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Evaluation of Dowel Bearing Strength of Structural Composite Lumber(SCL) on the Effect of Moisture Content*[1]

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ABSTRACT

This study investigated the effect of moisture content and loading direction on dowel bearing strength of two types of SCL. Dowel bearing tests of LVL and PSL were conducted with two different MC level, 7.5% and 19%, and two different oriention, L-direction(loading parallel to grain) and X-direction(loading perpendicular to grain). Most of specimens showed typical load-deformation curves and intersected 5% offset line. Failure modes were classified into two categories; spliting(for L-direction specimens) and peeling(for X-direction specimens). Dowel bearing strength generally decreased with increasing MC. The decreasing rate was more significant in X-directon. ESG also decreased with increasing MC, and the ratio of ESG of 7.5% versus 19% was about 1.47. Dowel bearing strength of LVL and PSL in L-direction was higher than that of X-direction. This results indicated that MC and loading orientation had a significant effect on dowel bearing strength of SCL. The average dowel bearing strength of LVL were higher than that of PSL in each loading direction.

Two types of probability distribution model were chosen to quantify strength distribution, normal and 2-parameter weibull distribution. The two models showed good agreement with the data, especially in lower tail of the cumulative distribution. Normal and 2-parameter weibull distribution seemed to proper model of the dowel bearing strength for each MC levels.

Keywords: LVL, PSL, ESG, dowel bearing strength, normal distribution, 2-parameter weibull distribution

1. INTRODUCTION

Structural composite lumber(SCL) defines a family of engineered wood products that combine veneer sheets or strands with exterior structural wood adhesives(Smulski, 1997). SCL, lumber-like product, has been gaining success in wood construction and intended for use structural framing materials for the same structural application as the dimension lumber and timber for which they substitute, especially heavy load is applied. As SCL products are widely used in wood construction industry, SCL products require an evalution of the mechanical and physical properties and their response to changing environments. Also they require the

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establishment of and conformance to standard performance specification for quality of products(ASTM, 1999).

The performance of wood structure or assembly is critically dependent on the behavior of joint connections. In general, SCL products are used in construction with a variety of connections. These connections are mainly loaded to laterally and load is transmitted through the connection to the member. The performance of connection is based on several parameters such as fastener diameter, fastener bending yield strength, main and side member thickness, main and side member bearing strength, etc.

Among these parameters, dowel bearing test is used to determine the static load resistance and deformation characteristics of connections in wood and wood composites for a single fastener subjected to lateral shear load(ASTM, 1997).

In the North America, structural connection utilizing wood under lateral loading are currently designed by the yield theory(NDS, 1997). Laterally-loaded connections in wood structures are designed based on a series of "yield limit equations" when fasteners are used to transmit loads in shear. This "yield model" of connection behavior describes connection yield as an interaction between plastic hinge formation in the fastener and deformation/ crushing of wood fibers in bearing against the fastener.

For lateral load capacity of fasteners, dowel bearing strength shall be conducted in accordance with test standard. Test standard for dowel bearing strength is relatively new, and limited amount of information is available in the effect of moisture content and fastened orientation on bearing capacity of SCL. Specifically, the purpose of study was to provide experimental data on the effect of moisture content on dowel bearing strength of SCL and compare other data and design values for acceptance criteria.

Table 1. Experimental design parameters and variables.

Design parameter	Variables
Mositure content(EMC)	7.5%, 19%
Fastened orientation directions[1]	L(parallel), X(perpendicular)
Materials	LVL, PSL
Number of sample size	20

1) refer to Figure 1.

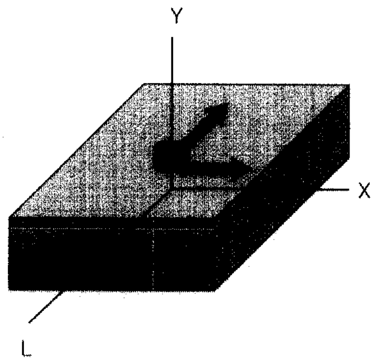


Fig. 1. Fastened orientation directions. L; logitudinal direction of samples, dowel installed in Y-direction, load applied in L direction(parallel to face grain) and X-direction(perpendicular to face grain).

2. MATERIALS and METHODS

2.1. Experimental Design

Experimental design focused on evaluating the test results that include following variables; two moisture content levels, two fastened orientation directions and two different type of materials. Experimental design parameters and variables were shown in Table 1.

2.2. Materials

The dowel bearing tests were performed on

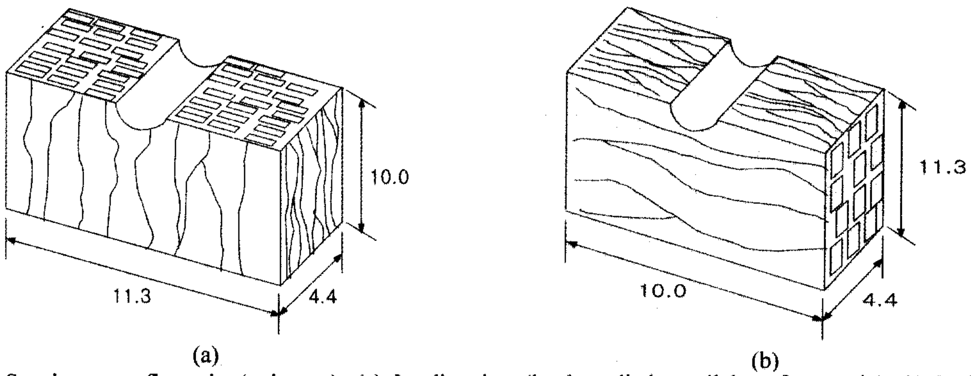


Fig. 2. Specimen configuration(unit: cm). (a) L- direction (load applied parallel to face grain) (b) X-direction (load applied perpendicular to face grain).

laminated veneer lumber(LVL) and parallel strand lumber(PSL). The nominal size of tested materials were 45 mm in thickness, 120 mm in width and 1800 mm in length. The intial mositure content of LVL and PSL were 9.5% and 10.3%, respectively.

Specimens were prepared and cut to two samples from raw materials, 750 mm in length. The specimens were end-matched section to test different moisture levels from same materials. Each samples were placed into conditioning chamber to achieve target moisture content, 7.5% and 19%. The chamber condition was 35℃, 40% RH(7.5%) and 27℃, 90% RH(19%).

After reaching the specified moisture content, 12.7 mm diameter holes were drilled perpendicular to the plane and through the specimens, and cut to the half hole test samples like shown in Figure 2. Matched parallel-and perpendicular-to-face grain specimens were derived from adjacent material. The final dimension were as follows; For load applied parallel to face grain samples, width and thickness were 113 mm and 44 mm respectively, and depth was 100 mm. For load applied perpendicular to face grain samples, width and thickness were 100 mm and 44 mm respectively, and depth was 113 mm. Then prepared specimens were returned to the conditioning chamber until testing. Just before testing, all specimens were sealed in plastic bags to keep specified the moisture content.

2.3. Test Procedure

The dowel bearing test was conducted on prepared specimens according to ASTM D 5764. 12.7 mm diameter rod and steel plate were used to apply load through the testing machine. Load was applied to each fastened orientation and the rate of testing was a constant 1 mm/min. Load/deformation were measured automatically and load-deformation curves were obtained. The test orientation were L- and X-direction shown in Figure 1. Figure 3 shows a L-direction testing(parallel to face grain) under load.

For each orientation, 5% diameter offset value was obtained from the load-deformation curves and used to attain values of dowel bearing strength.

2.4. 5% offset Value to Determine Yield Load

The 5% diameter offset value is either the peak load or the intersection of a parallel line offset 5% of dowel diameter from the load-deformation curves. To obtain yield load, de-

Fig. 3. Dowel bearing test configuration(L-direction).

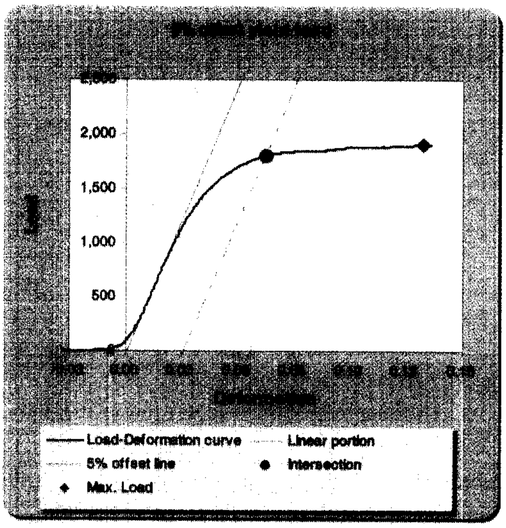
veloped program was used. This program uses linear regression analysis among appropriate portion of maximum load(for example, between 20% and 40%, etc). Then the 5% offset lines were plotted on the curves parallel to linear portion of load-deflection curves. Dowel bearing strength is then determined by dividing the 5% offset value by the dowel diameter and specimen thickness. If the offset line does not intersect the load-deflection curve, the maximum load was used as yield load (ASTM D 5764, 1997).

3. RESULTS and DISCUSSION

3.1. Load-deformation Curves and Failure Mode

Load-deformation curves were obtained for each test. Typical load-deformation curves were plotted from the test results and 5% offest values were plotted on this curve like shown in Figure 4. Most of specimens showed typical curves and intersected 5% offset line. Some of load parallel-to-grain specimens didn't intersect 5% offset lines because the load-deformation curves were almost linear up to failure, so maximum load was used to determine the yield load.

Two different failure modes were observed



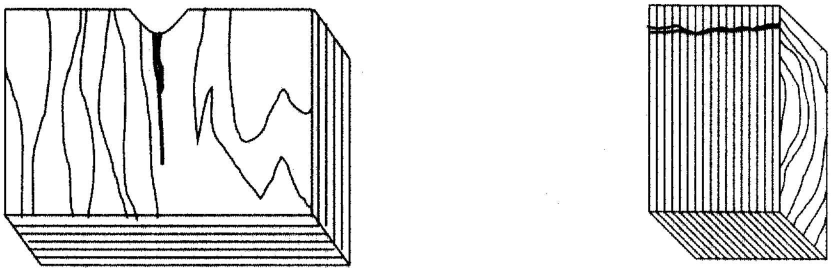
(unit; load-lb, deformation-inch)

Fig. 4. Typical load-deformation curve and determination of yield load.

for the test(Fig. 5). For L-direction loading specimens, typical failure mode was spliting both sides of specimens. Failure was initiated under the dowel and propagated along the longitudinal direction of specimens. Spliting failure was predominant in PSL specimens and mixed with bearing failure was observed some of LVL specimens. This spliting failure mode was rapidly occured as the increasing moisture content of specimens. For X-direction specimens, failure mode was peeling upper side of specimens near the dowel. Localized crushing was observed under dowel in early stage of testing, and then peeling failure was occured. This failure mode was observed all of X-direction loading specimens.

3.2. Effect of Moisture Content and Oriention on Dowel Bearing Strength

The results of test were summarized in Table 2. Figure 6 showed the MC versus DBS data



spliting
(a)

peeling
(b)

Fig. 5. Failure mode of SCL in dowel bearing test. (a) loading parallel-to-grain (b) loading perpendicular-to- grain.

Table 2. Average dowel bearing strength(DBS) and dowel bearing equivalence(ESG) at each moisture content levels.

Materials	LVL			PSL		
-MC 7.5%						
Loading direction	L		X	L		X
DBS(kg/cm^2)	501.4(9.3)		331.8(8.3)	425.9(6.9)		296.7(9.3)
% difference(L/X)		51			44	
ESG	0.64		0.66	0.54		0.61
Avg. ESG		0.65			0.58	
ESG specified[a]		0.65			0.57	
-MC 19.0%						
DBS(kg/cm^2)	341.9(10.1)		192.6(7.8)	298.0(8.1)		166.9(9.2)
% difference(L/X)		56			56	
ESG	0.43		0.45	0.38		0.41
Avg. ESG		0.44			0.39	
ESG specified[a]		0.44			0.39	

( ); coefficient of variation(COV) of dowel bearing strength, a; For each materials, ESG is within 0.03 of average, then the average ESG is specified

for LVL and PSL. Solid line connect the average value on L-direction and dotted line connect the average value on X-direction. Dowel bearing strength generally decreased with increasing MC. The decreasing rate was about 45% for L-direction and more than 70% for X-directon. From the test results, the effect of MC seemed to be higher in X-direction. Figure 7 showed the comparison of data for each direction of LVL and PSL. Dowel bearing strength of SCL was also affected by fastener orientation. Dowel bearing strength of L-direction was higher than that of X-direction. The ratios of L-direction to X-direction were 1.51 and 1.44 for LVL and PSL at 7.5% MC, 1.46 and 1.47 at 19% MC, respectively. This results indicated that grain orientation had a significant effect on dowel bearing strength. The same tendency are found in nail bearing strength for wood(Rammer, 2001).

The average bearing strength of LVL was higher than that of PSL in each direction. For the direction, the average dowel bearing strength ratios of LVL to PSL were 1.17 in

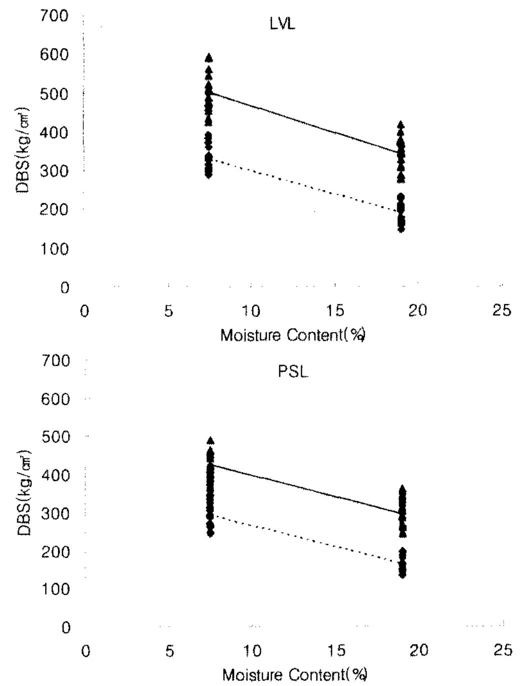


Fig. 6. dowel bearing strength and moisture content. ▲: L-direction data, ◆: X-direction data, ——: connect the average value on L-direction, ········: connect the average value on X-direction.

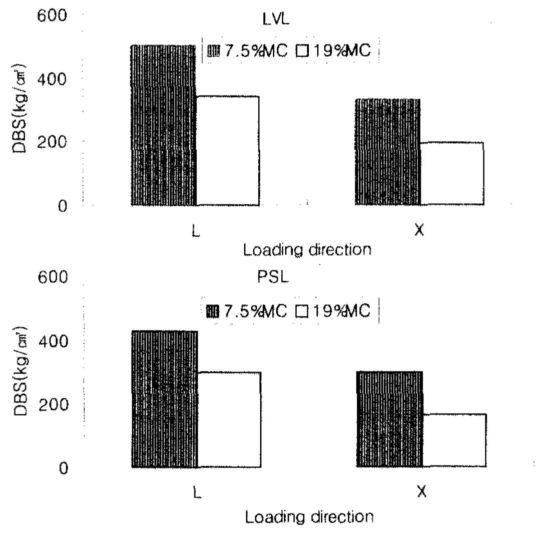


Fig. 7. Comparison of dowel bearing strength in L- and X-direction.

L-direction, and 1.11 in X-direction at 7.5% MC, 1.14 and 1.15 at 19% MC, respectively. This might be attributed to element size of materials, veneer and strand.

3.3. Equivalent Specific Gravity of Dowel Bearing Strength

The equivalent specific gravity(ESG) of SCL is determined using average of test values for a given orientation provided that they do not differ from the average of test results by more than 0.03. If the derived ESG value differs by more than 0.03, the ESG is the lowest value plus 0.03(ASTM D5456, 1999). The formula in the foot note of Table 8A of NDS-97 was adopted to get accurate ESG for each direction:

$ESG = DBS/11200$ for loading parallel to grain.

$ESG = [(DBS \times D^{1/2})/6100]^{0.6897}$ for loading perpendicular to grain.

where: DBS = Dowel bearing strength, (psi)

D = Dowel diameter (inches)

The procedure and results also summarized in Table 2. For each orientation in LVL, ESG was within 0.03 of average, then the average ESG is specified at each moisture content levels. However, ESG of PSL at 7.5% MC differed from the average by more than 0.03, then ESG is lowest value plus 0.03, thus it became 0.57. ESG of LVL was higher than that of PSL, by more than 12% regardless of loading direction. ESG also decreased with increasing MC, and ESG of 7.5% versus 19% was 1.47 for LVL and 1.46 for PSL. The ESG of LVL was higher than that of PSL in each MC levels. These values were compared to 0.5 in LVL and PSL(Johnson and Woeste, 2000), and others were shown in Fig. 8. ESG 0.5 is the same to Douglas-fir-Larch. In high MC condition(19%),

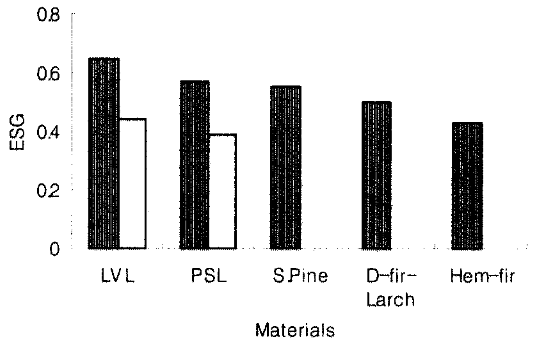


Fig. 8. ESG of LVL and PSL to conventional lumber. The bar contain solid line in LVL and PSL is ESG of 7.5% MC and vacant bar is ESG of 19% MC condition. Others are in oven-dried specific gravity.

the ESG of LVL was about the same to Hem-fir(0.43). Also, the ESG of PSL was the same to Aspen(0.39) or Coast sitka spruce (0.39). This seemed that ESG of SCL is critically affected by MC change and needed carefullness under high MC condition.

3.4. Parametric Distribution Models of Dowel Bearing Strength

Data on each of the intervening variables should be provided in the form of statistical information. Moreover, the probability distribution is needed in design methodology for load and resistance factor design or reliability calculation to quantify strength distribution. In this study, normal and 2-parameter weibull distributions were chosen, these models are typically applied to classify mechanical properties of wood and wood based materials.

Normal distribution is described by density function, f(x):

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

Where σ is standard deviation, μ is mean.

2-parameter weibull distribution should be the most appropriate model for modeling strength of wood(Barrett and Lau, 1994), and is described by density function, f(x):

$$f(x) = \frac{k}{m^k} x^{k-1} \exp\left(-\frac{x}{m}\right)^k$$

Where m is scale parameter, k is shape parameter

Also, probability density function(PDF), $F(x)$ for 2-parameter weibull distribution is derived from density function and which is :

$$F(x) = 1.0 - \exp\left(-\frac{x}{m}\right)^k$$

Percentile values of 2-parameter weibull fitting are 5th, 50th percentile, which they represent standard strength values. When $F(x)$ is 0.05, and 0.5, the strength of SCL, x, is calculated from the above PDF equation.

The distribution parameters to normal and 2-parameter weibull distribution are shown in Table 3 and 4. The weibull curves obtained are shown with the data in Figure 9. In two types of probability distribution model, the 2-parameter weibull distribution model showed good agreement with the data, especially in lower tail of the cumulative distribution. Some differences occured above lower tail in LVL at 7.5% MC. In high MC condition, the models were fitted to lower and higher tails of the cumulative distribution curves for LVL and PSL. In the middle portion of two model curves, the data showed a little differences. Based on the analysis results, normal and 2-parameter weibull distribution seemed to proper model to the bearing strength for each

Table 3. Dowel bearing strength probability distribution parameters and percentile in normal and 2-parameter weibull distributions at 7.5% MC.

Materials	LVL		PSL	
Loading direction	L	X	L	X
Normal				
mean	501.4	331.8	425.9	296.7
standard deviation	46.5	27.7	29.5	27.5
2-p weibull				
scale parameter	521.52	343.03	438.82	308.34
shape parameter	13.13	14.62	17.79	12.82
5th percentile	415.95	279.97	371.35	244.59
50th percentile	507.16	334.55	429.87	299.65

Table 4. Dowel bearing strength probability distribution parameters and percentile in normal and 2-parameter weibull distributions at 19% MC.

Materials	LVL		PSL	
Loading direction	L	X	L	X
Normal				
mean	341.9	192.6	298.0	166.9
standard deviation	33.6	24.7	36.7	18.1
2-p weibull				
scale parameter	356.3	203.1	313.6	175.0
shape parameter	12.4	9.3	9.7	11.1
5th percentile	280.2	147.6	231.0	133.8
50th percentile	345.9	195.3	302.0	169.0

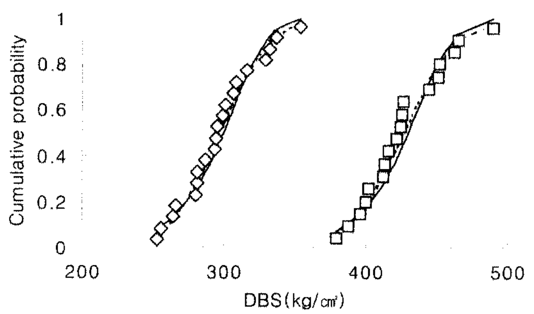


Fig. 9. Typical cumulative probability plot (PSL at 7.5% MC), ----: 2-p weibull distribution fit ·········: Normal distribution fit, □: L-direction data ◇: X-direction data.

MC levels.

4. CONCLUSION

Experimental tests were performed to determine the effect of moisture content and fastener orientation on dowel bearing strength of two types of SCL, LVL and PSL. Based on the test results, the following conclusions were drawn.

- Most of specimens showed typical curves and intersected 5% offset line. Two different failure modes were observed for the test. Typical failure mode was spliting for load parallel-to-grain loading specimens(L-direction). For load perpendicular-to-grain loading specimens (X-direction), failure mode was peeling upper side of specimens near the dowel.

- Dowel bearing strength generally decreased with increasing MC. The decreasing rate was about 45% for L-directon and more than 70% for X-directon. ESG also decreased with increasing MC, and ESG of 7.5% versus 19% was 1.47 for LVL and 1.46 for PSL.

- Dowel bearing strength of L-direction was higher than that of X-direction. This results indicated that MC and loading orientation had a significant effect on dowel bearing strength of SCL.

- The average dowel bearing strength of LVL were higher than that of PSL in each loading direction.

- The probability distribution is needed to quantify strength distribution. The normal and 2-parameter weibull distribution models showed good agreement with the data, especially in lower tail of the cumulative distribution. In high MC condition, the models were generally fitted to lower and higher tails of the cumulative distribution curves. In the middle portion of 2 model curves, the data showed a little differences. Based on the results, normal and 2-parameter weibull distribution seemed to proper model the dowel bearing strength for each MC levels.

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