ROLLING SHEAR MODULUS OF SWEETGUM PLYWOOD AND UNIDIRECTIONALLY LAMINATED VENEER[1]

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ABSTRACT

Experimentally obtained values of apparent rolling shear modulus and strength of sweetgum 4-ply, 12.7-mm-thick plywood, when the shear forces are applied parallel to the face grain of the plywood, are presented. Also presented are experimental values of true rolling shear modulus (G_{TR}) of unidirectionally laminated sweetgum veneer tested in the dry condition. Finally, the experimentally obtained value of the apparent rolling shear modulus of the tested sweetgum plywood was closely predicted using the obtained G_{TR} and G_{LR} values.

Keywords: Sweetgum, plywood, veneer, rolling shear, modulus, strength, true rolling shear, parallel shear.

INTRODUCTION

Sweetgum (*Liquidambar styraciflua*) represents approximately 12% of all growing hardwood stock in the South. Wood of this species is easily peeled into veneer and glued into plywood with extended phenolic resin for structural purposes. An earlier study by the author and others indicated that CDX plywood from sweetgum had equal or higher flexural strength and stiffness, plate shear modulus, and rail shear strength compared to southern pine plywood of equal grade, thickness, density, and number of plies (Biblis and Lee 1984).

Rolling shear stress and deformations develop in certain structural members made either entirely or partially from structural plywood. Such structures may be box-beams, I-beams, gusset plates, and stressed-skin panels. Although knowledge of rolling shear modulus and strength is required for designing structural members with plywood, no quantitative information is available for these properties of sweetgum plywood.

In rotary-cut veneer, four shear planes can be recognized. Two shear planes are in the longitudinal direction (along the wood fibers)—the longitudinal-tangential (LT) plane and the longitudinal-radial (LR) plane. The other two shear planes are in a direction perpendicular to the fibers (without cutting them)—the tangential-radial (TR) plane with force applied in the tangential direction and the radial-tangential (RT) plane with force applied in the radial direction. Shear that develops in the TR and RT planes is called rolling shear because the wood fibers, if not firmly connected together, would roll on one another in response to shear forces.

In unidirectionally laminated veneers, shear stresses and shear deformations can develop in any of the four planes, LT, LR, TR, and RT, depending on the direction of the applied shear forces. In plywood, because of the crossbonding of veneers, when subjected to shear forces certain veneer plies are stressed in parallel shear, while veneer plies that are perpendicularly oriented would be stressed in rolling shear. The resulting total shear stress in plywood is called apparent rolling shear since the resulting shear stresses and strains are some-

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where between the parallel shear and rolling shear in magnitude.

There are two types of apparent rolling shear in plywood. One involves shear in the plane of the plies with shear forces applied parallel to the face grain of plywood. The other involves shear force applied perpendicular to the face grain.

Previous studies determined properties and factors affecting rolling shear strength and modulus of several western plywood species (Chow 1974; Foschi 1970; Palka 1967; Palka and Hejjas 1977; Samek 1970; Smith 1974). Other studies determined rolling shear properties of solid wood from nine softwoods (Bendtsen 1976; Munthe and Ethington 1968). Additional studies presented accurate methods for predicting apparent rolling shear modulus of plywood by knowing the true rolling shear (G_{TR}) and G_{LR} of the veneer species and construction of plywood (Lee and Biblis 1979). In these studies the following equation (1) was developed and used for accurately predicting the rolling shear modulus of plywood.

$$G = \frac{nG_{TR}}{n_{\perp} + n_{\parallel}\frac{G_{TR}}{G_{LR}}} \tag{1}$$

where

n = number of total veneer plies

$n_{\perp}$ = number of veneer plies with grain perpendicular to applied force,

$n_{\parallel}$ = number of veneer plies with grain parallel to applied force,

G = plywood rolling shear modulus,

G_{LR} = parallel shear modulus of veneer, and

G_{TR} = true rolling shear modulus of veneer

If the ratio of G_{TR}/G_{LR} is very small and therefore negligible, then Eq. (1) becomes the simplified predicting formula for the plywood rolling shear modulus.

$$G \approx G_{TR}\left(\frac{n}{n_{\perp}}\right) \tag{2}$$

If plywood is not made with veneers of equal thickness, then n, $n_{\perp}$ and $n_{\parallel}$ of Eqs. (1) and (2) should be replaced by the total thickness of plywood (t), total thickness of perpendicular veneers ($t_{\perp}$), and total thickness of parallel veneers ($t_{\perp}$), and total thickness of parallel veneers ($t_{\parallel}$), respectively.

It should be noted that Eqs. (1) and (2) can be used for computing $G_{\parallel}$ (plywood rolling shear modulus with force applied parallel to the direction of face grain) and $G_{\perp}$ (plywood rolling shear modulus with force applied perpendicular to the direction of face grain).

Values of rolling shear modulus (G_{TR}) and strength of sweetgum can not be found in the literature. Perhaps the reason for this is that the determination of these values for plywood is difficult, time consuming, and expensive. It requires successful bonding of 15.2- × 45.7-cm plywood specimens to 12.7-mm-thick steel plates.

Therefore, the primary purpose of this paper is to present experimentally obtained values of apparent rolling shear modulus and strength of sweetgum 4-ply, 12.7-mm-thick plywood when the shear forces are applied parallel to the face grain of the plywood. Also, experimental values of the true rolling shear and parallel shear of unidirectionally laminated sweetgum veneer tested in the dry condition are presented. Furthermore, the experimentally obtained values of the apparent rolling shear modulus of the sweetgum plywood were compared to the predicted values obtained from Eq. (1).

MATERIALS AND METHODS

Two sweetgum plywood panels 1.22 × 2.44 m (4 × 8 ft), 4-ply, 12.7-mm (½-inch)-thick and one panel of sweetgum unidirectionally oriented veneer were constructed and used for this study. The above panels were constructed with all C grade veneers in a southern pine plywood mill. Due to the insignificant effect of veneer lathe check orientation on rolling shear properties (Hunt and Matteson 1976; Palka 1978), the experimental plywood was fabricated according to commercial process without regard to lathe check orientation. A commercial extended phenolic resin was used with a spread of 0.44 kg per square meter of double glueline. All panels were prepressed at room temperature with 1,103 KPa (160 psi) for approximately 3 min and then were hot-pressed with 1,400 KPa (200 psi) at 149°C (300°F) for 4 min. The 4-ply, 12.7-mm plywood was constructed with the two middle plies parallel to each other and perpendicular to face veneer grain.

The 4-ply, 12.7-mm unidirectionally laminated veneer panel was used to obtain 22 specimens 15.24 × 45.7 cm (6 × 18 in.) for true rolling shear (G_{TR}) and 11 specimens for parallel shear (G_{LR}).

The two sweetgum plywood panels were used to obtain 24 specimens 15.24 × 45.7 cm (6 × 18 in.) with the face grain parallel to the long side for determination of the apparent rolling shear properties (with shear force applied parallel to the face grain).

All plywood and unidirectional specimens were first conditioned to equilibrium moisture content (EMC) at 22.2°C (72°F) and 65% relative humidity (RH). The EMC of all specimens was about 10%. After reaching equilibrium, all specimens were measured in two locations for thickness, width, and length to the nearest 0.025 mm (0.001 in.). Specimens were then bonded to the steel loading plates with an epoxy resin and curing agent (Shell Epon-820 and curing agent V-40 in the ratio of 4 to 1). Bonding pressure was applied to steel plates by C-clamps. Curing heat was provided by heat lamps for 4 h. The temperature on the bonded surface of the steel plates was approximately 60°C (140°F) during the last 2 h of the curing period. Specimens were then reconditioned at 22.2°C (72°F) and 65% RH for 18 h before testing.

Rolling shear tests were performed according to ASTM D 2718-90 (1996). The deformation between the steel plates as measured on a dial gage graduated in 0.0025 mm (0.0001 in.). The deformation was measured at each 908 kg (2,000 lb) increment of load for true rolling shear and apparent rolling shear and at each 2,270 kg (5,000 lb) increment of load for parallel shear. The load-deformation data were processed by a computer program to fit a straight line by the least squares method.

Maximum shear stress and shear modulus were computed from the following equations, respectively:

Shear strain $\gamma = d/t$ (3)

Shear stress $\tau = P/LW$ (4)

Shear modulus $G = \tau/\gamma = Pt/LWd$ (5)

where,

d = deformation between two steel loading plates (mm),

L, W, t = specimens length, width, and thickness (mm),

P = load corresponding to deformation (d) within proportional limit, and

G = shear modulus (KPa)

The tested specimens were carefully examined to determine the types of failure and percentage of failure to the nearest 5%. Measurements were made with a 15.25- × 45.7-cm (6- by 18-in.) transparent sheet, which was equally divided into 100 rectangles. Three types of observed failure were 1) epoxy failure between surfaces of the steel plate and the specimen, 2) phenolic glueline failure between surfaces of veneers, and 3) wood failure within veneers. Specimens that developed more than 30% delamination at the steel plates were excluded.

RESULTS AND DISCUSSION

The results given in Table 1 provide heretofore unavailable information on the apparent rolling shear properties of 4-ply, 1.27-cm (½-in.) sweetgum plywood and true rolling shear of unidirectionally laminated sweetgum veneer. The apparent rolling shear modulus of the tested sweetgum plywood, with load applied parallel to face grain 298.2 MPa (43,250

TABLE 1. *Average values of true rolling shear modulus and strength, parallel shear of unidirectionally laminated veneer, and apparent rolling shear with force parallel to face grain of sweetgum plywood all 4-ply, 12.7-mm (½-in.)-thick tested in the dry condition.*

				Shear modulus		Shear strength		
No. of plies	Thickness (mm)	Veneer grade	No. of specimens tested	No. of specimens accepted	Mean (MPa)[b]	No. of specimens accepted[a]	Mean (KPa)[b]	Wood failure %
				True rolling shear, G_{TR} (Unidirectionally laminated veneer tested perpendicular to grain)				
4	12.7	CCCC	21	13	164.8 (46.7)[c]	18	1,450 (207)	90
				Parallel shear, G_{LR} (Unidirectionally laminated veneer tested parallel to face grain)				
4	12.7	CCCC	11	7	1,884 (243.5)	9	2,480 (655)	90
				Apparent rolling shear (Plywood tested parallel to face grain)				
4	12.7	CCCC	22	17	298.2 (53.1)	17	2,135 (234)	80

[a] Specimens with more than 30% epoxy delamination between surface and steel plates were excluded.
[b] MPa equals to 1,000 KPa. One psi equals to 6.895 KPa.
[c] Number in parentheses indicates standard deviation.

psi), is slightly lower than the corresponding values reported for southern pine plywood (Biblis et al. 1972) of equal thickness and construction. The true rolling shear modulus G_{TR} of the tested sweetgum plywood is approximately 22% higher than the corresponding values reported for southern pine plywood. The parallel to grain shear modulus of the unidirectionally laminated sweetgum veneer G_{LR} is only 36% of the corresponding value reported for southern pine laminated veneer.

Using the obtained experimental values of true rolling shear modulus G_{TR} and parallel to grain shear modulus G_{LT}, the apparent rolling shear modulus of the tested sweetgum plywood was accurately predicted using Eq. (1) as shown in Table 2.

TABLE 2. *Comparison between observed and predicted apparent rolling shear moduli ($G_{\parallel}$) of sweetgum plywood in the dry condition.*

Thickness (mm)	No. of plies	Veneer grade	$G_{\parallel}$ Observed (MPa)	$G_{\parallel}$ Predicted by Eq. (1) (MPa)	Error (4) − (3)/(3)
	(1)	(2)	(3)	(4)	(5)
12.7	4	CCCC	298.2	303	1.6

CONCLUSIONS

Apparent rolling shear modulus and strength of 4-ply, 12.7-mm-thick (½-in.) sweetgum plywood and true rolling shear moduli of unidirectionally laminated sweetgum veneer were experimentally determined. It can be concluded that the obtained true rolling shear moduli of the laminated veneer closely predicted the apparent rolling shear modulus of the tested sweetgum plywood.

REFERENCES

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM). 1996. Standard method of testing plywood in rolling shear. ASTM D 2718-90, Philadelphia, PA.

BENDTSEN, B. A. 1976. Rolling shear characteristics of nine structural softwoods. Forest Prod. J. 26(11):51–56.

BIBLIS E. J., W. L. CHEN, AND W. C. LEE. 1972. Rolling shear properties of southern pine plywood and unidirectionally laminated veneer. Forest Prod. J. 32(2):45–50.

———, AND W. C. LEE. 1984. Properties of sheathing-grade plywood made from sweetgum and southern pine. Wood Fiber Sci. 16(1):86–92.

CHOW, S. 1974. Lathe-check influence on plywood shear strength. Inf. Rep. VP-X-122. Can. Forest Serv., West. Forest Prod. Lab., Vancouver, BC.

FOSCHI, R. O. 1970. Rolling-shear failure of plywood in structural components. Inf. Rep. VP-X-67. Can. Forest. Serv., West. Forest Prod. Lab., Vancouver, BC.

HUNT, M. O., AND D. A. MATTESON. 1976. Structural characteristics of weathered plywood. J. Structural Div., Am. Soc. Civil Eng., 102(ST4):759–768.

LEE, W. C., AND E. J. BIBLIS. 1979. Predicting rolling shear modulus of plywood. Forest Prod. J. 29(4):31–34.

MUNTHE, B. P., AND R. L. ETHINGTON. 1968. Method for evaluating shear properties of wood. USDA Forest Serv., Res. Note FPL-0195. Forest Prod. Lab. Madison, WI.

PALKA, L. C. 1967. Influence of loading methods on rolling shear. Forest Prod. J. 17(3):30–36.

———. 1978. Rolling-shear properties of single-species canadian softwood plywoods. Inf. Rep. VP-X-177. Can. Forest Serv., West. Forest Prod. Lab., Vancouver, BC.

———, AND J. HEJJAS. 1977. Effect of moisture content on the mechanical properties of Douglas-fir plywood in rolling shear. Forest Prod. J. 27(4):49–53.

SAMEK, J. 1970. Effect of moisture content on shear in the plane of the plies (rolling shear) strength of sheathing grade Douglas-fir plywood. Council For. Industries BC, Rep. 93. North Vancouver, BC.

SMITH, G. R. 1974. The derivation of allowable unit stresses for unsanded grades of Douglas-fir plywood from in-grade strength test data. Council For. Industries BC, Rep. 193. North Vancouver, BC.