Effect of Ring Angle on Shear Strength Parallel to the Grain of Wood

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Abstract
To determine the effect of ring angle on shear strength parallel to the grain of wood, 125 block shear tests were conducted. The angle between ring orientation (tangent of the ring) and shear plane ranged from 0 to 90 degrees in increments of 10 degrees. The tests were conducted in accordance with ASTM standard D 143 using Douglas-fir. Statistical analysis at the 5 percent probability level showed that there were no significant differences between shear strengths at various ring angles. Linear regression analysis showed a poor relationship between ring angle and shear strength. The other factors such as specific gravity and percent latewood showed better relationships with shear strength of wood.

American Society for Testing and Material (ASTM) standard D 143 (1) described the test procedure for shear strength based on small, clear specimens. The standard recommends that the specimens have to be made in two different orientations: radial (the shear plane along the radial surface) and tangential (the shear plane along the tangential surface) (Fig. 1). The requirement on the shear test specimen implies that the orientation of growth rings on the shear plane must be considered in determining the shear strength of wood. The effect of ring angle on mechanical properties, especially on shear strength, has not been reported in the literature, except for tangential, radial, and 45-degree orientation. The only unpublished data on Dahurian larch (Larix dahurica) showed that there may not be any relationship between ring orientation and shear strength (Fig. 2).

The objective of this study was to examine the effect of ring angle on shear strength of wood based on small, clear specimens. The secondary objective was to determine the effect of other variables such as specific gravity, percent latewood, and the number of growth rings per inch on the shear strength of wood.

Some factors that might affect the shear strength, particularly for small clear specimens, have been examined by Okkonen and River (9). Among other factors, they investigated effects of growth ring orientation (only radial and tangential shear planes) on the apparent shear strength of Douglas-fir, southern pine, white oak, and hard maple. They reported that ring orientation was a strong but inconsistent factor affecting shear strength parallel to the grain. Tangential shear plane produced significantly higher shear strength than did radial shear plane for maple and oak. Conversely, in Douglas-fir and southern pine, radial shear plane produced significantly higher shear strength than did tangential shear plane.

Bendtsen and Porter (6) determined radial and tangential shear strengths and shear strength at a 45-degree orientation to the annual ring. They found that the average radial shear strength was greater than the average tangential shear strength, and the average of the radial and tangential shear strength was only 2 to 3 percent greater than the shear strength at a 45-degree ring orientation. They attributed this slight difference to a slightly lower specific gravity for the 45-degree specimens.

The Wood Handbook (15) describes the value of shear strength parallel to the grain as the average of equal numbers of specimens with 0- and 90-degree growth ring orientations. It also mentions that for some species, there is no difference in 0- and 90-degree orientation; other species exhibit slightly different shear strengths.

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along those two orientations. The effect of ring angle on mechanical properties at intermediate growth ring orientations has been studied in a limited way (15). In some species, the 45-degree orientation has lower values for some properties. For those species with lower properties at a 45-degree orientation, properties tend to be about equal at 0- and 90-degree orientations. For species with about equal properties at 0- and 45-degree orientations, properties tend to be higher at a 90-degree orientation (15).

There is very little literature on the effect of ring angle on the mechanical properties of wood. Edhington et al. (7) observed the effect of ring angle on compressive strength perpendicular to grain for Dahurian larch (Larix dahurica). The ring angle was defined as the angle between the direction of load and the direction of growth rings. They found an indication that compressive strength perpendicular to the grain depends on the orientation of the growth ring. The property is highest with the load at a 90-degree angle to the growth rings (radial stress), lowest with the load at some intermediate angle of roughly 30 to 50 degrees, and intermediate at 0 degrees (tangential stress).

**Material and Testing Procedure**

**Material and Specimen Preparation**

Specimens for this study were cut from Douglas-fir beams measuring 5 by 7 inches in cross section and 8 feet in length. The beams were obtained from the Frank Lumber Company sawmill at Mill City, Oreg. All beams came from the same log, and from the outer side of the log. All beams were mostly heartwood with some sapwood at one of the four corners of the beams.

The initial moisture content (MC) of the beams was about 25 percent. All beams were placed in a conditioning room with constant temperature at 68°F and relative humidity of 70 percent (about 15% MC) for 2 weeks. The beams were cut to remove all the defects, such as knots, checks, slope of grain, etc. The clear parts of the beams were cut along the longitudinal axis into several blocks measuring 5 by 7 by 3 inches. A total of 125 blocks were obtained. All blocks were again stored in the conditioning room and monitored until they reached about 15 percent MC.
A method similar to one reported by Olson (10) was used in determining the angle of growth ring to the shear plane. Figure 3 shows the orientation of shear block specimens with respect to ring angle orientation within a block of wood. The final size (all dimensions) and shape of the block shear specimen complies with ASTM standard D 143 (1) for determining shear strength of wood. The samples in this study were randomly allocated to 10 different groups; each group contained 8 to 17 specimens. These groups were 0 (tangential shear plane), 10, 20, 30, 40, 50, 60, 70, 80, and 90 (radial shear plane) degrees ring angle orientation.

**EQUIPMENT AND TESTING PROCEDURE**

All specimens were tested using a shear test jig recommended by ASTM standard D 143 (1). The jig was loaded in a Tinius-Olsen machine with a capacity of 60 kips.

The ultimate load was recorded to determine the shear strength parallel to the grain by dividing the ultimate load (lb.) by the actual shear plane area (in.²). This is the shear strength parallel to the grain at the MC at the time of the test. This shear strength was adjusted to shear strength parallel to the grain at 15 percent MC using the procedure given in ASTM standard D 1990 (2), which is then the shear strength parallel to the grain reported in the rest of the report.

A part of the specimen was used to determine MC and specific gravity (SG); MC was determined in accordance with ASTM standard D 4442 (4), method B, and SG was determined using ASTM standard D 2395 (3), method B (ovendry basis).

Percent latewood was measured quantitatively by measuring the actual width of the ring angle and the width of the latewood within each ring. Percent latewood was the average of the three measurements of three different growth rings in the shear plane. The number of rings per inch was counted in each specimen. The failure mode of each specimen was sketched after the test was completed.

**RESULTS AND DISCUSSION**

The average shear strength for the specimens in each ring angle orientation group is shown in Table 1, along with actual MC of the specimen at the time of test, average SG, number of rings per inch, and percent latewood. The average shear strength in Table 1 is adjusted shear strength at 15 percent MC.

Statistical analyses were employed to analyze the data. The first analysis was focused on the distribution of the shear strength at each ring angle. The Maximum Normal Residual (MNR) method (13) was used to determine any extreme observation value within each ring angle. The results showed that one observation at the 40-degree ring angle had an MNR equal to 0.695. Significance levels of the MNR for a normal sample from Table A16 (i) in Snedecor and Cochran (13) for a sample size equal to 17 were 0.655 (for a 5% significance level) and 0.724 (for a 1% significance level). This means that at the 1 percent significance level the observation is not considered an outlier; therefore, the observation was included in all statistical analyses.

**Table 1.** The average shear strength of wood at 10 different ring angles.

<table>
<thead>
<tr>
<th>Group</th>
<th>Ring angle (degrees)</th>
<th>No. of specimens</th>
<th>MC (%)</th>
<th>Average shear strength (psi)</th>
<th>COV (%)</th>
<th>SG (%)</th>
<th>COV (%)</th>
<th>Rings per inch</th>
<th>COV (%)</th>
<th>Percent latewood</th>
<th>COV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>10</td>
<td>17.0</td>
<td>1.173</td>
<td>16</td>
<td>0.59</td>
<td>3</td>
<td>10</td>
<td>24</td>
<td>33</td>
<td>22</td>
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<td>2</td>
<td>10</td>
<td>11</td>
<td>17.3</td>
<td>1.278</td>
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<td>0.59</td>
<td>7</td>
<td>10</td>
<td>33</td>
<td>35</td>
<td>33</td>
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<td>3</td>
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<td>14</td>
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<td>1.255</td>
<td>12</td>
<td>0.58</td>
<td>9</td>
<td>9</td>
<td>34</td>
<td>36</td>
<td>38</td>
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<td>4</td>
<td>30</td>
<td>17</td>
<td>17.8</td>
<td>1.240</td>
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<td>43</td>
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<tr>
<td>9</td>
<td>80</td>
<td>10</td>
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<td>1.238</td>
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<td>0.57</td>
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<td>9</td>
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<td>36</td>
</tr>
</tbody>
</table>

*MC = moisture content (ovendry); SG = specific gravity (ovendry); COV = coefficient of variation.*

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**Figure 3.** — End grain of a rough block of wood showing the orientation of a block shear specimen.
Okkonen and River (9) found similar results. One of the factors that caused different shear strengths between the radial shear plane and the tangential shear plane was the anatomical features of the wood. The cell wall of latewood is thicker than that of earlywood (11); a cross section of Douglas-fir wood shows that latewood cells are rectangular, with the long sides parallel to the growth ring or tangential direction and the short sides parallel to the radial direction. So, if the wood is failed on shear parallel to the grain or slipped along the longitudinal axes at tangential face, the failure will probably cut the cell longitudinally through the wider cell cavity. If it happens along the radial face, the failure will cut the cell longitudinally through the narrower cell cavity and therefore the failure will cut more of the cell walls. This probably explains why shear strength at the radial face is stronger than that at the tangential face.

A simple linear regression analysis between shear strength and ring angle indicated a low correlation ($r^2 = 0.002$) (Fig. 5). Even without the 40-degree angle data, the linear relationship was very low ($r^2 = 0.002$). The regression line appears to be horizontal, with the intersection on the Y axis (shear strength) equal to 1,235 psi. The shear strength was not affected by ring angle, and the value of the intersection represented the average shear strength of all samples regardless of ring angle (Fig. 5).

ASTM standard D 143 (1) required that small, clear specimens for shear strength parallel to the grain be made at a 0-degree ring orientation (tangential shear plane) and at a 90-degree ring orientation (radial shear plane). This study found, however, that those two orientations produce lower shear strength than that at other angles. On the basis of this study, we suggest that the specimens for shear strength will be more representative if the orientation of the ring angle is randomly chosen between 0 and 90 degrees. The latest edition of ASTM D 143 (5) has removed the restriction of having 0- and 90-degree ring orientation on small, clear specimens for determining shear strength parallel to the grain of wood.

Relationships between shear strength parallel to the grain and other factors (SG, rings per inch, and percent latewood) were also analyzed with a simple...

Figure 4.— Typical shear failures at each ring angle.

Analysis of variance was performed to determine differences in the mean of shear strength parallel to the grain between ring angles. The results of one-way classification analysis (12) indicated that statistically there was no difference between the means of shear strengths parallel to the grain at different ring angles ($p$-value = 0.69).

Based on the observations during the test, at any ring orientation, the failure plane always crossed some growth rings. This means that the shear plane, regardless of ring angle orientation, always crosses more or less the same amount of latewood, which gives a strong contribution to the strength properties of the wood. Several types of failure modes for different ring angles are shown in Figure 4. Although failure modes from the end grain appear to differ, they had the same failure mode on the shear plane; in each case almost the same amount of latewood was sheared across the ring.

Although there were no statistically significant differences between the shear strengths parallel to the grain at different ring orientations, Table 1 shows that the average shear strength at radial shear plane (90 degrees) was 5 percent greater than that of tangential shear plane (0 degrees). Bendtsen and Porter (6) and...
linear regression. SG has a positive relationship with shear strength parallel to the grain ($r^2 = 0.46$), which indicates that a higher SG of wood produces higher shear strength parallel to the grain. The regression line is shown in Figure 6. The same result was shown by the relationship between shear strength parallel to the grain and percent latewood in Figure 7 ($r^2 = 0.46$). The number of growth rings per inch in the specimen had a lower negative relationship with shear strength, which indicates that the more rings per inch, the weaker the shear strength parallel to the grain of wood (Fig. 8). These relationships show that latewood and SG play an important role in the shear strength of wood.

Tsoumis (14) has described wood density or SG as the best and simplest index of the strength of wood without defects. As density increases, strength also increases because density is a measure of the wood substance contained in a given volume. Greater density derives from a greater proportion of cells with thick walls and small cavities; this is why denser, defect-free wood has greater strength. In most cases, the relationship between density and strength is linear (8 in (14)).

**Conclusions**

The following conclusions are based on the results of this study:

1. There were no significant differences between shear strength parallel to the grain of wood at various ring angles.

2. Quantitatively, the average of shear strength parallel to the grain at radial shear plane (90-degree angle) was 5 percent greater than that at tangential shear plane (0-degree angle).

3. Specific gravity and percent latewood have a good positive relationship with shear strength parallel to the grain ($r^2 = 0.46$ for both).

4. The number of rings per inch has a low negative relationship with shear strength parallel to the grain ($r^2 = 0.21$).

**Literature Cited**


Figure 7. — Regression line of shear strength on percent latewood for Douglas-fir.

Figure 8. — Regression line of shear strength on number of rings per inch for Douglas-fir.