Determining Tensile Properties Of Sweetgum Veneer Flakes

Eddie W. Price

Abstract

Rotary-cut sweetgum veneer flakes measuring 3 inches along the grain, 3/8 inch wide, and 0.015 inch thick, were stressed in tension parallel to the grain at gage lengths from 0.50 to 1.25 inches for unpressed control and at 0.75 inch gage length for flakes pressed in a flakeboard mat. The control flakes had an average tensile strength of 9,400 psi for the smaller gage length classes, 8,000 psi for the upper range of gage lengths, and moduli averaging from 460,000 psi to 675,000 psi. Platen pressure with heat increased core flake density by 6.3 percent and face flake density by 13.9 percent above that of untreated control flakes. Core flakes, which had an average MC of 6.3 percent, decreased 6.5 percent and 7.25 percent in tensile strength and modulus, respectively. Face flakes, which had an average MC of 5.5 percent, had 7.6 percent greater tensile strength and 9.8 percent greater modulus than unpressed controls. Unpressed control flakes had an average MC of 6.5 percent.

THE MECHANICAL PROPERTIES of individual flakes and the changes that flakes undergo during fabrication limit the strength and elasticity of the flakeboard. Assuming that flakes behave just like solid wood can result in erroneous predictions of flakeboard strength, for several studies have shown that tensile strengths of small wood specimens are lower than those of ASTM standard specimens (Biblis 1969, 1970; Manwiller 1972). Moreover, when flakes are compressed into boards, their density and thus their mechanical properties are altered. The change is not uniform but varies with the flake's location within the board, as is shown by the fact that flakeboard has a vertical density profile (Suchsland 1962).

The present study compares the mechanical properties of sweetgum (*Liquidambar styraciflua* L.) flakes before and after they are combined in a composite. Flakes from both outer and inner layers of board were tested.

Procurement of Test Specimens

Short sweetgum bolts were rotary peeled to produce veneer strips 3 inches wide and 0.015 inch thick. These strips were clipped into flakes 3 inches by 3/8 inch by 0.015 inch. From about 1 ton of thoroughly mixed, dried flakes, three 5-pound samples were taken. Flakes from one sample, the control, were conditioned and tested in a chamber held at 50 percent relative humidity (RH) and 72°F. The other two samples were sprayed with water to obtain 11 percent mat moisture content (MC) and subjected to flakeboard fabrication process except that no binder was used. Other specifications for these two no-resin mats were as follows:

Mat size: 1/2 inch by 20 inches by 18 inches

Specified density: 42 lb./ft.^{3} (0.673 g/cc) at 6 percent MC

Press temperature: 335°F

Press time: 6 min. (including 45-sec. closing time)

After completing the press cycle, flakes from the mats were also conditioned and tested in the chamber.

Since no resin was applied, flakes composing the mats could be manually separated into 10 layers of equal weight. Layers one and 10 were from the surfaces of the board; layers five and six were the middle layers, or core, of the board. The few flakes that were damaged during separation were considered unacceptable as test specimens and were discarded. The thoroughly mixed, acceptable flakes were conditioned in the test chamber for 1 month before test initiation. From the conditioned flakes, test specimens from each layer were randomly selected for evaluation of tensile properties.

Test Procedure

The flakes were loaded in tension parallel to the grain at the strain rate normally used in flakeboard bending tests (0.005 in./in./min.). Flakes were held by

---

The author is Wood Scientist, USDA Forest Service, So. Forest Expt. Sta., Alexandria, La. This paper was received for publication in November 1975.

pneumatic grips supplied with 90-psi air pressure and having 50-grit sandpaper rigidly attached to surface of the grips. The crosshead movement (i.e., change in distance between grips) was plotted against load. From the crosshead movement, tensile modulus was calculated on the basis of Hooke's Law. Before the tensile test, flake width and thickness were measured to the nearest 0.001 inch. In addition, grain slope with respect to the flake's 3-inch edge was measured with a microscope equipped with a goniometer eyepiece. This slope indicates the fiber deviation in the longitudinal-tangential plane. Fiber deviation through the thickness (longitudinal-radial plane) was not measured. After the tension test, one half of each failed specimen was used for MC determination. The other half was immediately weighed to the nearest 0.001 gram, then immersed in mercury to obtain its volume in an Amsler volume-meter for density determination based on the weight and volume at time of test.

Test data were recorded for failures occurring between the grips or angling into the grips. The reason for accepting failures partially within the grips was the possibility that failure originated in the gage area and progressed into the grips.

Gage Length Determination

When small objects are tested in tension, increasing the gage length (distance between grips) increases the possibility of including a structural flaw or low strength area. The mean tensile strength, therefore, diminishes with increasing gage length (Rosen 1967); and flakes evaluated at different gage lengths can yield different strength populations. To determine a suitable gage length for evaluating flake tensile properties, 50 flakes were tested at each of four gage lengths (0.50, 0.75, 1.00, and 1.25 in.). Density and MC accounted for a nonsignificant (0.05 level) amount of variation among maximum stress and tensile modulus values; grain slope did account for a significant amount of variation. When maximum stress and tensile modulus means were adjusted for grain slope by covariance analysis, the maximum stress decreased, but the modulus increased as gage length increased. For the extreme gage lengths, 0.50 and 1.25 inches, both the maximum stress and tensile modulus were significantly different based on Duncan's multiple range test. (In the tabulation below, significantly different adjusted means are marked with different letters.)

Gage length (in.)	Maximum stress (psi)	Tensile modulus (10^3 psi)
0.50	9,523^a	469.3^c
0.75	9,306^a	571.8^d
1.00	8,132^b	553.9^d
1.25	7,889^b	674.7^e

Since grain slope accounts for a significant amount of variation, regression equations for maximum stress and tensile modulus versus grain slope (Table 1) were calculated. A single value of *b* of −504.87 psi per degree of slope would give acceptable strength-grain slope relationships, but no common value was appropriate for tensile modulus of all gage-length classes. At zero degree grain slope, strength values obtained with the smaller gage-length regressions were closer to the solid wood value of 12,500 psi (Forest Products Laboratory 1974) than were those obtained with longer gage lengths. Because of this similarity to solid wood and because mean values of strength for the 0.50-inch and 0.75-inch gage lengths were the same, either length could have been selected. The 0.75-inch length was preferred because it is easier to manipulate.

Table 1. — REGRESSION EQUATIONS OF TENSILE PROPERTIES VERSUS GRAIN SLOPE FOR FLAKES TESTED AT DIFFERENT GAGE LENGTHS (DISTANCES BETWEEN LOADING HEADS). (AVERAGE FLAKE DENSITY BASED ON WEIGHT AND VOLUME AT TEST = 0.586. AVERAGE FLAKE MC = 6.98%.)

$Y = a + bX$*		$S_{y \cdot x}$
Maximum tensile stress		
$\sigma_{0.50} = 11{,}575 - 394.29\,\theta$	0.3501	2,304.5
$\sigma_{0.75} = 12{,}331 - 599.08\,\theta$	.4547	2,782.6
$\sigma_{1.00} = 10{,}902 - 543.46\,\theta$	.5080	2,237.8
$\sigma_{1.25} = 10{,}354 - 486.76\,\theta$	.5502	1,896.7
Tensile modulus		
$E_{0.50} = 5.011 - 0.0558\,\theta$	.0933	74,613
$E_{0.75} = 6.245 - .1030\,\theta$	.1788	93,606
$E_{1.00} = 6.490 - .1843\,\theta$	.4318	88,478
$E_{1.25} = 7.691 - .1825\,\theta$	.4076	94,832

*Y = Maximum tensile stress (σ_a, psi) or tensile modulus (E_a, 10^6 psi), where a = gage length in inches.
$X = \theta$ = grain slope, deg., with respect to flake's longitudinal edge.

Tensile Modulus Of Individual Flakes

Regardless of gage length, the tensile modulus (MOE) of the flakes was lower than the published values for small, clear, solid wood specimens. Young's modulus for air-dried sweetgum tested in the longitudinal direction is 1.640×10^6psi (Forest Products Laboratory 1974). The regression equations from this study yielded values of 0.5011 to 0.7691×10^6 psi for flakes with zero grain angle. The discrepancy between solid wood values and flake values could be caused, in part, by the possibility of grain slope through the thickness of each flake, cell damage occurring during the flake machining process, MC, and inability to measure correct strain by the procedure used.

Tensile modulus calculations were based on crosshead movement, which indicates change in the distance between the grips. Although the grips were covered with sandpaper to reduce the tendency to slip, any slippage which did occur would introduce an error in the strain measurements. To evaluate the level of strain measurement error, tensile modulus was also calculated from strain-gage readings. Electrical resistance strain gages with 0.25-inch gage lengths were glued on nine flakes. These flakes were then tested in tension with a spacing between grips of 0.75 inch. Of the nine flakes, specimens numbered one through five were specifically selected because of their small grain slopes. Other specimens were randomly selected. A separate flake was used in a half-bridge arrangement for temperature compensation. To obtain more data, six of the flakes were loaded repeatedly before loading to failure.

Table 2. — TENSILE MODULUS CALCULATED FROM CROSSHEAD TRAVEL AND FROM STRAIN GAGE MEASUREMENTS FOR INDIVIDUAL FLAKES TESTED WITH 0.75-INCH BETEEN LOADING HEADS.

			Tensile modulus: $\frac{\text{Strain gage}}{\text{Crosshead}}$, ksi				
Specimen	**Grain angle (degrees)**	**Maximum stress (psi)**	**Load 1**	**Load 2**	**Load 3**	**Load 4**	**Avg.**
1	0.0	17,562	$\frac{1,636}{699}$ (2.34)[1]	$\frac{1,472}{737}$ (2.00)			$\frac{1,554}{718}$ (2.16)
2	0.0	16,042	$\frac{2,514}{720}$ (3.49)				$\frac{2,514}{720}$ (3.49)
	0.4	19,470	$\frac{2,509}{880}$ (2.85)	$\frac{2,408}{1,022}$ (2.36)			$\frac{2,459}{951}$ (2.59)
4	0.0	10,835	$\frac{1,753}{729}$ (2.40)	$\frac{1,749}{790}$ (2.21)			$\frac{1,751}{760}$ (2.31)
5	0.2	13,086	$\frac{1,226}{582}$ (2.11)	$\frac{1,171}{615}$ (1.90)			$\frac{1,199}{598}$ (2.00)
6	9.6	8,561	$\frac{1,284}{787}$ (1.63)	$\frac{1,555}{677}$ (2.30)			$\frac{1,420}{732}$ (1.94)
7	6.6	6,897	$\frac{1,381}{566}$ (2.44)				$\frac{1,381}{566}$ (2.44)
8	0.2	9,946	$\frac{632}{396}$ (1.60)				$\frac{632}{396}$ (1.60)
9	3.0	14,466	$\frac{1,874}{962}$ (1.95)	$\frac{1,827}{816}$ (2.24)	$\frac{1,921}{845}$ (2.27)	$\frac{1,892}{836}$ (2.26)	$\frac{1,879}{865}$ (2.17)

[1] Ratio of the strain gage/crosshead modulus.

The MOE calculated with a strain gage was closer to values for solid wood than the MOE based on crosshead movement (Table 2). With the average tensile moduli from the nine flakes, a linear regression with a correlation of 0.825 can be calculated. Based on this regression, the average crosshead MOE would equal the average strain gage MOE only if gage length were 0.9 inch greater than the one used. However, the percentage of error is not constant for all flakes because the stiffer the specimen, the greater the possibility for underestimating gage length.

Though apparently more accurate than that based on crosshead movement, strain gage MOE can be in error by at least 12 percent because of the reinforcing effect of a gage applied to a thin section (Price 1974). Therefore, MOE values obtained by either method for thin specimens may not reflect the true tensile modulus.

Properties of Compressed Flakes

Density of face flakes compressed in the simulated flakeboard averaged 0.631 g/cc, an increase of 13.9 percent over the density of 0.554 for the unpressed flakes (Table 3). Core flake density, however, increased only 6.3 percent. Since the density was based on weight and volume at time of testing, the flake MC will contribute to density variability. Based on Duncan's multiple range test, the average MCs of core and control flakes are equivalent and significantly

Table 3. — FLAKE STATISTICS WITH TENSILE PROPERTIES ADJUSTED BY COVARIANCE ANALYSIS TO A MEAN GRAIN SLOPE.

	Layers		
Flake statistics	Outside	Middle	**Control**
Number of observations	200	200	**200**
Grain slope (degrees)			
Mean	6.030	6.018	**5.715**
SD[1]	4.153	4.945	**4.245**
Density (g/cc)			
Mean	0.631	0.589	**0.554**
SD[1]	0.087	0.081	**0.064**
Moisture content (%)			
Mean	5.53	6.32	**6.53**
SD[1]	1.84	1.92	**1.9**
Maximum stress (psi)			
Mean	8,986	7,801	**8,484**
SD[1]	3,375	3,209	**3,159**
Adjusted for grain slope	9,034	7,844	**8,393**
Tensile modulus (10^3 psi)			
Mean	654.1	552.4	**600.2**
SD[1]	168.1	144.4	**137.5**
Adjusted for grain slope	655.7	553.8	**597.1**

[1] Standard deviation

different from those of face flakes (Table 3). With a near-zero linear correlation between MC and tensile strength or modulus, no flake property adjustments for MC were performed.

The average grain slopes for the layers and for the unpressed controls were unequal. Thus, adjusted means for maximum stress and tensile modulus were obtained from a covariance analysis with grain slope, density, and grain slope plus density as covariates. Grain slope accounted for significantly more variation than did density or grain slope plus density. Comparison between the linear- and nonlinear-adjusted means for grain slope yields no significant difference. Also, the quadratic relationships are essentially linear in the data range; therefore, the linear regression adequately explains the relationship between grain slope and maximum stress or tensile modulus.

Although adjusted means for tensile strength differ among the three types of flakes (Table 3), the strength-grain slope regressions have statistically equivalent slopes (Table 4). Thus, compressing the flakes increased face flake strength by 7.6 percent and decreased core flake strength by 6.5 percent, but it did not alter the relationship between strength and grain slope.

Tensile modulus-grain slope regressions have unequal slopes and means. These differences could result from mat compression or from the measuring technique since the higher a flake's true MOE, the greater the probability for slippage, and thus for an underestimate in the calculated MOE. Of course, this flaw in the measuring technique implies that the 9.8 percent increase in face flake MOE and the 7.3 percent decrease in core flake MOE are conservative.

Discussion

Although all individual flakes were stored in the test environments at least 1 month before testing, unpressed flakes and core flakes had MCs significantly different from those of face flakes. A flakeboard under a similar conditioning cycle could have similar variations in MC.

The pressing cycle resulted in a vertical density profile because of flake densification throughout the board. But below a certain compaction ratio (compressed density: initial density), flake tensile strength would decrease, as evidenced by the reduced tensile strength of core flakes. Surface irregularities or indentations caused by compressing the flakes may explain the lowered strength of the core. On the other hand, at high densification ratios, the increased strength in the densified wood may be so large that it outweighs any strength loss caused by stress concentrations resulting from indentation. Thus, face flakes had greater tensile strength than did the controls. Tensile moduli results may also be affected similarly. Of course, the resin bonding effect that must occur in actual flakeboard is not reflected in these results.

Table 4. — REGRESSION EQUATIONS OF TENSILE PROPERTIES VERSUS GRAIN SLOPE FOR CONTROL FLAKES AND FLAKES REMOVED FROM A SIMULATED FLAKEBOARD.

$Y=a+bX$*		S_{yx}
Maximum tensile stress (10^3 psi)		
$\sigma_c=11.372-0.505\theta$	0.461	2.326
$\sigma_o=11.589-0.432\theta$	0.282	2.867
$\sigma_m=10.216-0.401\theta$	0.383	2.527
Tensile modulus (10^5 psi)		
$E_c=6.769-0.134\theta$	0.172	0.125
$E_o=7.363-0.364\theta$	0.114	0.159
$E_m=6.561-0.172\theta$	0.349	0.117

*Y = Maximum tensile stress (σ_i, 10^3 psi) tensile modulus (E_i, 10^5 psi), when i = location (control, outside, middle)

X = θ = grain slope, deg., with respect to flake's longitudinal edge.

Literature Cited

Biblis, E. J. 1969. Tensile properties of loblolly pine growth zones. Wood and Fiber 1(1):18-28.

Biblis, E. J. 1970. Effect of thickness of microtome sections on their tensile properties. Wood and Fiber 2(1):19-30.

Forest Products Laboratory. 1974. Wood handbook: wood as an engineering material. USDA Agri. Handb. 72, rev.

Manwiller, F. G. 1972. Wood and bark properties of spruce pine. USDA Forest Serv. Res. Pap. SO-78, So. Forest Expt. Sta., New Orleans, La. 25 pp.

Price, E. W. 1974. Analysis of southern hardwoods as furnish for a wood flake-resin composite structural material. Ph. D. thesis, Dept. of Theoretical and Applied Mechanics, Univ. of Illinois, Urbana-Champaign, Ill.

Rosen, B. W. 1967. The strength and stiffness of fibrous composites. Pages 106-120 *in* L. J. Broutman and R. H. Krock (eds.), Modern Composite Materials. Addison-Wesley Publ. Co., Reading, Mass. 581 pp.

Suchsland, O. 1962. The density distribution of flake boards. Quarter. Bull., Michigan Agri. Expt. Sta., Michigan State Univ., 45(11):104-121.