

# A comparison of the shear strength of structural composite lumber using torsion and shear block tests

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## Abstract

The objective of this study was to compare the shear strength of structural composite lumber (SCL) based on shear block to that of shear strength based on torsion test. Shear blocks in two different orientations from laminated veneer lumber, parallel strand lumber, and laminated strand lumber (LSL) were tested and their shear strengths were compared to the shear strengths of full-sized specimens based on torsion tests from the literature. The results showed that the shear strength based on torsion is 12 to 39 percent lower than the shear strength based on shear block. The failure mode of LSL using shear blocks is predominantly compression parallel. The study concluded that the shear block is not an appropriate test method to determine the shear strength of SCL.

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Shear strength of structural composite lumber (SCL) is determined using a small specimen, commonly known as shear block. It is similar to the current standard test specimen for solid-sawn lumber (SSL), which uses a small, clear, straight-grained specimen (ASTM 2002a). The standard does not define the orientation of the shear plane for SSL. In contrast, standard specification for the evaluation of SCL products (ASTM 2002b) requires two separate test series to induce shear failure in the longitudinal-tangential plane (LT) and longitudinal-radial plane (LR). Besides, the shear block test, which uses small specimens, there are two test methods to induce shear failure in full-sized members: several types of bending tests on short, deep beams or torsion tests on any size beams. Several previous studies (Gupta et al. 2002a, Riyanto and Gupta 1998, Rammer et al. 1996) have shown that the shear strength of SSL based on shear block is not representative of shear strength of full-sized lumber based on either various bending tests or torsion test. Furthermore, shear strength of SSL based on bending tests depends upon the type of bending set-up used and is affected by the presence of other

stresses in the specimens (Mandery 1969). Hence, shear strength based on bending tests of full-sized specimens may not be the true shear strength of the material (SSL or SCL). On the other hand, torsion tests produce pure shear stresses (other stresses are extremely small and may realistically be ignored) in the specimen, and the maximum shear stresses in the specimen can be taken as the shear strength of the material (Gupta et al. 2002b). This also compliments the way other mechanical properties, such as bending, tension, and compression, are determined, where predominantly only one type of stress is present in that portion of the specimen which is of interest. The objective of this study was to determine the shear strength of SCL using a shear block test and compare it to the torsion-based shear strength obtained from Gupta and Siller (2005a).

Recently, several researchers (Rammer et al. 1996; Riyanto and Gupta 1998; Gupta et al. 2002a, 2002b) have compared shear strength based on full-sized specimens under various types of bending tests ( $\tau_B$ ) and shear strength based on shear block ( $\tau_{ASTM}$ ). All of these studies showed that  $\tau_B$  is affected by:

1. size of the specimen,
2. type of bending test set up, and
3. span-to-depth ratio.

These studies indicate that  $\tau_{ASTM}$  is different compared to  $\tau_B$ . Riyanto and Gupta (1998) and Gupta et al. (2002a) compared shear strength of full-sized lumber based on torsion test ( $\tau_T$ ) to

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$\tau_{ASTM}$ . These studies showed the  $\tau_T/\tau_{ASTM}$  ratio to always be higher than unity for all sizes, again indicating that even after using a method other than bending,  $\tau_{ASTM}$  is different than the shear strength of full-sized SSL ( $\tau_B$  or  $\tau_T$ ). These studies confirm that  $\tau_{ASTM}$  is not representative of the shear strength of full-sized SSL. The same may be true for SCL.

Hunt et al. (1993) showed that shear block testing yielded the highest average values for shear strength, 6.34 MPa, followed by the three-point bending test, 5.72 MPa, and the five-point bending test, 4.76 MPa, for plank-oriented laminated veneer lumber (LVL). In 1998, Bradtmueller et al. obtained shear strength of joist-oriented LVL using the five-point bending test (and no shear block test). Craig and Lam (2000, 1996) showed that shear strength of SCL (LVL and parallel strand lumber [PSL]) based on shear block is generally higher than the shear strength based on full-sized bending tests, again showing that the shear block test may be inappropriate for determining shear strength.

Several factors contribute to the inappropriateness of shear block to estimate the shear strength of full-sized specimens (Radcliffe and Suddarth 1955, Tingley et al. 1996) including orientation of grain to load, size effects, anisotropy, defects in full-scale samples (homogeneity), and shear block test configuration and test apparatus effects. The torsion test applies pure shear stresses that are determinable, and this was identified by Ylinen (1963) as one of the characteristics of an ideal shear test specimen and methods. Yoshihara and Ohta (1997) considered the torsion test to be "the most appropriate method for determining the shear stress-shear strain relationship because a pure shear stress can be applied to the material." Hanox (1972) also showed that tensile and compressive stresses are not induced on the specimen under torsion; thus, a more accurate value of shear strength can be determined.

Heck (1997) provides a detailed discussion of test methods for determining shear strength of various materials. Methods used to determine shear strength of wood include the following: notched beam (Radcliffe and Suddarth 1955), modified block shear specimen, double shear specimen, shear specimen with oblique grain (Ylinen 1963), torsion (Ylinen 1963, Mack 1940), and Arcan (Liu 1984).

### Material and methods

Eighty-five structural-size SCL beams (twenty-nine 1.5E LSL, thirty 1.9E LVL, and twenty-six 2.0E PSL) with nominal dimensions of 44 by 140 by 1524 mm were obtained from TrusJoist – A Weyerhaeuser Business. A small piece (76 mm) was cut from each end of the specimens for shear block tests. The remaining length, 1372 mm, was used for torsion tests (Gupta and Siller 2005a).

Based on ASTM D 5456, the tests were conducted in two different setups (Fig. 1) to induce shear failure in the longitudinal-tangential (LT) plane, called the plank orientation, as well as in the longitudinal-radial (LR) plane, called the joist orienta-

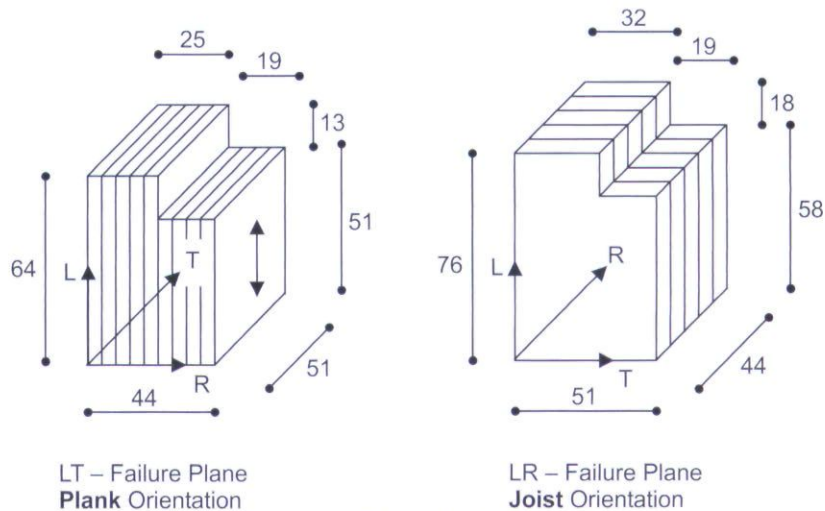


Figure 1. — Shear block dimensions.

tion. Two shear blocks were taken from each specimen to obtain one sample in each orientation. Consequently two series of 85 samples each, or 170 samples in total, were tested. The dimensions of the shear blocks had to be modified from those given in ASTM D 143 since the width of the samples was only 44 mm which is less than the required 51 mm. According to ASTM D 5456, the shear failure plane was kept constant at 2600 mm<sup>2</sup>. Therefore adjustments in the height of the samples were necessary for the joist specimens, i.e., the height had to be increased from 51 to 58 mm. The different dimensions, orientations and failure planes are shown schematically in Figure 1. The shear block tests followed ASTM D 143. The shear strength of the specimen was taken as the maximum load divided by the shear area (51 by 51 or 44 by 58 mm<sup>2</sup>). A detailed description of test methods and specimens is given in Siller (2002).

## Results and discussion

### Failure modes

Photographs of failed samples are shown in Figure 2 for the joist orientation and Figure 3 for the plank orientation. Two different views are shown for each composite: first, the inside view (a: LSL; b: LVL; c: PSL) of the shear plane and second, the bottom view (d: LSL; e: LVL; f: PSL) of the failed shear blocks. The failure plane is rather rough for samples in the joist orientation (Fig. 2), whereas it is generally smooth for plank-oriented specimens (Fig. 3), possibly resulting in higher shear strength in joist orientation (Table 1). This phenomenon is most pronounced for LSL. In the plank orientation, LSL and PSL show delamination, i.e., adhesive failure at the interface between strands and adhesive. The longitudinal alignment of the strands is much better for PSL as opposed to LSL, since PSL strands are longer. However, it is the other way round regarding the tangential alignment, as can be observed in Figure 3 (d, f). PSL shows some cohesive failure of the wood strands, since the individual strands are thicker and not always as accurately parallel aligned with the shear plane compared to LSL.

### Shear strength

The average moisture content (MC) for all specimens was between 6.5 percent and 8.2 percent. The specific gravity (SG) of all three SCL products was higher than solid wood SG, be-



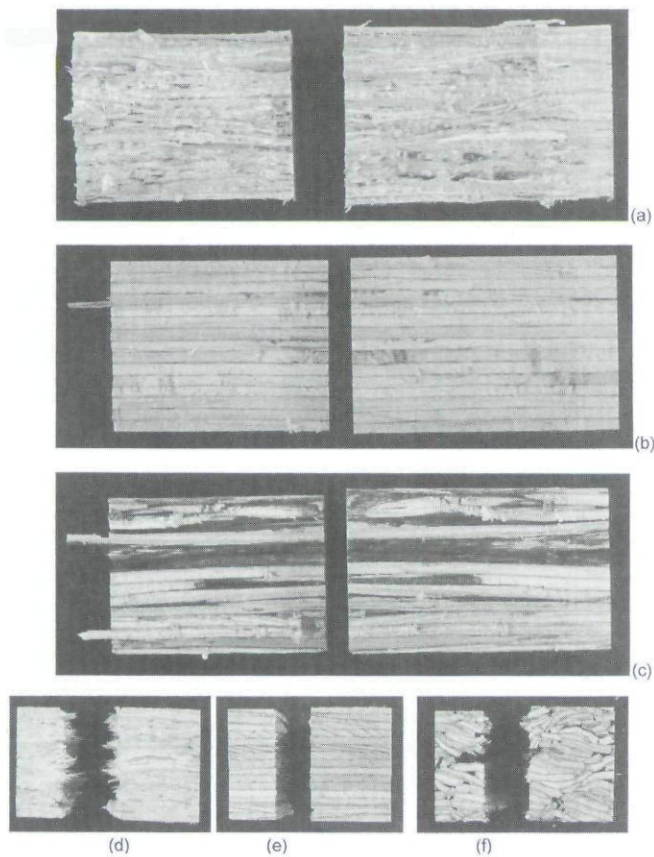


Figure 2. — Failed shear block samples – joist orientation.

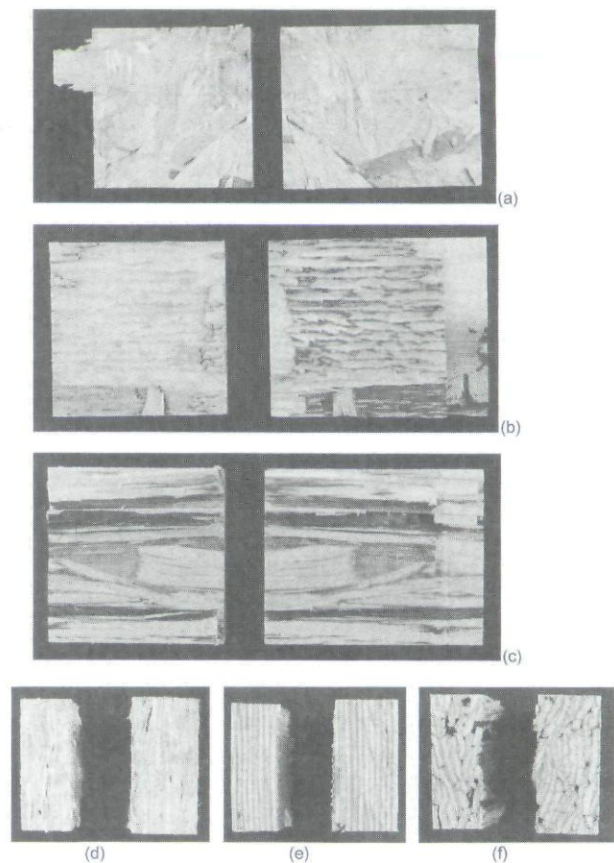


Figure 3. — Failed shear block samples – plank orientation.

Table 1. — Shear strength based on shear block and torsion.<sup>a</sup>

Material <sup>b</sup>	Orientation	Shear stresses (MPa)		Ratio $\tau_T/\tau_{ASTM}$
		Torsion $\tau_T$	ASTM block $\tau_{ASTM}$	
LSL	Joist	12.69 (8.3)	16.91 (13.9)	0.75
LVL	Joist	7.96 (6.3)	9.27 (8.2)	0.86
PSL	Joist	6.82 (7.1)	9.43 (16.9)	0.72
LSL	Plank	6.43 (8.3)	7.28 (12.0)	0.88
LVL	Plank	4.90 (6.3)	6.99 (19.2)	0.70
PSL	Plank	4.55 (7.1)	7.49 (15.0)	0.61

<sup>a</sup> Values in parentheses are coefficients of variation.

<sup>b</sup> LSL is aspen; LVL and PSL are Douglas-fir.

cause of the densification during the manufacturing process. The shear block test results along with torsion results from Gupta and Siller (2005a) are given in **Table 1**. Detailed test results are given in Siller (2002).

As shown in **Table 1**, mean shear strengths values in joist orientation were consistently higher compared to those obtained in plank orientation. This is due to the fact that, in joist orientation, the shear plane is oriented across veneer or strands (**Fig. 1**). The numerous strand or veneer boundaries that cross the shear plane might resist crack propagation. PSL showed slightly higher shear strength in both orientations compared to LVL, which might be attributed to the higher SG. In the plank orientation the shear strengths of all three materials were within a very close range. The same was valid in joist orienta-

tion for LVL and PSL, whereas the value for LSL was extraordinary high, which will be discussed later.

Craig and Lam (1996, 2000) determined shear strength of LVL and PSL in joist and plank orientations using shear block tests. The results (shear strength and coefficient of variation [COV]) of their study are different from this study. This might partly be due to slightly lower stiffness rating and a higher MC (8.6% to 10%) of their specimens. Another possible factor is the difference in shear area (44 by 51 mm) that at the same time might cause higher variability in the referenced study, due to the smaller shear plane. The smaller the specimens are, the higher is the percentage void areas in shear plane, therefore causing higher variability. Therefore, it is recommended that, if the shear block test is used for SCL, the size should be predefined in ASTM D 5456 standard more clearly, for instance, a shear area of 38 by 38 mm<sup>2</sup>, for a better comparison of test results. Since SCL products are available in widths smaller than 51 mm, the requirement of a constant shear area of 2600 mm<sup>2</sup> results in an increase of the depth. This, however, might change the state of stress in the specimen and the problems that can be caused will be discussed later.

The very high shear strength of LSL (16.9 MPa in **Table 1**) in joist orientation might be compression parallel to the grain strength rather than shear strength, because LSL in joist orientation hardly ever fails in shear. For LSL, only 8 out of 29 specimens failed in a typical shear mode. The majority, however, failed either in a combined failure mode of shear and compression parallel to the grain (crushing) or in crushing alone. But it was difficult to differentiate these two failure modes in some



cases. Delamination, separation of strands, and crushing of strands at or close to the contact areas marked the samples that failed in modes other than shear only. The specimen in **Figure 4** shows typical signs of compression parallel to grain failure. But, some samples did not show any obvious signs of failure along the intended shear plane. Although the strength value listed in **Table 1** was based on only those eight samples that failed in shear, the value might still be deceptive, because the average shear strength of all specimens, irrespective of failure mode, is very close to the average shear strength of those eight specimens that failed in shear.

The different failure behavior for LSL in the joist orientation can be explained by its design, namely the geometry or size and the alignment of the strands, as well as the high degree of densification. LSL strands are only about 1 mm (0.04 in) thick, roughly a third of the thickness of PSL strands or LVL veneers. It is, therefore, easier to align LSL strands parallel to the tangential direction than for PSL, as shown in **Figure 2 (d, f)**. The higher degree of densification compared to the other two composites further improves the tangential alignment. LSL strands are also shorter and a little wider compared to PSL. Furthermore, LVL and PSL are more or less fully aligned longitudinally, whereas within LSL there is definitely less than 100 percent strand alignment in the longitudinal direction. In addition, the strand alignment might vary through the thickness in LSL. There are many inclined strands that deviate from the longitudinal axis as shown in **Figure 3 (a)** or **Figure 4**. These inclined strands might transfer the compressive load within the sample from the load bearing plate to the base plate past the offset and mainly be stressed in compression parallel to the grain. This, however, leads to a change in the state of stress within the specimens. Therefore, the ASTM shear block test does not seem to be suitable for LSL.

Moses (2000) studied the influence of strand alignment on mechanical properties of LSL and reported the same problem. Shear blocks with the failure plane across the strands (joist orientation) did not fail in shear, but rather in crushing or separation of the strands, with no visible signs of failure along the intended shear plane. Moses concluded that the quantity of oriented strands markedly influenced the material properties.

The veneer-based composite LVL is, compared to the two strand-based composites, a more homogenous material with less interfaces and therefore behaves differently. The shear plane of joist-oriented LVL is smoother and not jagged (**Fig. 2 b, e**). The fracture surface of LVL might be influenced by lathe checks within the individual veneers. Lathe checks also exist within PSL strands, but they might not play the same role as within LVL, since PSL is more compressed. Many lathe checks are, for instance, detectable in the light-colored fourth or seventh veneer layer from the bottom in the sample shown in **Figure 5** and the small kink at the shear plane in the second layer might also be attributed to a lathe check. The crack path follows the lathe check until it stops at an earlywood/latewood interface and continues in the tangential direction toward the pre-defined shear plane and from there on traverses the remaining portion of the veneer layer again in the radial direction. This is just one example that illustrates how lathe checks might affect the shear failure of joist-oriented LVL. It is not possible to make a general comment on plank-oriented LVL, since the variability for this setup is very high and it is not appropriate to speak of a representative sample in this case. The specimen that



Figure 4. — Typical compression failure in joist-oriented LSL block.

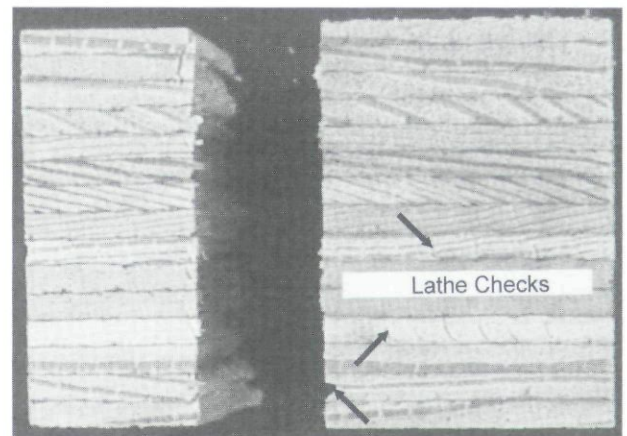


Figure 5. — Lathe checks in failed LVL shear block.

is chosen as an example in **Figure 5** shows mainly cohesive failure of the wood veneer. Though, others showed mainly adhesive failure, or delamination.

Based on all of the previous discussion it is recommended that another shear test method be used as a standard test method for determining shear strength of SCL. Additionally, the ASTM shear block is asymmetric and a bending moment is exerted on the specimen that results in a complex state of stress with superimposed tensile and compressive stresses. A high stress concentration acts at the sharp reentrant corner close to the top of the specimen.

#### Full-sized specimens vs. small shear blocks

Mean shear strength values based on full-sized specimens under torsion ( $\tau_T$ ) are presented in **Table 1**. The details of  $\tau_T$  are given in Gupta and Siller (2004a). In general, the full-sized torsion test resulted in lower shear stresses than did the shear block test. Shear strength based on torsion is 12 to 39 percent less than the shear strength based on shear block. This is opposite of what Riyanto and Gupta (1998) and Gupta et al. (2004a) found for SSL. Lower shear strength values of SCL based on torsion compared to shear block is due to the orthotropic nature of the material as described in Gupta and Siller (2005a, 2005b). Since torsion produces pure shear stresses in the specimens, shear strength based on torsion is the true shear strength of the materials. Therefore, results indicate that shear strength based



Table 2. — Comparison of different full-sized test results.

Study	Setup	Species <sup>a</sup>	Size (mm <sup>2</sup> )	Moisture content (%)	Specific gravity	Shear strength (MPa)	Coefficient of variation (%)	Ratio $\tau_T/\tau_B$
LVL – Joist orientation								
Siller 2002	Torsion	DF	44 by 140	7.6	0.58	7.96	6.3	
Craig/Lam 2000	3-point	DF	44 by 184 (I) <sup>b</sup>	9.3	0.57	6.83	10.0	1.165
Craig/Lam 1996	3-point	DF	44 by 184	10.0	0.57	5.60	7.0	1.421
Bratdmueller et al. 1998	5-point	SP	38 by 58	7.7	0.67	8.14	5.8	0.978
LVL – Plank orientation								
Siller 2002	Torsion	DF	44 by 140	7.6	0.58	4.90	6.3	
Hunt et al 1993	3-point	SP	38 by 58	7.6	0.63	5.72	9.4	0.857
Hunt et al. 1993	5-point	SP	38 by 58	7.6	0.63	4.76	8.1	1.029
PSL – Joist orientation								
Siller 2002	Torsion	DF	44 by 140	8.2	0.67	6.82	7.1	
Craig/Lam 2000	3-point	DF	44 by 184 (I)	10	0.66	5.88	12.4	1.160
Craig/Lam 2000	3-point	SP	44 by 184 (I)	9.4	0.69	6.87	11.3	0.993
Craig/Lam 1996	3-point	DF	44 by 184	9.2	0.64	5.49	7.0	1.242
Craig/Lam 1996	5-point	DF	44 by 184	8.8	0.65	6.75	8.0	1.010
PSL – Plank orientation								
Siller 2002	Torsion	DF	44 by 140	8.2	0.67	4.55	7.1	
Craig/Lam 2000	3-point	DF	44 by 184	9.3	0.63	4.14	13.0	1.099
Craig/Lam 2000	3-point	SP	44 by 184	7.8	0.69	4.73	14.2	0.962

<sup>a</sup> DF is Douglas-fir; SP is southern pine.

<sup>b</sup> (I) is I cross-section.

on shear block may not be representative of the shear strength of the material.

Hunt et al. (1993) also observed lower shear strength values via full-sized bending tests on southern pine LVL compared to shear block tests. Craig and Lam (1996) also observed lower shear strength values for joist-oriented Douglas-fir LVL and PSL based on three-point and five-point bending tests, compared to shear block tests. Craig and Lam (2000) performed a second study on Douglas-fir LVL, as well as Douglas-fir and southern pine PSL, proving the same tendency to be valid for three-point tests conducted on beams with I-shaped cross-sections in joist orientation. However, the same composites with rectangular cross-section had higher shear strength when subjected to five-point bending in the joist orientation compared to shear block shear strength.

A comparison of different full-sized SCL test results of various studies is shown in **Table 2**. Each section of the table has results from this study and similar results from the literature. **Table 2** clearly shows that the torsion test generally results in the highest values for shear strength and the lowest variability. The last column of the table shows the ratio between  $\tau_T$  and  $\tau_B$  from the literature. The ratios indicate that torsion-based shear strength is generally higher than shear strength based on three-point bending. Plank-oriented LVL with a 14 percent lower shear strength in torsion did not follow the general trend. This may be because LVL tested under three-point bending was southern pine and had a higher SG (0.63) than the Douglas-fir LVL (0.58) tested under torsion. Most other specimens tested were Douglas-fir and had similar SG.

The high  $\tau_T/\tau_B$  ratios of 1.421 and 1.242 are for the three-point bending test of joist-oriented LVL and PSL, respectively. This is because the three-point bending test results in low shear failure percentage. Therefore, the evaluated shear strength always marks the lower tail of the shear strength distribution, since not all specimens fail in shear, but rather many in bending. The shear strength based on three-point bending tests are hence even less comparable to torsion-based shear strength, and may not be the representative shear strength of SCL.

A comparison of shear strength obtained under torsion ( $\tau_T$ ) and five-point bending results in the ratio close to 1. However, this comparison may not be valid as two (0.978 and 1.029) of the three comparisons are between Douglas-fir and southern pine beams and the last one (1.010) is between two Douglas-fir beams of different sizes. These ratios indicate how complex the shear phenomenon is and how many factors might influence shear strength. It is, therefore, rather difficult to compare different shear test results. In bending, there are always tensile and compressive parallel to grain stresses superimposed over shear stresses parallel to grain and compression stresses perpendicular to grain. The state of stress is even more complex within small shear blocks where stresses perpendicular to grain further cloud the issue. Therefore, it is not possible to determine the true shear strength using bending or small block tests and each approach has to be considered as an approximation. The lower variation of shear stresses based on torsion compared to bending and shear block tests and the fact that all torsion samples fail in shear, owing to a state of pure shear strength are further arguments in favor of torsion. Low variation means more



reliability, resulting in higher characteristic, or 5th-percentile tolerance, values and finally higher design values. Therefore, torsion test is recommended as a standard test method for determining pure shear strength of SCL, which is also similar to other pure strength properties (bending, tension, compression).

### Conclusions and recommendations

1. Shear strength values of LSL, LVL, and PSL based on ASTM shear block test in joist orientation were consistently higher than in plank orientation.
2. Shear strength based on torsion is 12 to 39 percent lower than the shear strength based on shear block.
3. Failure in joist-oriented shear block produces a rough surface because the failure is across veneer or strands, possibly resulting in higher shear strength compared to plank orientation.
4. Lathe checks resulting from rotary peeling and internal checks possibly decrease the shear resistance of LVL and PSL.
5. LSL in joist orientation hardly ever fails in shear when using the shear block test. The main failure mode is compression parallel, resulting in unusually high shear strength. Therefore, shear block test specimen is not suitable for LSL.
6. It is recommended that if shear block is used for determining shear strength of SCL, shear area of 38 by 38 mm<sup>2</sup> should be specified because different size specimens have different amounts of void spaces resulting in different states of stress in different size specimens and in increased variability in results.
7. Since shear strength based on torsion is lower than shear strength based on shear block and torsion provides a state of pure shear stress, torsion test is recommended as a standard test method for determining pure shear strength of SCL, which is similar to other pure strength properties (bending, tension, compression).

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