Effect of Density on the Properties of Oriented Strandboard Web Stock Used in Wood I-Joists

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Abstract

Numerical simulation of structural member behavior requires knowledge of mechanical properties. This study proposes a methodology to obtain reliable mechanical properties of the oriented strandboard (OSB) web of I-joists, including variability. OSB panel samples were scanned by X-ray densitometry to measure in-plane density variation. Specimens were cut from predefined homogeneous density areas in three different orientations (parallel, perpendicular, and diagonal to the strong axis) to measure three basic elastic properties required for an elastic model of the OSB web of I-joists: modulus of elasticity (MOE) parallel and perpendicular to the panel's strong axis and shear modulus (G). Given the required small specimen size, shear modulus was determined using a combination of in-plane tensile MOEs, including MOE at 45°. Results showed a strong relationship between OSB density and small-scale mechanical properties: coefficients of determination (R^2) varied between 0.57 and 0.79. This provided information on I-joist OSB web mechanical properties as a function of density for input into a numerical model. Properties showed considerable variability in the 600 to 900 kg/m^3 density range, with a 207 percent increase in tensile modulus of elasticity in the parallel direction, 187 percent in the perpendicular direction, and 172 percent at 45°. The mechanics-based OSB shear modulus equation used proved to be reliable.

Oriented strandboard (OSB) is a commonly used wood-based composite product. It is widely used across North America for residential construction and home remodeling. It also plays a structural role in engineered wood products such as wood I-joists, where it is used for the web. Because OSB is used mainly for structural purposes, it has to meet performance standards to ensure public safety. OSB web I-joists (commonly referred to as web stock OSB) are proprietary products designed to meet specific I-joist manufacturer standards. Therefore, I-joist OSB web properties are not available to the public. Consequently, they could vary depending on the manufacturer's needs and might differ from OSB produced to a specific standard.

Information on the material mechanical properties must be input into numerical models to simulate the performance of this material. OSB is commonly assumed to be an orthotropic material and is described by a set of engineering properties. The literature contains extensive information on solid wood flanges, for which the material properties are readily available (Bodig and Jayne 1993, Forest Products Laboratory 2010). However, this is not the case for the OSB web stock of I-joists. Furthermore, the quality control tests that OSB panel manufacturers run do not cover all the mechanical properties required to fully characterize the material for simulation. It is also generally recognized that OSB has homogeneous properties at large scale and heterogeneous properties at small scale. Thus, global or local properties should be determined if the OSB is considered to have homogeneous or heterogeneous properties, respectively. Consequently, extra care should be taken when determining the test protocol and specimen size to measure the required engineering properties. If global OSB properties are studied, testing to obtain mechanical

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properties should preferably be performed at large scale to be representative. To consider local OSB properties, these should be determined on small-scale specimens.

Grandmont et al. (2010) considered global OSB properties and described this orthotropic material with a set of engineering properties: modulus of elasticity (MOE) in tension in the three principal directions (E_1, E_2, and E_3; see Fig. 1 for the reference coordinate system), Poisson's ratios (v_{12}, v_{23}, and v_{13}), and shear modulus (G_{12}, G_{23}, and G_{13}) in the three principal planes. Grandmont et al. (2010) found that the most important properties of the OSB web for wood I-joist bending simulation purposes are G_{12}, E_1, E_2, and v_{12}, with G_{12} by far the most significant. Because OSB properties are highly variable at small scale, the specimen size must be adapted to the finite element mesh size used in the model. Previous work (Grandmont et al. 2010) suggests that mesh size should be less than 30 mm. The variation in properties could then be considered in the model, using information on OSB panel local density, for instance.

Karacabeyli et al. (1996) conducted an extensive study on OSB panels, including the results of tests performed to develop Canadian standards for structural grade OSB. The objective was to determine design values for OSB graded according to the CSA O452 standard (Canadian Standards Association [CSA] 1994a) and to include these values in the CSA O86.1 standard (CSA 1994b). Series of tests were performed on medium- to large-scale specimens of different thicknesses and from different plants to determine OSB properties. The results provide information on the variability and distribution of engineering properties. For one group of 9.5-mm-thick panels, E_1 and E_2 were determined at 4,860 and 3,850 MPa, respectively, using ASTM D3500 Test Method B (ASTM International 2009). Calculated in-plane shear stiffness was 1,190 MPa for G_{12} and 1,210 MPa for G_{21} using ASTM D2719 Test Method C (ASTM International 2007). As the test setup creates near pure shear stress, the obtained G_{12} and G_{21} were almost identical. Calculated rolling shear stiffness (using ASTM D2718; ASTM International 2006b) G_{23} and G_{32} were 180 and 200 MPa, respectively. Notably, Karacabeyli et al. (1996) did not consider the OSB web of specific I-joists, for which results could differ. Poisson's ratio is a less documented OSB property. For instance, Thomas (2003) calculated in-plane OSB Poisson's ratio by measuring deformations in the two principal directions while applying a load in one of them. Deformations were measured over a 0.203-m span. The values of Poisson's ratios v_{12} and v_{21} were 0.23 and 0.16, respectively. Because these values were obtained from tests performed on medium-size specimens, they are not representative of the local property variability that characterizes OSB.

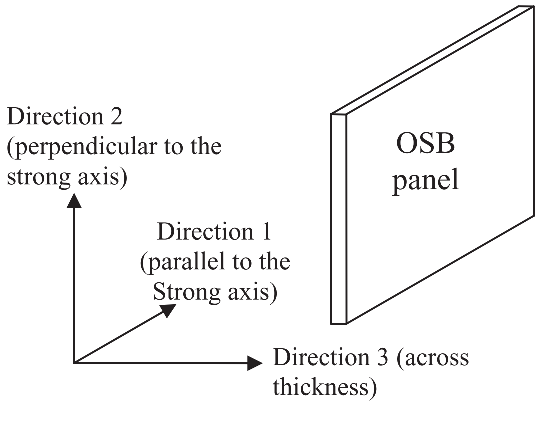

Figure 1.—Reference coordinate system.

Zhu (2003) also determined OSB mechanical properties to provide input for a finite element model of wood I-joists in order to study the influence of web openings and buckling up to failure (Guan and Zhu 2004, Zhu et al. 2005, 2007). Elasticity matrix components were determined experimentally using six small specimens, as suggested by Guitard (1987). Properties in tension and compression were determined to identify differences. Tension tests were performed on bone-shaped specimens according to the British standard BS EN 789 (British Standards Institution 1996). Outer specimen size was 400 by 90 mm, with a narrower center section of 100 by 60 mm. Compression tests were performed according to the same standard. Specimens were made by gluing together five rectangular 240 by 50-mm OSB panels. Prior to testing, specimens were reduced to 40 by 240 mm. Longitudinal and transverse displacements were measured on each specimen using strain gauges. Average E_1 and E_2 values obtained in tension were 3,770 and 2,563 MPa, respectively, and 3,647 and 2,765 MPa, respectively, in compression. Given the similarity of the values obtained in tension and compression, Zhu (2003) used the same OSB properties in the elastic zone for both cases in his model but considered them different beyond the elastic zone. The wood I-joist bending deflection simulation results correlated well with experimental results. Because the study was performed on British OSB considering global properties, the bending deflection might differ for OSB manufactured elsewhere using other wood species. Morris et al. (1996) borrowed Zhu's (2003) use of six specimens to determine properties, based on the following solid mechanics equation (Zhu 2003):

$$E_D = \left[\frac{l^4}{E_1} + \left(\frac{1}{G_{12}} - \frac{2\nu_{12}}{E_1}\right) l^2 m^2 + \frac{m^4}{E_2}\right]^{-1} \tag{1}$$

where E_D is the MOE on a diagonal at a specific angle between directions 1 and 2, and l and m are the cosine of the angle between the diagonal and direction 1 and between the diagonal and direction 2, respectively. When using a diagonal at 45° (thus E_D becomes $E_{45°}$) and when G_{12} is isolated, Equation 1 is simplified as follows:

$$G_{12} = \left(\frac{4}{E_{45°}} - \frac{1 - 2\nu_{12}}{E_1} - \frac{1}{E_2}\right)^{-1} \tag{2}$$

Zhu (2003) obtained a calculated G_{12} value of 1,419 MPa using tension test results and 1,323 MPa using compression test results. He used an average value of 1,370 MPa because tension and compression properties were considered equal in the elastic zone. Zhu (2003) also calculated Poisson's ratio from the tension and compression test results: in-plane Poisson's ratios v_{12} and v_{21} were 0.18 and 0.13, respectively. Poisson's ratio v_{21} can also be calculated using Equation 3.

$$\nu_{21} = \frac{E_2}{E_1}\nu_{12} \tag{3}$$

When computing v_{21} from Equation 3 using average E_1 and E_2 values obtained by Zhu (2003) of 3,770 and 2,563 MPa, respectively, with v_{12} of 0.18, the result is 0.12, which is in line with the experimental result of Zhu (2003) of 0.13. These values are similar to those reported by Thomas (2003).

Zhu (2003) also investigated for a correlation between OSB local density and measured properties. He showed that OSB engineering properties were strongly related to density in some cases (R^2 ranged from 0.26 to 0.86).

Chui et al. (2005) developed a model to improve OSB web design to reduce knife-through failure and studied the impact of multiple web openings on stress distribution in the web. Vibration and static tests were performed on medium- to small-scale specimens. Vibration tests were conducted flatwise on 75 by 1200-mm specimens to determine bending MOE and shear stiffness. The authors found 1,402 and 1,074 MPa for G_{12} and G_{21}, respectively, in the same range as the results of Karacabeyli et al. (1996) but with a greater difference between G_{12} and G_{21}. Both E_1 and E_2 were determined from tension and compression tests. Tension tests were performed following ASTM D3500 Test Method B using smaller than prescribed specimens (50 by 500 mm instead of 152 by 1,219 mm). Values of 5,201 and 3,459 MPa (ASTM International 2009) were obtained for E_1 and E_2 in tension, respectively. Compression tests were performed on 46 by 177-mm specimens made of three layers of laminated OSB. Values of 5,243 and 3,895 MPa were obtained for E_1 and E_2 in compression, respectively. It is generally recognized that the elastic properties of OSB are similar in tension and compression, as the previous results show. Interestingly, the elastic properties obtained by Chui et al. (2005) for the OSB web of Canadian I-joists are in the same range as those obtained by Karacabeyli et al. (1996) for structural grade OSB not intended for use in I-joists and by Zhu (2003) for the OSB web stock of British I-joists.

Chui et al. (2007) investigated the impact of OSB web properties on wood I-joist bending stiffness and shear capacity performance. Vibration and static tests were used to determine OSB web mechanical properties. Edgewise bending and vibration tests were used to determine bending E and G_{12}. Specimen sizes were 76.2 by 558.8 mm for vibration tests and 76.2 by 279.4 mm for edgewise bending tests. Flatwise bending tests were also performed in accordance with CAN/CSA O325.1 (CSA 1988). Test sample density was found to be a poor indicator of OSB mechanical properties: the coefficient of determination ranged from 0.11 to 0.46. The coefficients of determination between properties and density were lower than those found by Zhu (2003). The larger specimen size used by Chui et al. (2007) could explain this difference.

The objective of the present study was to determine the OSB web mechanical properties required to develop a finite element model of wood I-joist bending behavior. In order to develop a realistic model, the OSB was considered as an orthotropic material with variable local properties. In order to capture heterogeneity, the simulated OSB web of the I-joist was divided into small parts, each with its own properties. Properties were then determined on small specimens to capture local variation and consider it in the model. Density information obtained by density mapping was related to OSB properties to further assign local properties in the model. The mechanical properties to be determined (G_{12}, E_1, E_2, and ν_{12}) were selected based on a model sensitivity study by Grandmont et al. (2010).

Materials and Methods

OSB web mechanical properties were determined in two phases. In the first phase, OSB was considered to be homogeneous and to have global properties. The mechanical properties were then obtained using standard testing procedures, and the results were compared with the literature. Special care was taken to obtain reliable data from large-scale tests to determine G_{12}, which is known to be the most important OSB web property (Grandmont et al. 2010). Results of Phase 1 provided benchmark values to determine the impact of horizontal density variation on mechanical properties of I-joist OSB web. In the second phase, OSB was considered to be heterogeneous with variable local properties. Therefore, all tests were performed on small specimens. The measured properties were then related to local average density across panel thickness.

Phase 1: Determination of OSB web properties of global I-joists

Poisson's ratio (ν_{12}), in-plane tension moduli (E_1 and E_2), and shear stiffness (G_{12}) were determined. All tests were performed on 9.5-, 9.8-, and 10.0-mm-thick OSB panels from Norbord (Val d'Or, Quebec, Canada). Panels ($n = 4$ for each of the three thicknesses) were conditioned in a climate chamber at 20°C and 50 percent relative humidity (RH) prior to testing to obtain 6.2 percent equilibrium moisture content. Average density (air dry mass/air dry volume) of 650, 620, and 620 kg/m^3 was determined after conditioning for the 9.5-, 9.8-, and 10.0-mm-thick panels, respectively.

A series of tension tests was performed according to ASTM D1037-06a (ASTM International 2006a) to determine in-plane tension E and Poisson's ratio. Prescribed bone-shaped tensile specimens ($n = 10$) of 250 by 50 mm with a narrower center section of 50 by 38 mm were tested. Two types of measuring devices were used. An optical system (Averna Technology, Montreal; Fig. 2) was used in a first test series to measure surface strains. This measuring device allowed multiple strain measurements at once on a large surface, reducing the impact of local heterogeneity of OSB. The system is equipped with a black-and-white digital camera tracking the movement of predefined points on the specimen in a two-axis coordinate system. Tension E values thus obtained were validated against results obtained with a standard extensometer from a sample taken in the same 9.5-mm-thick panel. A second test series was carried out to

Figure 2.—ASTM D1037 tension test setup with optical displacement measurement device.

determine strains, using the same standard as for the previous tension tests but with a Hewlett-Packard 6.35-mm direct current differential transformer (DCDT). Tension tests were performed parallel (Direction 1) and perpendicular (Direction 2) to strands orientation on 9.5-, 9.8-, and 10.0-mm-thick panels. Fifteen specimens were tested for each direction and for each of the three thicknesses considered. The 9.5-mm-thick specimens used for both tension test series were cut from the same OSB panel to allow validation of the optical measurement results.

In-plane shear modulus was determined according to ASTM D2719-89-C (ASTM International 2007) using large-scale 0.609 by 0.406-m specimens. Five tests were performed for both directions (G_{12} and G_{21}) and for each of the three thicknesses. Shear modulus was determined in both directions, although they are considered equal for an orthotropic material.

Phase 2: Determination of OSB web properties of local I-joists

Small specimens are used to determine OSB properties in order to relate the material mechanical properties to local horizontal density. This allows integrating local OSB mechanical properties into a finite element simulation model. Small specimens in the range of a prescribed finite element model mesh size of approximately 30 mm (Grandmont et al. 2010) were therefore used. Given this specimen size, shear modulus was not determined directly but with a procedure used by Morris et al. (1996) and Zhu (2003; Eq. 2). Properties in compression and tension were considered equal because the model was limited to the elastic domain. This reduced the number of required test specimens from six to three. Zhu (2003) used six specimens to test both tension and compression but found similar properties for both directions in the elastic zone.

Test material was provided by Abitibi-LP (Larouche, Quebec, Canada). Panels ($n = 40$) were 10 mm thick and conditioned in a climate chamber at 20°C and 50 percent RH prior to testing. Average density obtained in these conditions was 720 kg/m^3. A series of tension tests was performed according to a modified ASTM D1037-06a protocol to determine tension MOE in three directions (Fig. 3). Bone-shaped tensile specimens were 250 mm long by 50 mm wide with a narrower center section of 50 by 30 mm. Specimens were narrower than in Phase 1 (30 mm instead of 38.1 mm) for a closer match to the finite element model mesh (Grandmont et al. 2010). Tests were performed on an MTS (Material Testing Solution) Alliance RT/50 universal testing machine. DCDT extensometers were installed on both sides of the specimen to measure displacement (Fig. 3). Typical OSB has an asymmetrical density profile through thickness that causes a heterogeneous deformation between specimen faces. The average of both deformation measurements was used to limit the impact of this potential heterogeneous deformation on the properties measured.

The same standard size ($n = 40$, 1.22 by 2.44 m) OSB web panels sampled from Abitibi-LP's I-joist plant were scanned for horizontal density measurement using the Alberta Research Council's (Edmonton, Alberta, Canada) X-ray densitometer. Density-contour lines were drawn horizontally on the panels for density mapping. Specimens were then cut from three homogeneous horizontal density range areas: 600 to 700 kg/m^3, 700 to 800 kg/m^3, and 800 to 900 kg/m^3. This was done to ensure sampling in the low and high end of the horizontal density range (600 to 900 kg/m^3). In total 315 specimens were tested for E (E_1, E_2, and E_{45}) in tension (35 × 3 directions × 3 thicknesses = 315). Central sections of tested specimens were cut after testing to measure their vertical density profile and apparent average density. A QMS (Quintek Measurement Systems) QDP-01X density profiler was used to measure the vertical density profile.

Figure 3.—ASTM D1037 in-plane tension test setup with two direct current differential transformers.

Results and Discussion

Phase 1: Determination of OSB web properties of global I-joists

The Poisson ratios determined from tension tests using optical displacement measurement are presented in Table 1. The average ratios of 0.23 and 0.15 for v_{12} and v_{21}, respectively, are in line with Thomas (2003) and Zhu

Table 1.—Poisson's ratio of oriented strandboard panels determined according to ASTM D1037 and using an optical displacement measurement device.[a]

Sample	v_{12}	v_{21}
1	0.12	0.15
2	0.18	—
3	0.33	—
4	0.16	—
5	0.26	—
6	0.27	0.28
7	0.23	—
8	—	0.08
9	0.31	0.15
10	0.23	0.11
Average	0.23	0.15
SD	0.07	0.08
COV (%)	30	50

[a] SD = standard deviation; COV = coefficient of variation.

(2003), even though the OSB was made from another wood species. The missing values in Table 1 can be explained by point tracking problems in the transverse direction with the measurement device.

Tension E values were calculated from measured displacement. Table 2 shows the tension E values obtained using optical measurement and using a DCDT extensometer. Average results for E_1 and E_2 using optical measurement were 3,495 and 2,815 MPa, respectively. Results using the DCDT extensometer were 2,919 and 2,582 MPa for E_1 and E_2, respectively. The coefficients of variation are in the 20 to 40 percent range, which was expected given the small specimen size. No significant difference at the 95 percent confidence level was found between the two strain measurement techniques. Optical displacement measurement could be useful to determine the mechanical properties of nonhomogeneous material such as OSB. The optical strain measurement system gave accurate results in the longitudinal axis.

In-plane shear modulus was also investigated. Results obtained following ASTM D2719-89-C are presented in Table 3. Average results for the 9.5-mm-thick panels were 1,319 and 1,295 MPa for G_{12} and G_{21}, respectively. These values are in the same range as those found by Karacabeyli et al. (1996). Three different nominal thicknesses were tested. Results were similar in both directions because the test specimens were large enough to develop near pure shear stress. The coefficient of variation ranged from 4 to 8 percent for these large 0.406 by 0.610-m specimens. The coefficients of variation were lower than for the above-discussed tension test results because OSB properties tend to be homogeneous at large scale.

Table 2.—In-plane tension modulus of elasticity (MOE) of oriented strandboard web of I-joists obtained following ASTM D1037 in Phase 1.[a]

	Tension MOE (MPa)	
	E_1	E_2
Optical measurement device		
Average	3,495	2,815
Min	2,332	1,754
Max	4,651	4,898
SD	757	803
COV (%)	22	29
DCDT		
Average	2,919	2,582
Min	2,063	1,518
Max	4,938	4,639
SD	788	973
COV (%)	27	38

[a] SD = standard deviation; COV = coefficient of variation; DCDT = direct current differential transformer.

Table 3.—In-plane shear modulus of oriented strandboard web of I-joists obtained following ASTM D2719-C.[a]

Tested property ($n = 5$)	Nominal thickness (mm)	G (MPa)	SD	COV (%)
G_{12}	9.5	1,319	86	6
G_{21}	9.5	1,295	56	4
G_{12}	9.8	1,164	56	5
G_{21}	9.8	1,225	98	8
G_{12}	10	1,150	47	4
G_{21}	10	1,314	87	7

[a] n = sample size; SD = standard deviation; COV = coefficient of variation.

These results show that the tested I-joist OSB web has engineering properties comparable with those found by Chui et al. (2005) for similar material, by Karacabeyli et al. (1996) for structural grade Canadian OSB, and by Zhu (2003) for OSB web of British I-joists. These similarities were unexpected, considering the three different products evaluated. High coefficients of variation were obtained for tension tests on small-scale specimens. This suggests that local OSB web properties should be considered for simulation purposes. Phase 1 tests allowed comparison with the literature and provided reference values for Phase 2.

Phase 2: Determination of OSB web properties of local I-joists

Density.—OSB apparent density and vertical density profiles were measured on all tension test specimens (35 for each of the three directions and each of the three density groups, for a total of 315). Figure 4 shows the average vertical density profiles obtained for different density groups. The higher the density group, the greater the difference is between surface and core densities. Differences between surface and core density were roughly 275, 250, and 170 kg/m^3 for the 800 to 900 kg/m^3, 700 to 800 kg/m^3, and 600 to 700 kg/m^3 density groups, respectively. The density profile was also asymmetrical, one surface layer presenting a higher density than the other. This pattern can be explained by the manufacturing process. Gravity combined with vibration of the mat on the conveyors causes fine strands to reach the bottom of the mat before hot pressing.

These results confirm that the tension test setup used in Phase 1 could be improved. Only one measurement device was used on one side of the specimen. The measured deformation appeared to be sensitive to the chosen measurement side. It was then assumed that the asymmetrical vertical density profile could cause the specimen to bend while loaded in tension. In this regard, two measurement devices were then used in Phase 2 to measure the displacement from both sides of the specimen.

Mechanical properties.—Figures 5 to 7 show the tension MOE results as a function of the specimen apparent density for each tested direction (parallel, perpendicular, and at

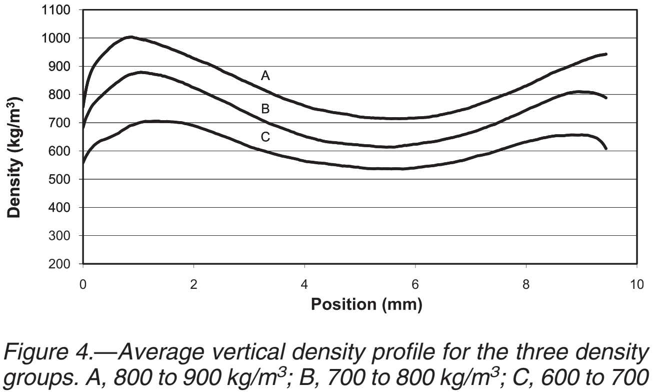

Figure 4.—Average vertical density profile for the three density groups. A, 800 to 900 kg/m^3; B, 700 to 800 kg/m^3; C, 600 to 700 kg/m^3 (n = 105 for each profile).

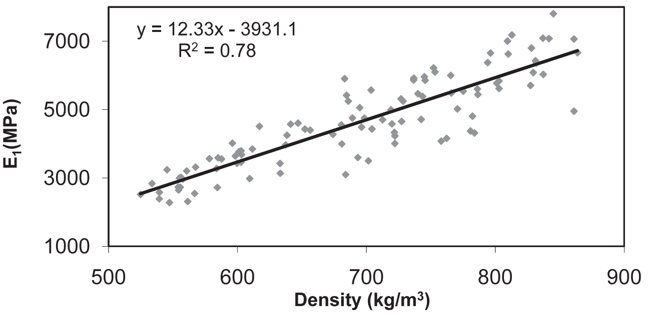

Figure 5.—Tension modulus of elasticity of the oriented strandboard web of I-joists in the parallel direction (E_1) as a function of average local apparent density determined following ASTM D1037.

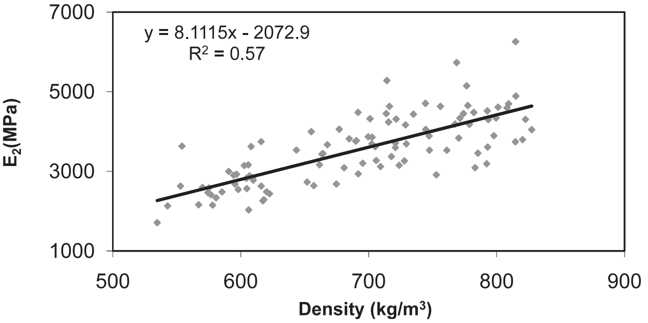

Figure 6.—Tension modulus of elasticity of the oriented strandboard web of I-joists in the perpendicular direction (E_2) as a function of average local apparent density determined following ASTM D1037.

45°). A linear regression plotted for each data set gave the following equations:

$$E_1 = 12.33D - 3,931 \tag{4}$$

$$E_{45} = 7.71D - 1,409 \tag{5}$$

$$E_2 = 8.11D - 2,073 \tag{6}$$

where D is the apparent density (kg/m^3) of the test sample. Equations 4 to 6 relate the material mechanical properties to local apparent density. Knowing these relationships and the horizontal density distribution obtained from density mapping, a specific property set can be assigned to a given density in the model. A specimen with an apparent density equal to the measured average apparent density of the OSB panels (694 kg/m^3) would have 4,621, 3,938, and 3,553 MPa for E_1, E_{45}, and E_2, respectively. Referring to Equation 2 and considering a v_{12} of 0.18, this OSB panel would have a shear stiffness (G_{12}) of 1,679 MPa. These values are in agreement with the average measured properties shown in Table 4. Figures 5 to 7 show that for a density range of 600 to 900 kg/m^3, E_1, E_2, and E_{45} would increase from 3,467 to 7,166 MPa, from 2,794 to 5,227 MPa, and from 3,217 to 5,530 MPa, respectively. These increases represent 207, 187, and 172 percent in the 600 to 900 kg/m^3 density range, showing high variability of both density and mechanical properties.

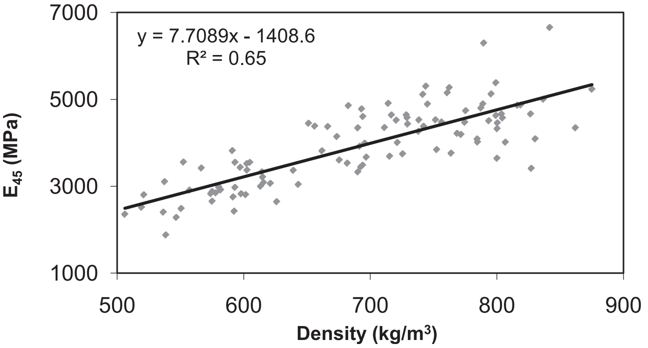

Figure 7.—Tension modulus of elasticity of the oriented strandboard web of I-joists at 45° as a function of average local apparent density determined following ASTM D1037.

A strong relationship was found between OSB apparent density and all tested properties: R^2 ranged from 0.57 to 0.78. The relationship between local density and mechanical properties was stronger than that found by Chui et al. (2007) and similar to that found by Zhu (2003). This was attributable to specimen size and the large number of specimens tested. The coefficient of determination (R^2) of the linear regression was higher for the parallel direction (E_1). The coefficient of determination obtained for E_{45} and E_2 followed in descending order. This shows the lower variability of E in the strands' principal direction.

Figure 8 shows the values calculated from the linear regression equations presented in Figures 5, 6, and 7. Shear modulus G_{12} was calculated from Equation 2 using a Poisson's ratio of 0.18, obtained from the literature (Thomas 2003, Zhu 2003) and from Phase 1 results. Calculated

Table 4.—Average mechanical properties of oriented strandboard web of I-joists using ASTM D1037.

Property	Average tension MOE (MPa) (n = 315)[a]
E_1	4,657
E_2	3,548
$E_{45°}$	3,948
G_{12}[b]	1,684

[a] MOE = modulus of elasticity; n = sample size.

[b] Calculated based on E_1, E_2, and $E_{45°}$.

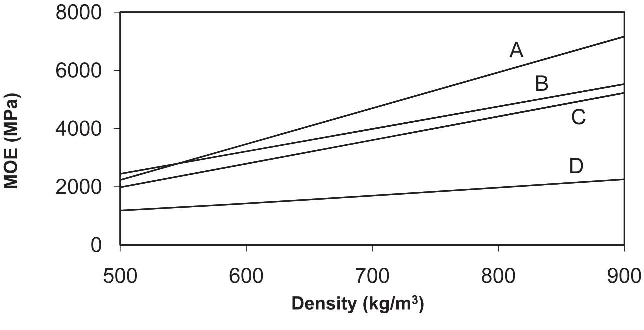

Figure 8.—Calculated tension modulus of elasticity of the oriented strandboard web of I-joists in relation to average local apparent density. A, parallel (E_1); B, 45°; C, perpendicular (E_2); D, calculated in-plane shear modulus of the panel (G_{12}).

results obtained for G_{12} give consistent results over the density range. The predicted tensile E show unexpected results in the 500 to 600 kg/m^3 density range, with an inversion between E_1 and E_{45}. Thus, Equations 4, 5, and 6 should be used in the 600 to 900 kg/m^3 density range. Results in the 500 to 600 kg/m^3 density range are due to the difference between horizontal density mapping and the measured apparent density of the specimen central section. The results obtained in Phases 1 and 2, in which E_1 and E_2 were determined using a similar protocol with slightly different specimen sizes, were then compared. The shear stiffness (G_{12}) calculated with Equation 2 and presented in Table 4 has a value of 1,684 MPa and represents 36 and 47 percent of E_1 and E_2, respectively. Phase 1 G_{12} obtained on large specimens in accordance with ASTM D2719-89-C was 1,307 MPa, representing 37 and 46 percent of E_1 and E_2, respectively. The proportions obtained were almost the same in both cases, which confirms the use of Equation 2 to determine G_{12} for OSB panels using small specimens.

Conclusions

Global and local mechanical properties of the OSB web of I-joists were determined for simulation purposes. When global OSB properties were considered, a shear modulus of about 1,300 MPa was obtained for 9.5-mm-thick web stock OSB. Poisson's ratios were in line with the literature, at an average of 0.18 for v_{12} and v_{21}. An optical displacement measurement device was used and found promising for future studies.

When testing OSB in tension, it was found that the displacement should be measured on both sides of the specimen because it varied depending on the chosen measurement side. The asymmetrical density profile observed for the OSB web could have caused the specimen to bend under axial load. The measured vertical density profiles tended to support this idea, especially for higher density zones, which showed steeper vertical density profiles.

A solid mechanics equation was used when considering local in-plane shear modulus (G_{12}), and tests were conducted on small-scale specimens. An average shear modulus of 1,684 MPa was determined. Results were in line with those from large-scale mechanical testing following ASTM D2719-89-C (ASTM International 2007). The results on small specimens showed that web stock OSB properties varied with average local panel density. A strong relationship was found between average density and tensile modulus of elasticity. The coefficient of determination varied from 0.79 to 0.57 for the tensile modulus of elasticity E_1 and E_2, respectively. In the apparent local density range of the test specimens (600 to 900 kg/m^3), the modulus of elasticity in tension increased by 207 percent in the parallel direction (E_1), by 187 percent in the perpendicular direction (E_2), and by 172 percent at 45° (E_{45}). This high variability shows that a model simulating I-joists made with OSB web material would be more realistic if properties were considered heterogeneous and strongly related to average local density. Based on the measured horizontal density distribution and on the regression equations determined in the current study, local properties could be introduced in a finite element simulation model. This will be the purpose of a further study.

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