METHOD FOR EVALUATING SHEAR PROPERTIES OF WOOD
Abstract

A test procedure is described for determining the shear properties of wood where the shear stress is in radial or tangential planes. If the shear force is across the grain, it is often termed "rolling" because of the tendency for the shearing forces to roll the wood fibers. The specimen is not difficult to fabricate, and the test gives a state of almost pure shear. Values for rolling shear properties for the pieces tested were 10 to 20 percent of the values for the same properties from tests with a longitudinal shear force in the longitudinal-tangential plane. Components of variance associated with the tests of closely matched specimens are given.

Rolling shear properties are particularly important for selected plywood applications, such as for box beams or for gusset plates. Successful design requires a better understanding and appreciation of the nature of rolling shear.
METHOD FOR EVALUATING SWEAR PROPERTIES OF WOOD

By

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Introduction

Plywood offers almost unlimited engineering applications and can be used for esthetic purposes in the design of houses, churches, schools, auditoriums, and many other types of structures or structural components. An evaluation of the mechanical behavior of plywood by empirical testing would require thousands of tests because of the many variables in plywood, such as number of plies, thickness of plies, grain direction, ring curvature, material, and grade. Therefore to evaluate plywood it is necessary to apply, in mathematically developed formulas, data obtained on mechanical properties of solid wood and to check the basic assumptions in the formulas by supplementary tests on plywood (6)2

The designer has research data available on the mechanical properties of wood. He needs more information, however, on shear strength of wood and on its elastic properties where the shearing force is in a longitudinal–transverse plane and perpendicular to the grain—rolling shear (in rotary-cut plywood, shearing in the tangential plane and perpendicular to the grain).

A standardized method for evaluating the rolling shear properties of wood and of plywood is needed. A wide variety of equipment and procedures has been described for making shear tests, such as the cube shear, block shear, stepped

1 Maintained at Madison, Wis., in cooperation with the University of Wisconsin.
2 Underlined numbers in parentheses refer to Literature Cited at the end of this Note.
Figure 1.—Relation of shear stress to position along centerline of width of 1/2-inch wide specimen. Inset shows how parallel and closely spaced cross-sectional planes were sheared in opposite directions. (Adapted from Coker (2).)
shear, two-plate tension shear, and two-plate compression shear. It is possible that some of these methods could be applied for measuring rolling shear. In work at the University of Wisconsin, M. J. Rhude prepared a compendium of the shear tests used prior to 1950; more recently some tests developed specifically for measuring rolling shear have been described (7, 9). Many types of test specimens are used; they vary in sizes and shapes with shear areas from 1 to 50 square inches or more.

Coker (2, 3) studied shear stress distributions photoelastically. He used a thin plate suitably clamped; thus parallel and closely spaced cross-sectional planes were sheared in opposite directions (fig. 1, Inset). He found that shear stress along the centerline of the unclamped portion of the plate rises from zero at the end of the specimen to a maximum stress that occurs very close to the end. The stress then decreases slightly to the middle of the specimen (fig. 1). Furthermore, as the ratio of depth to thickness is decreased, the stress maximums become greater, until finally, at a ratio of about one, the maximums merge to give a parabolic distribution. It can be deduced from the figure that the stress distribution is almost uniform if the ratio of specimen depth to thickness is about 10 or greater.

The boundary conditions imposed by Coker can be supplied by bonding a prismatic specimen between much stronger and stiffer loading plates. This two-plate shear method is used for evaluating the shear strength and the modulus of rigidity of core materials and sandwich constructions (1). The method was used by the Forest Products Laboratory to evaluate the rolling shear properties of plywood (5). Palka (8) used a similar test to evaluate entire cross sections of plywood. The two-plate compression shear test appears to have potential as a method for evaluating rolling shear properties of wood.

This study presents the results of exploratory research designed to:

1) Evaluate and compare the basic shear strength and modulus of rigidity of average-growth Sitka spruce when the shearing force $(f_s)$ is
   a) In the tangential plane of the wood and parallel to the grain, LT $f_{LT}$ (shear stress, $G_{LT}$ = modulus of rigidity);
   b) In the tangential plane of the wood and perpendicular to the grain, TL $f_{TL}$ (rolling shear) (shear stress, $G_{TR}$ = modulus of rigidity);
   c) In the radial plane of the wood and perpendicular to the grain, RL $f_{RL}$ (rolling shear) (shear stress, $G_{RT}$ = modulus of rigidity).

Throughout this report, where double subscripts are used, the first subscript indicates the direction of load.
Figure 2.--Sectional cut (1 by 3 by 7 inch) of Sitka spruce plank used for the test specimens showing ring curvature, and orientation.

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Figure 3.--Cutting plan for 3- by 7-inch by 12-foot Sitka spruce plank: A, Plank cut into six 3- by 7-inch by 2-foot sections; B, Orientation of twenty-seven 1/2- by 2- by 6-inch shear specimens and two specific gravity (SG) specimens cut from each section: a, Shearing force in tangential plane of wood and parallel to grain (LT). b, Shearing force in tangential plane of wood and perpendicular to grain (TL, rolling shear). c, Shearing force in radial plane of wood and perpendicular to grain (RL, rolling shear). Each specimen consisted of three 1/2- by 2- by 2-inch blocks butt-jointed together.

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2) Estimate components of variance associated with tests of closely matched specimens.

3) Gain some experience with the two-plate compression shear test for determining rolling shear properties.

Sitka spruce was selected for this study because it was readily available in the quality desired. All shear specimens were cut from one Sitka spruce timber. The results are not intended to describe how these properties are distributed for this species, but should give an indication of the proper order of magnitude for these properties for good quality Sitka spruce.

**Specimen Preparation**

The specimens were cut from a clear flat-sawed 3- by 7-inch by 12-foot Sitka spruce plank kiln-dried to a moisture content of approximately 12 percent. The wood was straight grained and uniform throughout the plank, had an average specific gravity of 0.36, and had an average growth rate of 8 rings per inch. The ring curvature and orientation are illustrated in a sectional cut of the plank in figure 2.

The plank was cut into six 24-inch-long sections, and the three specimen orientations were systematically assigned, each to one-third of a section (fig. 3). Each section yielded two 1- by 3- by 7-inch specific gravity specimens and twenty-seven 1/2- by 2- by 6-inch shear specimens. Thus, the third of a section designated for any particular orientation was essentially 100 percent sampled. The specimen distribution was as follows:

<table>
<thead>
<tr>
<th>Type of specimen shear</th>
<th>Number of specimens in--</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>One section</td>
</tr>
<tr>
<td>LT</td>
<td>9</td>
</tr>
<tr>
<td>TL (rolling shear)</td>
<td>9</td>
</tr>
<tr>
<td>RL (rolling shear)</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
</tr>
</tbody>
</table>

Specific gravity       2 12

1Shear stress in planes indicated.
Figure 4.—Types of specimens for determining shear properties in A, LT plane; B, TL (rolling shear) plane; and C, RL (rolling shear) plane.
Figure 5.--Two-plate compression shear apparatus with a Sitka spruce rolling shear specimen in position for testing.

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A specimen for each type of shear test is shown in figure 4. Because the plank was only 3 inches in depth, it was necessary in preparing each of the group (RL) shear specimens to use three \( \frac{1}{2} \)-by-2- by 2-inch blocks butt-jointed at their radial edge, as shown in figure 4.

After conditioning the specimens to a moisture content of 12 percent, they were bonded to steel loading plates in groups of 12 with an epoxide resin (100 parts by weight of Epibond 122 with 12 parts by weight of hardener 952). The glue bonds were cured by sealing the specimens in plastic containers and heating them in an oven at a temperature of 140°F. for 1 hour. Because there was a slight loss in the moisture content of the specimens (from 12 to 11.5 percent) after the heat treatment, they were reconditioned for 24 hours at a temperature of 75°F. and 65 percent relative humidity before testing.

**Test Method**

The test procedure was similar to that described in ASTM Designation C 273-61 (1). A shearing force was applied to the specimen through the rounded ends (3/8-inch radius) of two rigid steel loading plates (3/4 by 2 by 7 inch) that were bonded to the opposite sides of the specimen (fig. 5). The specimen with the attached loading plates was mounted between two grooved (3/8-inch radius) loading blocks between the platens of the testing machine. The lower loading block was fastened to a spherical loading base that was centered on the weighing platen of the testing machine.

After placing an initial load of 50 pounds upon the specimen, the spherical loading base was tapped with a hammer until the loading plates were firmly and evenly seated and then fixed in position by four adjustment bolts to prevent shifting of the specimen during test. The movable head (upper head) of the testing machine was driven at a constant rate of speed of 0.005 inch per minute until the proportional limit was surpassed and at 0.01 inch per minute thereafter. The deformation between the shear plates was interpolated to the nearest 0.00001 inch with a dial indicator graduated in 0.0001 inch.

After test, the failed specimens and glue were removed from the shear plates by heating them in an oven at 275°F. for 1 hour. The plates were sanded with a fine abrasive cloth to remove the remaining residue and were then ready for the next bonding operation.
### Table 1.--Average properties for each specimen orientation

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Property</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proportional limit stress</td>
<td>P.s.i.</td>
</tr>
<tr>
<td></td>
<td>Maximum stress</td>
<td>P.s.i.</td>
</tr>
<tr>
<td></td>
<td>Modulus of rigidity</td>
<td>1,000 p.s.i.</td>
</tr>
<tr>
<td>LT</td>
<td>480</td>
<td>1,320</td>
</tr>
<tr>
<td>TL (rolling shear)</td>
<td>57</td>
<td>248</td>
</tr>
<tr>
<td>RL (rolling shear)</td>
<td>56</td>
<td>256</td>
</tr>
</tbody>
</table>

*1 Moduli $G_{LR}$, $G_{TR}$, and $G_{RT}$, correspond to LT, TL, and RL orientations respectively.*

### Table 2.--Analysis of variance to evaluate difference between $G_{RT}$ and $G_{TR}$

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks (sections)</td>
<td>5</td>
<td>835,006</td>
<td></td>
</tr>
<tr>
<td>Orientation</td>
<td>1</td>
<td>2,600,910</td>
<td>8.22</td>
</tr>
<tr>
<td>Error</td>
<td>5</td>
<td>316,682</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*1 Significance at 5 percent level.*
Figure 6.--Relation of average modulus of rigidity from tangential force perpendicular to the grain ($G_{TR}$) and from radial force perpendicular to the grain ($G_{RT}$) to serial position in plank. Each potted point is average of nine specimens.
The average moisture content for all specimens was 12.3 percent, and the average specific gravity was 0.36. Individual specimens deviated very little from these values.

Averages for the properties investigated in this work are given in table 1; each average is based on 54 observations. Proportional limit stress and maximum stress are almost the same for the two perpendicular-to-grain orientations, and 10 to 20 percent of these properties parallel-to-grain.

For an elastic material, we expect the two moduli of rigidity associated with a transverse plane to be the same; that is, \( G_{\text{TR}} = G_{\text{RT}} \). To evaluate the significance of the apparent difference in table 1, the analysis of variance shown in table 2 was conducted, using the average for nine specimens from a section as an observation (because each section was completely sampled).

The effect of orientation was significant at the 5 percent level but not at the 1 percent; we can assume the two properties are different with little chance of being wrong. As described, the orientations were systematically assigned within each block. The cutting plan, figure 3, shows that the specimens used for \( G_{\text{TR}} \) always fell to the left of those used for \( G_{\text{RT}} \) (or to the right, depending on how the plank is viewed).

It is reasonably well substantiated that properties decrease with increasing height in tree or along the grain. Thus \( G_{\text{RT}} \) could be greater than \( G_{\text{TR}} \) because for every section used to evaluate \( G_{\text{TR}} \), there was a matching section lower in the bole used to evaluate \( G_{\text{RT}} \). Figure 6 is a plot of average modulus of rigidity versus the number of the serially taken position of specimens. It seem apparent that the averages for the two orientations differ too consistently to conclude that they both measure the same thing, and that the difference is not just because of position in the plank.

The shear strength associated with the LIT orientation was 1,320 pounds per square inch. By contrast, the Wood Handbook (4) gives 1,150 pounds per square inch for a 0.40 average specific gravity, and that strength is the average from an equal number of LT and LR orientations.
Table 3.---Estimates of components of variance

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Sample standard deviations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$s$</td>
<td>$s_p^2$</td>
</tr>
<tr>
<td></td>
<td>P.s.i.</td>
<td>P.s.i.</td>
</tr>
</tbody>
</table>

PROPORTIONAL LIMIT STRESS

<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LT</td>
<td>42</td>
<td>53</td>
</tr>
<tr>
<td>TL (rolling shear)</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>RL (rolling shear)</td>
<td>9</td>
<td>12</td>
</tr>
</tbody>
</table>

MAXIMUM STRESS

<table>
<thead>
<tr>
<th>Orientation</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LT</td>
<td>58</td>
<td>79</td>
</tr>
<tr>
<td>TL (rolling shear)</td>
<td>18</td>
<td>33</td>
</tr>
<tr>
<td>RL (rolling shear)</td>
<td>17</td>
<td>26</td>
</tr>
</tbody>
</table>

MODULUS OF RIGIDITY

<table>
<thead>
<tr>
<th>Orientation</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LT</td>
<td>12,100</td>
<td>19,900</td>
</tr>
<tr>
<td>TL (rolling shear)</td>
<td>338</td>
<td>455</td>
</tr>
<tr>
<td>RL (rolling shear)</td>
<td>435</td>
<td>598</td>
</tr>
</tbody>
</table>

$^1$Variation between closely matched specimens treated alike.

$^2$Variation in a single 12-foot plank.
The rolling shear strengths are about one-half those reported by Tuluzakov (9) for alburnum of 0.36 specific gravity at 11 percent moisture content. They are similar to those given by Freas (5) for Douglas-fir of 0.5 specific gravity at 8 percent moisture content. The moduli of rigidity in table 1 for rolling shear are about two-thirds of those reported for alburnum and only about two-fifths of those for Douglas-fir reported by Freas. Tuluzakov found that $G_{RT}$ exceeded $G_{TR}$ by about 300 pounds per square inch, which is similar to that recorded in table 1.

Each of the mechanical properties—proportional limit stress, maximum stress, and modulus of rigidity—was subjected to an analysis as shown here to determine the components of variance:

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Expected mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sections</td>
<td>5</td>
<td>$\sigma^2 + 6\sigma_P^2$</td>
</tr>
<tr>
<td>Specimens within sections</td>
<td>48</td>
<td>$\sigma_P^2$</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td></td>
</tr>
</tbody>
</table>

The symbol $\sigma^2$ represents the true variance associated with closely matched specimens treated alike, and $\sigma_P^2$ is the true variance between sections or positions in the plank. Conceptually in this analysis, the sections should have been selected at random from the plank. Because they were selected quietly systematically, the estimate of $\sigma_P^2$ will be biased. The nine specimens taken within each section represent a 100 percent sample of the section; therefore, the sample estimate of $\sigma_P^2$ should be unbiased.

In table 3 the variance estimates (expressed as standard deviations) for each property and each orientation are given. In each, the standard deviation within sections is smaller than that between sections. This observation is not surprising because deviation between sections reflects variation between sections as well as variation within sections. The tabulated values of $\sigma$ suggest the sort of variation that can be expected between closely matched specimens treated alike. This variation probably occurs because of the inherent difference between
specimens that are matched as closely as possible, as well as to error in the testing process. Values of $s_P$ suggest the variation that can occur in a single 12-foot plank, considering that this value of $s_P$ is biased by the systematic sampling procedure.

The load-deformation diagram in each orientation had a pronounced straight-line portion to the order of accuracy measured and plotted in this study. Typical diagrams for each orientation are given in figure 7. For the LT orientation, the loads were divided by 5 to permit the use of the same scale as for the other two orientations. Deformation in the figure is the actual measured relative movement between the two steel plates.

In almost all test specimens, shear failure took place entirely within the wood. In a few, a small amount of glue failure was observed. Failures typical of the orientation are shown in figure 8. The LT failures were characterized by a sudden drop in load and a complete, rapid failure. The TL and RL failures were not so abrupt.

The two-plate compression shear apparatus is of rather simple construction. It is easy to mount the specimen in the testing machine, and the actual testing time is about 5 minutes. The specimens are easy to fabricate, and no difficulty was experienced in bonding the wood to the steel shear plates.

Summary

The two-plate shear test, used for obtaining properties of cores in sandwich construction, was employed to evaluate shear properties of dry Sitka spruce. Tests were made with a shearing force in the tangential plane of the wood and parallel to the grain, in the tangential plane of the wood and perpendicular to the grain, and in the radial plane of the wood and perpendicular to the grain. The test procedure gives a state of essentially pure shear, and specimens are easy to fabricate and load. No problem of glue failure was experienced.

Rolling shear strength and proportional limit were about the same in the two perpendicular-to-the-grain orientations studied and were 10 to 20 percent of the same properties obtained where a longitudinal shear force was imposed parallel to the grain. The modulus of rigidity from shear force in the radial plane perpendicular to the grain averaged 10 percent greater than that from shear force in the tangential plane perpendicular to the grain, apparently a real difference.
Figure 7.—Relation of load to deformation for each orientation.

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Figure 8.—Shear failures typical for orientations: A, LT; B, TL (rolling shear; and C, RL (rolling shear).
Standard deviation of the properties for closely matched specimens treated alike was small; standard deviations between sections within the same plank were somewhat higher. These components of variance are given in table 3, as an aid in designing further experiments.

**Literature Cited**


(9) Tuluzakov, V. V. 1962. On testing timber for pure shear across the grain Zavodskaya Lab. 28(8): 987–990.
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