Modulus of Rigidity of Rotary-Peeled Southern Pine Veneer Laminates At Various Moduli of Elasticity

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ABSTRACT. Modulus of rigidity (G_{LT}) of veneer laminates was shown to be unrelated to dynamic modulus of elasticity (E_D) of single veneers and also, within the range of samples tested, unrelated to specific gravity. Values determined by the flexure test (G_{LR}) were consistent with those from standard plate shear tests (G_{LT}).

THE OBJECTIVE of the study reported here was to determine whether modulus of rigidity of rotary-cut southern pine veneer is related to modulus of elasticity. Values of modulus of elasticity parallel to the grain (E) are available for most species, but data on modulus of rigidity (G) are somewhat limited. In the absence of more precise knowledge, the value of G is frequently assumed to be 1/16 of E in tension and compression (USDA Forest Products Laboratory 1955, p. 78).

Deflection at midspan of a rectangular beam with center loading is calculated as follows:

$$\Delta = \frac{PL^3}{48EI} + \frac{0.3PL}{AG} \qquad [1]$$

where:

Δ = midspan deflection (in.)
P = total load on beam (lb.)
L = span length (in.)
E = modulus of elasticity (free from shear) parallel to the grain (psi)
I = moment of inertia of cross section (in.^{4})
A = cross-sectional area of beam (sq. in.)
G = modulus of rigidity (psi)

The first part of the equation states deflection due to bending; the second part, deflection due to shear (Newlin and Trayer 1941). Deflection due to shear is sometimes neglected in practical calculations, but it is essential to determinations of pure E in bending.

Wood is often modeled as an orthotropic material with three mutually perpendicular axes of symmetry — longitudinal, tangential, and

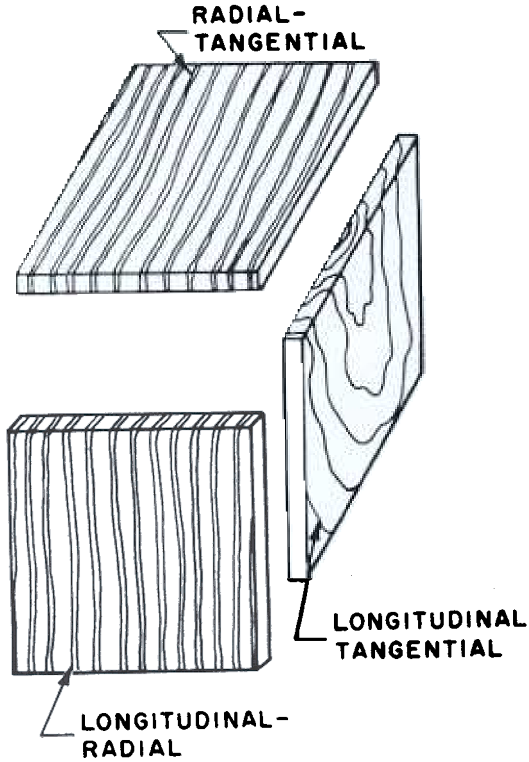

Figure 1. — Planes in which modulus of rigidity of woo[d] is of interest.

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radial. If it is cut along these three axes, each plane will contain two of the principal axes with the third axis normal to the plane (Fig. 1). Two of the three moduli affect the deflection of a beam loaded in bending; these two are defined as follows:

G_{LT} The modulus of rigidity associated with shear deformations in the longitudinal-tangential (LT) plane.

G_{LR} Modulus of rigidity associated with shear deformations in the longitudinal-radial (LR) plane.

Deformations in the radial-tangential (RT) plane do not importantly affect beam deflection and were not evaluated.

In the first part of the study, three-ply panels made from edge-glued strips of rotary-peeled veneer (Fig. 2) were evaluated by ASTM plate shear test for modulus of rigidity in the longitudinal-tangential plane (G_{LT}). In the second part of the study, small beams comprised of veneer were evaluated by flexure test for G_{LR}. This test was chosen because it is difficult to prepare rotary-peeled veneer samples for evaluation of G_{LR} by plate shear test.

Procedure

At a central Louisiana plywood plant, 102 southern pine bolts were selected at random and rotary-peeled. The veneer was clipped into sheets and dried to approximately 4 percent moisture content, at which time it measured 1/6-inch thick. The mill-dried veneer was conditioned (at 50 percent relative humidity and 72°F), straight-line ripped into strips about 2-3/8 inches wide, and cut to uniform length.

A 2-percent sample of the total population of 10,350 strips was drawn and measured for length, width, and thickness. Average length was 100.0 inches, average width 2.39 inches, and average thickness 0.169 inch. Every fifth strip of those remaining was selected for use in the study.

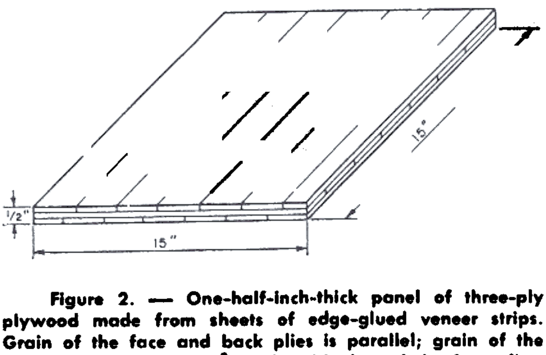

Figure 2. — One-half-inch-thick panel of three-ply plywood made from sheets of edge-glued veneer strips. Grain of the face and back plies is parallel; grain of the middle ply makes a 90° angle with that of the face plies.

Dynamic modulus of elasticity (E_D) of the veneer was determined by use of longitudinal stress wave propagation and velocity-measuring equipment developed at Washington State University (Galligan and Courteau 1965; Marra, *et al.* 1966). Details of the method were described by Koch and Woodson (1968).

E_D of each strip in the 2 percent sample was compared by linear regression with static E in tension for the same strips. The coefficient of determination (r^2) was 0.888, and the standard error of estimate was 172,000 psi (see Koch and Woodson (1968) for a plot of the data). It was thus concluded that the dynamic method provided satisfactory evaluation.

Samples were selected for three classes of E_D:

Class	E_D
Low	1,000,000 psi
Medium	1,800,000 psi
High	2,600,000 psi

A tolerance of ±125,000 psi was necessary to obtain the required number of strips in each class.

Evaluation of G_{LT}

For the first phase of the study, the central 80 inches of each strip was cut to yield five equal lengths of 15-3/4 inches. Square sheets of uniform E_D were made by edge-gluing the pieces together.

Three of these square sheets were required to make one three-ply panel for the plate shear test. In the core sheets strips were alternated so that those with loose side up (knife side of veneer as it came off the lathe) were adjacent to those with tight side up (nosebar side of veneer). Glue joints in the two face plies were staggered (Fig. 2) and the tight side was kept on the outside of the face plies.

Fifteen panels (five for each E_D class) were fabricated in a hot press, trimmed to 15 inches on each side, and allowed to condition 5 days.

The panels were evaluated by the standard plate shear test for plywood (American Society for Testing and Materials 1969). The effect of initial curvature was minimized by testing each panel twice — first with the loads acting downward on two opposite corners, and second with the loads acting upward on the same two corners. The values obtained in this manner proved to be very close, indicating that initial curvature was small (March, et al. 1942). The load-deflection curve was plotted for each panel, and from its slope G_{LT} was computed as follows:

$$G_{LT} = \frac{3u^2}{2h^3} \frac{P}{w} \qquad [2]$$

where:

P = load applied to each corner (lb.)
w = deflection relative to the center (in.)
h = thickness of the panel (in.)
u = distance on a diagonal from the center of the panel to the point of deflection measurement (in.)

Evaluation of G_{LR}

For the second phase of the study, four beams were fabricated from veneer of each of the three E_D classes. Each beam was 2 inches deep, being comprised of twelve 1/6-inch-thick laminae. After cold-press assembly, beams were planed to 2-inch width. The finished beams were therefore 2 inches square in cross section and 100 inches long. Sufficient load-deflection readings were taken to permit calculation of effective E over spans of 94, 80, 56, 40, 28, and 14 inches. Loads were applied at the center, and deflection was recorded at midspan. The stress level was kept well within the elastic range throughout testing; after each test, beams were returned to the conditioning room (maintained at 72°F and 50 percent relative humidity) for 24 hours. Long spans were tested first, and specimens were trimmed on each end for progressively shorter spans. Standard loading rates were calculated from the relationship (Wangaard 1950):

$$N = \frac{Zl^2}{6d} \qquad [3]$$

where

N = head travel (in./min.)
Z = 0.0015 in./in./min.
l = span (in.)
d = depth (in.)

The flexure method was used to determine pure E (shear-free) and G_{LR}. This method was first described by Preston (1954) and has since been used by Biblis (1965). It involves testing beams over long and short spans, calculating effective E, transforming the data, and determining pure E and G_{LR} by solving for the y-intercept and slope of a linear regression (Biblis 1965).

Results and Discussion

The results of the plate shear test are summarized in Table 1. Each entry for G_{LT} is an average of two values. Moisture content for all specimens averaged 9.0 percent, and average specific gravities for high, medium, and low E_D classes were 0.66, 0.59, and 0.54 (based on oven dry weight and volume at test). E_D for each panel (average of the component strips) proved to be very close to the class average.

A least-squares fit through the data for G_{LT} plotted against E_D proved nonsignificant at the 0.05 level, an indication that within the range of E_D tested the overall average of 117,900 psi is a meaningful estimate of G_{LT} regardless of the magnitude of E_D. Similarly, G_{LT} proved to have no significant correlation with specific gravity; therefore, the average of 117,900 psi gives the best estimate of G_{LT} at all specific gravities within

Table 1. — DYNAMIC MODULUS OF ELASTICITY (E_D) OBTAINED FROM SINGLE VENEERS AND MODULUS OF RIGIDITY (G_{LT}) OBTAINED FROM PLATE SHEAR TEST ON VENEER LAMINATES.

E_D Class and panel	Specific gravity[1]	Moisture content	E_D	G_{LT}
		Percent	1,000 psi	psi
High				
1	0.66	9.1	2,490	124,60
2	.68	8.8	2,690	111,90
3	.67	8.5	2,580	119,50
4	.64	9.0	2,520	112,60
5	.65	9.0	2,570	116,40
Avg.	.66	8.9	2,570	117,00
Medium				
6	.60	8.9	1,900	113,40
7	.58	9.0	1,690	116,50
8	.59	9.0	1,750	114,00
9	.57	9.0	1,850	116,40
10	.59	9.1	1,800	114,40
Avg.	.59	9.0	1,800	114,90
Low				
11	.53	9.1	900	124,20
12	.54	9.2	1,110	111,70
13	.53	9.0	960	131,10
14	.53	9.4	1,060	120,40
15	.56	9.1	1,010	121,30
Avg.	.54	9.2	1,010	121,70

[1]Specific gravity based on ovendry weight and volume at test.

Table 2. — PURE MODULUS OF ELASTICITY (FREE FROM SHEAR) AND MODULUS OF RIGIDITY (G_{LR}) OBTAINED FROM FLEXURE TESTS.

E_D class[1]	Specific gravity[2]	Moisture Content	E	G_{LR}
		Percent	1,000 psi	psi
High	0.64	10.1	2,600	121,900
Medium	.57	10.3	1,850	120,400
Low	.56	10.3	1,030	113,900

[1]Four beams in each class.

[2]Specific gravity based on ovendry weight and volume at test.

the range tested. This average corresponds closely with the value of 120,000 psi reported by Mark, et al. (1970) for Virginia pine (*Pinus virginiana* Mill.) of 10- to 15-percent moisture content, and with 122,000 psi reported for southern yellow pine by Biblis (1971).

The G_{LR} values obtained by flexure test closely approximated the G_{LT} values obtained in plate shear tests (Table 2). If it is assumed that no relationship exists between E and G_{LR} or between specific gravity and G_{LR}, then the average G_{LR} for all flexure specimens is 118,700 psi, which is slightly higher than the value of 117,900 psi for G_{LT} determined by the plate shear test. The corresponding value of G_{LR} obtained by Mark, et al. was 140,000-160,000 psi, while Biblis (1971) reported 110,000 psi.

It should be noted that the values reported here are for rotary-peeled veneer and veneer laminates, and not for sawn or solid wood. Lathe checks may influence modulus of rigidity, though it is possible that their effects are offset by glue penetration.

The shear-free E values in Table 2 are in good agreement with the E_D values from Table 1, an indication that the method of measuring dynamic modulus of elasticity was reliable.

It is concluded that the ratio G_{LT}/E is not constant in southern pine, since no relation was found between E_D of single veneers and G_{LT} of laminates.

No correlation was observed between specific gravity and G_{LT} of laminates. Doyle, et al. (1946) found none between solid and glued Sitka spruce. Biblis and Fitzgerald (1970), however, did observe a significant relationship in southern pine. They evaluated earlywood, latewood, and solid wood separately, and thus had a greater range of specific gravities than in the present study. In the same way, relationships may exist among species spanning a range of densities.

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