TS and WA are exposure time-dependent. Higher density products absorb water slower, reducing the rate of TS. Given enough exposure time, the higher density products will ultimately swell more. However, the data presented by Wang et al (2003) did not firmly show dependencies of 96-h WA and TS on density being different from those of 2-h, 8-h, and 24-h tests. The long-term (12-24 mon) cyclic RH exposure data obtained by Wu and Lee (2002) demonstrated that a higher density 3-layer board tended to have greater TS, whereas in single-layer uniform-density boards, density had a mixed effect on TS. Jin et al (2009) stated that the relatively poor contacts between strands in low-density panels result in weak bonds that are more likely to fail during water soaking and argued that although having greater swelling potential, higher density panels usually do not receive full water penetration during a 24-h water-soaking test to release the deformation. More studies are clearly needed to obtain reliable correlations.

Rolling shear strength. RS in both parallel and perpendicular directions responded to increasing density in a weak nonlinear manner. As in the cases of parallel MOR, parallel MOE, and IB, the relationship between parallel and perpendicular RS and panel density can be approximated with quadratic functions (Fig 7). Parallel RS values were smaller than those of perpendicular values. This is because shear failure usually happens at the core layer where density is the lowest, and the core strands were oriented perpendicular to the face strand alignment direction.

Although many studies have been conducted on the effect of OSB panel density on MOR, MOE, IB, and TS, relatively few published data are available on RS. Because RS is an important property that also influences other structural properties such as concentrated static load (Zhang et al 2005), more testing on the effect of panel density on RS is needed to expand the knowledge database.

Experimental error is an inevitable part of any pilot plant study. Although every effort was taken to control confounding factors in the processes of panel manufacturing, variability was inevitable in strand alignment, resin, strand geometry, and density distribution. Inexactness or inconsistency in measurement of panel properties could also contribute to the experimental error. In regression modeling problems, the residual mean square is often used to estimate the natural variance of the experimental error. Because both linear and quadratic regressions were used in this study, two types of statistical F-test were accordingly performed. For linear regressions, the F-statistic, that is, the ratio of the mean squares of regression to the mean squares of residual, was used to test the significance of fitness. Also, for quadratic regressions, an additional test using the difference between the mean squares removed by the quadratic regression (MS_{qua}) and the mean squares removed by the linear regression (MS_{lin}) was used to test if the quadratic regression leads to a significant improvement in fitness over the linear regression. The F-statistic was therefore calculated as the ratio of the difference (MS_{qua} - Ms_{lin}) to the mean squares of residual (MS_{res}) (Volk 1958). Table 2 is a summary of the regression and analysis of variance results. Although the F-tests for the linear regressions were all significant at the 0.001 level, the quadratic regression further improved the fitness. The significances of improvement were above the 0.05 level except for perpendicular shear.

Despite density being recognized as an important factor affecting major properties of OSB, there are limited information and literature in the public domain regarding panel density effect on OSB properties, which makes it somewhat difficult to compare the results from this experiment with previous ones over an extensive range of panel density.

CONCLUSIONS

Panel density influences major OSB properties such as MOR, MOE, IB, TS, WA, and RS.

Within the density range used in this study (449-705 kg/m^3), the tested properties of the aspen OSB generally improved as the average panel density increased. Effects of panel density on parallel MOR, parallel MOE, IB, and parallel and perpendicular RS can be approximated with convex quadratic functions, implying that in the lower density region, these panel properties improve more rapidly with increasing density than for higher density. When density reached a certain elevated level, little benefit was achieved with further increases in density.

The water-related properties, WA and TS after 24-h soaking, were found to linearly decrease with increasing panel density. This result is not in good agreement with some other published data. More study is recommended to find conclusive relations among WA, TS, and panel density.

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Table 2. Summary of regression and analysis of variance results.

	Linear regression			Quadratic regression		
	R^2	F-statistic	Significance	R^2	F-statistic[a]	Significance
$MOR_{\|\|}$	0.789	93.67	<0.001	0.843	8.24	<0.01
$MOR_{\perp}$	0.665	49.72	<0.001			
$MOE_{\|\|}$	0.652	46.77	<0.001	0.775	13.18	<0.005
$MOE_{\perp}$	0.679	52.76	<0.001			
IB	0.850	141.16	<0.001	0.890	8.91	<0.01
WA	0.878	179.13	<0.001			
TS	0.611	39.31	<0.001			
$RS_{\|\|}$	0.901	227.46	<0.001	0.920	5.63	<0.05
$RS_{\perp}$	0.841	132.49	<0.001	0.863	3.81	<0.10

[a] The F-statistic is expressed as the difference between the mean squares removed by the quadratic regression (MS_{qua}) and the mean squares removed by the linear regression (MS_{lin}) divided by the mean squares of residual (MS_{res}).

$\|\|$ = parallel; $\perp$ = perpendicular.

MOR, modulus of rupture; MOE, modulus of elasticity; IB, internal bond; WA, water adsorption; TS, thickness swelling; RS, rolling shear.

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