Dimensional and Relative Hygroscopic Properties Of Hardwoods From Southern Pine Sites

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ABSTRACT. Ten 6-inch trees from each of 22 species were sampled. Differences in EMC occurred at 85 and 71 percent RH but not at 50 or 25 percent; there was essentially no difference between sapwood and corewood. Radial shrinkage varied from 4.1 percent in water oak to 8.0 percent in hickory, while tangential shrinkage varied from 7.9 percent in sweetbay to 12.2 percent in hickory. For volumetric shrinkage, 61 percent of the variation was accounted for by SG; the relationship was linear. The apparent fiber saturation point varied from 28.1 percent for green ash to 33.1 percent for white oak.

THE LITERATURE reveals voluminous data on the hygroscopicity of wood (Stamm 1964, Kollmann and Côté 1968), particularly in relation to dimensional change. The *Wood Handbook* (U.S. Forest Products Laboratory 1974) presents species averages for many domestic woods. In southern hardwoods, however, only a few studies have been made on the variability within trees (i.e., Erickson 1949 and Barefoot 1963 for shrinkage in yellow-poplar), and species comparisons are not available.

We determined, therefore, to systematically sample and compare sapwood and corewood 6 feet above ground in 22 species of hardwoods. Data were taken on radial and tangential shrinkage and equilibrium moisture content (EMC) at various relative humidities (RHs). The species selected represent about 95 percent of the hardwood volume occurring on southern pine sites; in Tables 1 to 3 species are ranked in order of decreasing volumes, with sweetgum representing 21 percent and red maple and those below it representing 1 percent each. These species are currently of great interest as industry, faced with potential fiber shortages, attempts to find economic uses for wood hitherto regarded as largely unmerchantable.

Experimental Procedure

Sample Preparation

Since hardwoods on pine sites are typically small, sampling was restricted to trees 6 inches in diameter at breast height (DBH). For each species, 10 trees were obtained from throughout that portion of the range occurring in the 11-state area extending from Virginia to eastern Texas.

A cross-sectional disk was cut from each tree at a distance of 6 feet above ground. As portions of the disk were required for other studies, a wedge-shaped section was removed, air-dried, and allocated for present purposes. Cylindrical samples approximately 5/8 inch in diameter and 1/2 inch in length were taken from the wedge at locations near the bark and near the pith; cylinders were oriented parallel to the grain of the wood. Radial and tangential shrinkage were measured on each cylinder. From most wedges at least one and sometimes two cores were extracted from each type of wood. The classification of "corewood" was used because in some species the heartwood could not be distinguished from the sapwood on the basis of color.

Measurements

Samples were placed between blotters and were brought from air-dry to a fully swollen state in 4 days by the gradual addition of water. Their radial and tangential swollen dimensions were determined to 0.001 inch

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TABLE *EMCs (in percent) of various hardwood species at two nominal RH conditions. Values in parentheses are coefficients of variation (%).*

Species	Observations	85% RH	71% RH
Sweetgum (*Liquidambar styraciflua* L.)			
Hickory (*Carya* spp.)			
Black tupelo (*Nyssa sylvatica* Marsh.)			
Post oak (*Quercus stellata* Wangenh.)			
Southern red oak (*Q. falcata* Michx.)			
Water oak (*Q. nigra* L.)			
White oak (*Q. alba* L.)			
Yellow-poplar (*Liriodendron tulipifera* L.)			
Sweetbay (*Magnolia virginiana* L.)			
Black oak (*Q. velutina* Lam.)			
Cherrybark oak (*Q. falcata* var. *pagodaefolia* Ell.)			
White ash (*Fraxinus americana* L.)			
Green ash (*F. pennsylvanica* Marsh.)			
Red maple (*Acer rubrum* L.)			
American elm (*Ulmus americana* L.)			
Winged elm (*U. alata* Michx.)			
Hackberry (*Celtis* spp.)			
Northern red oak (*Q. rubra* L.)			
Scarlet oak (*Q. coccinea* Muenchh.)			
Shumard oak (*Q. shumardii* Buckl.)			
Laurel oak (*Q. laurifolia* Michx.)			
Blackjack oak (*Q. marilandica* Muenchh.)			

with calipers. The samples were then placed inside an environmental chamber at 105°F dry-bulb temperature and nominal 85 percent RH. A porthole in the chamber door allowed samples to be taken out and measured with minimum disturbance of the controlled environment. At equilibrium the weight of each sample was determined to 0.001 g, and radial and tangential dimensions were measured. This procedure was repeated for nominal RHs of 71, 50, and 25 percent at the same dry-bulb temperature. The samples were then oven-dried, weighed, and measured.

Following shrinkage measurements, the samples were placed in desiccators, evacuated for several hours, saturated with distilled water, and subjected to alternating vacuum and atmospheric pressure treatments until no more air bubbles could be detected. The specific gravity was then determined by the maximum-moisture-content method (Fogg 1967).

Results and Discussion

EMC

Analysis of variance indicated that species did not differ significantly in EMC at the two lower RHs. At 25 percent RH, EMC averaged 5.1 percent for all species with coefficient of variation of 3.4 percent, and at 50 percent RH it averaged 8.5 percent with coefficient of 2.8 percent. Since there were significant species differences (0.05 level of probability) at 85 percent RH and 71 percent RH, Duncan's multiple range test was applied. At 85 percent RH, species differences of 1.4 percent or more were significant, and scarlet oak contained significantly less moisture then did white oak, winged elm, hickory, and post oak, while Shumard oak contained less moisture than did hickory and post oak (Table 1). At 71 percent RH, species differences of 0.4 percent or more were significant; for example, hickory contained significantly more moisture than did all species except sweetgum, while scarlet oak contained less than all species except Shumard oak and green ash. Coefficients of variation among samples of a given species were generally small. Variance analyses indicated no significant difference between sapwood and corewood and no species x wood-type interaction. When species were analyzed separately, however, EMC of corewood averaged significantly less than that of sapwood in yellow-poplar (11.9% and 12.1%) and in Shumard oak (11.5% and 11.8%).

Specific Gravity (SG) and Shrinkage

Species average values for SG and total (green to ovendry) radial and tangential

TABLE 2. — *Average values of specific gravity ($\overline{G}$), radial shrinkage ($\overline{S}_R$) and tangential shrinkage ($\overline{S}_T$) in sapwood and corewood of various hardwood species.*[1]

Species	Sapwood				Corewood				Combined		
	Observations	$\overline{G}$	$\overline{S}_R$	$\overline{S}_T$	Observations	$\overline{G}$	$\overline{S}_R$	$\overline{S}_T$	Observations	$\overline{S}_R$	$\overline{S}_T$
			(%)				(%)			(%)	
Sweetgum	15	0.466	5.1	10.0	15	0.469	5.2	10.5	30		10.3
Hickory	18	0.791	8.0	12.2	17	0.786	7.9	12.1	35		12.2
Black tupelo	11	0.493	4.9	9.6	6	0.490	5.4	11.3	17		10.4
Post oak	17	0.718	6.1	10.2	17	0.718	6.6	11.9	34		11.1
Southern red oak	21	0.634	5.6	11.0	16	0.611	5.7	12.0	37		11.5
Water oak	20	0.604	3.9	10.0	13	0.593	4.3	11.0	33		10.5
White oak	15	0.718	6.6	11.4	15	0.713	7.1	12.6	30		12.0
Yellow-poplar	19	0.398	4.6	8.3	13	0.393	4.2	8.4	32		8.4
Sweetbay	21	0.435	4.2	7.8	14	0.435	4.1	8.0	35		7.9
Black oak	16	0.666	5.1	10.8	15	0.657	5.2	11.1	31		10.7
Cherrybark oak	19	0.646	5.2	11.2	12	0.632	5.2	11.7	31		11.5
White ash	19	0.642	6.1	9.2	19	0.631	6.0	8.9	38		9.1
Green ash	20	0.561	5.5	8.6	19	0.555	5.7	8.8	39		8.7
Red maple	17	0.602	4.2	8.8	13	0.578	4.5	9.2	30		9.1
American elm	21	0.538	5.1	10.5	16	0.532	6.0	11.1	37		10.8
Winged elm	19	0.642	5.2	10.2	18	0.640	5.3	9.9	37		10.0
Hackberry	16	0.536	4.5	9.3	15	0.525	4.8	9.5	31		9.4
Northern red oak	14	0.652	4.7	10.8	11	0.648	5.1	11.6	25		11.2
Scarlet oak	20	0.643	5.2	10.9	17	0.627	5.1	12.3	37		11.6
Shumard oak	17	0.788	4.8	11.0	16	0.766	5.2	11.2	33		11.1
Laurel oak	19	0.613	4.4	10.7	16	0.606	4.6	10.6	35		10.6
Blackjack oak	15	0.694	4.4	8.8	9	0.676	7.4	9.9	24		9.4

[1] Shrinkage measurements were made on samples resoaked from an air-dry condition.

shrinkage of sapwood and corewood are presented in Table 2. Shrinkage was computed from green dimensions. With the exception of white ash, green ash, and American elm, the average radial and tangential values agree closely with those presented in the *Wood Handbook* (U.S. Forest Products Laboratory 1974). Figure 1 illustrates the wide range of values within and among species. For corewood and sapwood samples combined (Table 2), differences of 0.6 percent or more in radial shrinkage were significant. Shrinkage was least—4.1 to 4.5 percent—in water oak, sweetbay, yellow-poplar, red maple, laurel oak, and hackberry. It was greatest in hickory (8.0%), white oak (6.8%), and post oak (6.3%). White and post oak shrank more radially than did the nine red oaks.

In tangential shrinkage, differences of 0.8 percent or more were significant. Sweetbay, with 7.9 percent tangential shrinkage, displayed statistically less shrinkage than all species except yellow-poplar. The ashes, red maple, blackjack oak, and hackberry, ranging from 8.7 to 9.4 percent, were next lowest and

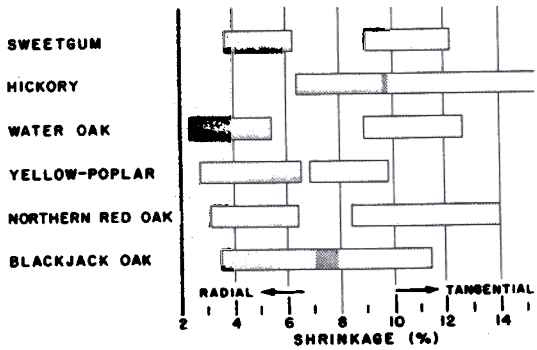

Figure 1. — Ranges of radial and tangenti shrinkage values for representative species.

not significantly different from each othe Hickory (12.2%), several oaks, and Americ elm (10.8%) shrank most.

SG tended to be lower—and shrinka accordingly less—in corewood than sapwood. In white oak, American elm, a blackjack oak, however, corewood shrinka significantly exceeded that of sapwood in both the radial and tangential directions. It was greater in the tangential direction only in black tupelo, water oak, southern red oak, black oak, scarlet oak, and northern red oak.

Reasons for these exceptions are not known; visual inspection of the samples revealed no evidence of collapse. Erickson (1949), however, indicated that wood near the pith of yellow-poplar samples shrank more than would be expected from the normal relation to SG.

Percent volumetric shrinkage (S_V) can be computed with close approximation (Skaar 1972) from radial (S_R), tangential (S_T), and longitudinal (S_L) shrinkage as follows:

$$S_V \cong S_R + S_T + S_L - (0.01)(S_R)(S_T)$$

Since the values for S_L and $(0.01)(S_R)(S_T)$ are both approximately 0.5 percent, they tend to cancel each other in the equation and apparent volumetric shrinkage can be expressed as:

$$S_V \cong S_R + S_T$$

The correlation coefficient between apparent volumetric shrinkage and SG was 0.78; i.e., only 61 percent of the variation was accounted for by variation in SG. For the 22 species means, the regression equation was $S_V = 7.40 + 13.61(G)$. Kelsey (1956) reported somewhat similar results for 131 species from Australia. He obtained a correlation coefficient of 0.76 for the relationship between unit volumetric shrinkage and basic density (g/cc), and the regression coefficient also was not unity, i.e., the regression line did not go through zero.

Fiber Saturation Point

The fiber saturation point—that MC at which cell lumens are devoid of water but cell walls are completely saturated—cannot be determined exactly since there is no sharp change in the MC-RH isotherm at that point. However, the shrinkage intersection point (apparent fiber saturation point) was obtained by plotting the linear pattern of volumetric shrinkage against MC and extrapolating this line to zero shrinkage (Kelsey 1956, Wangaard 1957). Because the wood is likely to be in a stressed condition, the value for volumetric shrinkage obtained at the ovendry condition tends to deviate from a straight line and is not used in determining shrinkage intersection points. Consequently only the four intermediate shrinkage points were used in

TABLE 3. — *Regression equations of the relationship between volumetric shrinkage ($\bar{S}_v$) and moisture content (M) for various hardwood species, and their intersection points.*

Species	Regression of $\bar{S}_v$ on M	Correlation coefficient	Intersection point %
Sweetgum	16.510 − 0.507(M)	−0.996	32.6
Hickory	20.330 − 0.617(M)	−1.000	32.9
Black tupelo	15.621 − 0.500(M)	−0.999	31.2
Post oak	17.026 − 0.516(M)	−0.998	33.0
Southern red oak	17.210 − 0.541(M)	−0.998	31.8
Water oak	14.487 − 0.476(M)	−0.996	30.4
White oak	18.916 − 0.572(M)	−0.999	33.1
Yellow-poplar	13.256 − 0.433(M)	−0.999	30.6
Sweetbay	12.073 − 0.429(M)	−0.998	28.1
Black oak	16.267 − 0.520(M)	−0.999	31.3
Cherrybark oak	16.943 − 0.543(M)	−0.999	31.2
White ash	15.197 − 0.524(M)	−0.994	29.0
Green ash	14.905 − 0.531(M)	−0.996	28.1
Red maple	13.800 − 0.477(M)	−0.999	28.9
American elm	16.900 − 0.551(M)	−0.999	30.7
Winged elm	15.664 − 0.564(M)	−0.999	27.8
Hackberry	14.130 − 0.481(M)	−0.999	29.4
Northern red oak	16.543 − 0.547(M)	−0.998	30.2
Scarlet oak	17.012 − 0.558(M)	−0.997	30.5
Shumard oak	16.329 − 0.559(M)	−1.000	29.2
Laurel oak	15.253 − 0.513(M)	−0.996	29.7
Blackjack oak	14.491 − 0.501(M)	−0.999	28.9

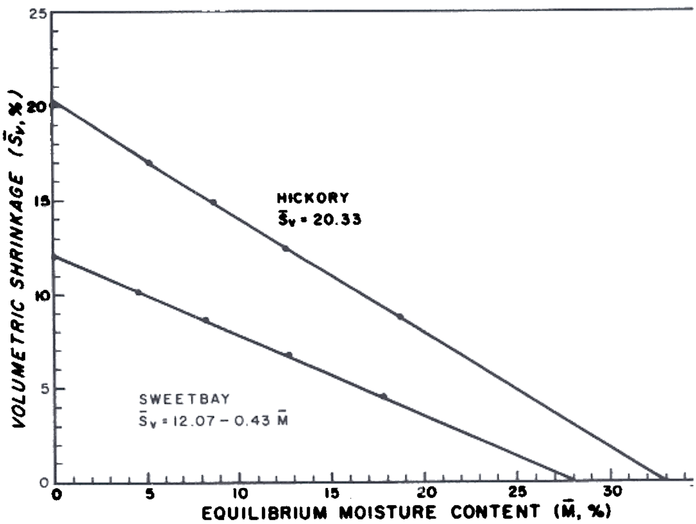

Figure 2. — Volumetric shrinkage as a function of EMC in hickory (R=–1.000) and sweetbay (R=–0.998).

deriving the regression equations listed in Table 3. As shown by the examples in Figure 2, these points lie almost exactly on a straight line. At S_v = zero, the equations (Table 3) yielded the shrinkage intersection point. This point was near 30 percent, ranging from 28.1 percent for sweetbay and green ash to 33.1 percent for white oak. That the intersection point is near 30 percent for all species indicates that it is a hygroscopic property and directly related to the fiber saturation point.

The slope of the shrinkage-MC curve can be considered an indicator of dimensional stability. A wood which exhibits a low slope (e.g., 0.429 for sweetbay) would have high stability, whereas a steep slope (e.g., 0.617 for hickory) would indicate low stability. Slope is also directly related to total green-to-ovendry shrinkage. When species means for total shrinkage were regressed on slope, the equation S_v=–3.34+36.87 (slope) was obtained. The correlation coefficient was 0.89—an indication that 79 percent of the variation was attributable to slope and only 21 percent to othe factors such as variation in shrinkage in tersection point.

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