THE EFFECTS OF PREVIOUS DRYING ON SHRINKAGE AND MOISTURE CONTENT OF SOME SOUTHERN BOTTOMLAND HARDWOODS[1]

Todd F. Shupe

Forest Products Specialist
Louisiana Cooperative Extension Service
Louisiana State University Agricultural Center
Baton Rouge, LA 70894-5100

Elvin T. Choong

Professor
School of Forestry, Wildlife, and Fisheries
Louisiana State University Agricultural Center
Baton Rouge, LA 70803-6202

Mark D. Gibson

Professor
School of Forestry
Louisiana Forest Products Laboratory
Louisiana Tech University
Ruston, LA 71272-0045

George A. Grozdits

Research Associate
Louisiana Forest Products Laboratory
Louisiana Tech University
Ruston, LA 71272-0045

and

O. Victor Harding

Remanufacturing Technologist
Forest Research Institute
Private Bag 3020
Rotorua, New Zealand

(Received September 1997)

ABSTRACT

Three logs for each of nine southern hardwood species were obtained, and specimens were separated into heartwood and sapwood. Specimens were dried from the initial green condition to oven-dry and then resaturated and dried again to oven-dry. A simple linear regression analysis was performed to determine the relationship between volumetric shrinkage and moisture content of never-dried and previously-dried specimens. The average fiber saturation point was 33.3 (33.6 for sapwood and 32.9 for heartwood) for never-dried specimens and 29.4 (28.2 for sapwood and 30.6 for heartwood) for previously-dried specimens. An average of 86% of the variability in volumetric shrinkage of never-dried specimens can be attributed to moisture content, and 90.5% of the variability in volumetric

[1] This paper (No. 97-220362) is published with the approval of the Director of the Louisiana Agricultural Experiment Station.

Wood and Fiber Science, 30(3), 1998, pp. 273–280

shrinkage of previously-dried specimens can be attributed to moisture content. Highly significant differences for the species factor were found to exist at an equilibrium moisture content of 90% relative humidity (RH) and 75% RH for both never-dried and previously-dried specimens. Volumetric shrinkage differed significantly for species and wood-types at 90%, 75%, and 0% RH for previously-dried wood and 75% and 0% RH for never-dried wood. A *t*-test revealed significant differences between volumetric shrinkage of never-dried and that of previously-dried wood for both wood-types of two species and one wood-type of three others.

Keywords: Equilibrium moisture content, fiber saturation point, shrinkage.

INTRODUCTION

The utilization of the southern bottomland hardwoods has lagged behind the southern yellow pines largely because of poorer tree form and longer rotation ages. Hardwood anatomy is much more complex than that of softwoods and thus hardwood properties, such as shrinkage, can often be more complex. Previous researchers interested in hardwood hygroscopicity have mainly focused on adsorption and desorption isotherms and on consequent dimensional change (Stamm 1964; Kollman and Côté 1968). Stamm (1959, 1964) showed that good estimates of fiber saturation point (FSP) can be made by measuring equilibrium moisture content (EMC) and dimensional changes at several relative humidities (RH). The ratio of EMC to swelling is relatively constant, and when this relationship is extrapolated to maximum swelling (or to zero), the EMC is at FSP.

The difference in FSP between never-dried wood and previously-dried has not been widely reported in the literature. Feist and Tarkow (1967) reported the FSP of never-dried and once-dried Sitka spruce (*Picea sitchensis* Bong. Carr.) wood to be 40% and 31%, respectively. Their methodology included soaking green wood in polyethelene glycol with a molecular size sufficiently large enough to prohibit penetration into the wood structure. The Feist and Tarkow (1967) method was applied to never-dried slash pine (*Pinus elliottii* Engelm.) and indicated a FSP substantially higher than those determined from the shrinkage observations of Nearn (1955); Higgins (1957); Choong (1969a, b). Similar studies on southern hardwoods are uncommon in the literature (Koch 1985).

Choong et al. (1989) found good correlations between volumetric shrinkage (S_v) and specific gravity (SG) for extracted and unextracted innerwood, middlewood, and outerwood of both baldcypress and tupelo. No correlations were performed between S_v and moisture content (MC). Choong and Manwiller (1976) found that 61 percent of S_v variation of 22 southern hardwood species was due to specific gravity. They reported the correlation coefficient between S_v and MC to range from -0.994 to -1.000. Recent research by Shupe et al. (1995a, b, 1996) has shown insignificant within-tree correlation between S_v and specific gravity (SG) for sweetgum, cottonwood, and yellow-poplar outerwood, middlewood, and corewood.

This present study has expanded on previous investigations of southern hardwoods hygroscopicity by (1) including other southern bottomland hardwood species, (2) examining the correlation between S_v and MC of heartwood and sapwood of never-dried and previously-dried wood, and (3) addressing the differences in some hygroscopic properties of never-dried and previously-dried southern hardwoods. These differences, especially for (FSP), have not been widely reported.

MATERIALS AND METHODS

Sample preparation

Three, defect-free 4.88-m sawlogs, without eccentric growth rings, were selected for each of nine southern bottomland hardwood species in the log yard at Plaqemine Hardwoods in Plaqemine, LA. Tree age was unknown for all species. All logs came from a 200-km radius of Baton Rouge, LA. A 15.24-cm-thick disk was cut 15.24 cm from the end of all logs. The disks were reduced in size, and eight specimens measuring 3.81 cm × 3.81 cm × 1.27 cm were obtained from both heartwood and sapwood regions of all disks. In species without a definite heartwood/sapwood transition, heartwood samples were simply taken from the center of the disk and sapwood samples near the edge. No heartwood samples contained pith.

Measurements

All shrinkage values were determined from the ratio of change in dimension from the swollen condition to oven-dry condition to swollen dimension, expressed as a percentage. Volumetric shrinkage was estimated from the summation of radial and tangential shrinkage, which has been shown to give a reliable and close approximation to the true volumetric shrinkage (Choong 1969a). The green radial and tangential specimen dimensions were measured to the nearest 0.001 in. (0.00254 cm) with a dial caliper, and green weight was measured to the nearest 0.01 g with a digital balance. Specimens were then conditioned in an Aminco chamber at 32°C and decreasing nominal relative humidities of 90%, 75%, 50%, 20% and approximately 0% before oven-drying at 105°C for 24 hours. Specimen dimensions and weights were recorded at equilibrium prior to each humidity change and in the oven-dry condition. All specimens were rehydrated in water until repeated weighings showed constant weight and thus the maximum MC had been achieved. These previously-dried samples were dried again using the same process as previously described.

Properties measured included (EMC) at various RH conditions, and radial, tangential, and volumetric dimensions. The experimental design was a completely randomized design. Data were analyzed by analysis of variance and simple regression techniques (Steel and Torrie 1980) in accordance with SAS programming procedures (SAS Institute 1989). All regression lines were fitted to three data points at 0%, 20%, and 90% RH.

TABLE 1. *Summary of analysis of variance.*[1]

Source	df[3]	EMC[2] 90% RH[4]	EMC 75% RH	Volumetric shrinkage 90% RH	Volumetric shrinkage 75% RH	Volumetric shrinkage 0% RH
			Never-dried wood			
Species	8	**	**	NS	**	**
Wood-type	1	NS	NS	NS	**	**
			Previously-dried wood			
Species	8	**	**	**	**	**
Wood-type	1	NS	NS	**	**	**

[1] ** = significant at alpha = 0.01; NS = not significant.
[2] EMC = equilibrium moisture content (%).
[3] df = degrees of freedom.
[4] RH = relative humidity (%).

RESULTS AND DISCUSSION

Equilibrium moisture content (EMC)

Data from never-dried and previously-dried specimens conditioned at 90% RH and 75% RH were included in an analysis of variance (ANOVA) to determine the effect of species and wood-type (Table 1). The sources of variation (SOV) were nearly identical in terms of significance for both never-dried and previously-dried wood. One exception was the highly significant species and wood-type factors for volumetric shrinkage at 90% RH for previously-dried wood. These terms were not significant for never-dried wood at the same conditions.

The species factor was highly significant for EMC at 75% RH and 90% RH (Table 1). These findings are in agreement with those of Choong and Manwiller (1976), who found significant species differences in EMC at 85% RH and 71% RH of 22 hardwoods with 6-inch diameters from southern pine sites. Apparently the relationship between EMC and high RHs is the same for wood from both juvenile and mature trees.

Volumetric shrinkage (S_v)

Highly significant differences ($P < 0.01$) were detected among species and wood-type for both never-dried and previously-dried specimens conditioned at 0% and 75% RH (Table 1). Although density values were not obtained from the samples, the relationship of density and shrinkage of different wood types is well documented in the literature (Choong et al. 1989; Shupe et al. 1995a, b, 1996). An interesting phenomenon occurred with the never-dried and previously-dried specimens conditioned at 90% RH. All SOVs were not significant for the never-dried specimens at 90% RH, but all SOVs were highly significant ($P < 0.01$) for previously-dried wood at 90% RH (Table 1). These specimens were well below FSP even at 90% RH. Consequently, hygroscopic properties change and the amount of bound water will be less, due to the effects of heat treatment during oven-drying. The heat treatment reduces the number of hydroxyl groups available for hydrogen bonding.

Table 2 presents regression equations of the relationship between volumetric S_v and MC for not previously-dried specimens. The S_v data of the not previously-dried specimens was compared to that of the previously-dried specimens using a *t*-test (Table 3). The *t*-test results are mixed. The S_v of willow, American elm, and white ash sapwood differed significantly; yet the heartwood of these species was statistically similar for never-dried and previously-dried specimens. Tupelogum and sweetgum differed significantly for both heartwood and sapwood. Choong and Manwiller (1976) found correlation coefficients between S_v and MC of -0.994 for white ash, -0.996 for sweetgum, and -0.999 for American elm and tupelo.

Linear regression of volumetric shrinkage on moisture content

The coefficient of determination (r^2) ranged from 0.66 to 0.99, with an average of 0.86 for the never-dried specimens (Table 2). This range indicates that much of the variation in S_v can be attributed to moisture content. It is interesting to note that willow sapwood and sycamore heartwood had an r^2 of 0.67 and 0.66, respectively. When these two mean values are removed, the remaining range of r^2 is now 0.89 to 0.99, which is in closer agreement with previous research by Choong and Manwiller (1976), who found the correlation coefficient (r) to range from -0.994 to -1.000 with an average of -0.998 for 22 southern hardwood species. The corresponding range of coefficients of determination (r^2) for Choong and Manwiller (1976) was 0.988 to 1.0 with an average of 0.996.

A strong relationship was also found for the previously-dried specimens. The r^2 ranged from 0.73 to 0.99, and the average was 0.90 (Table 3). The volumetric shrinkage in the previously-dried specimens correlates better with MC ($r^2 = 0.91$) than the never-dried specimens ($r^2 = 0.86$).

Fiber saturation point (FSP)

The fiber saturation point, the MC at which cell lumens are void of water but cell walls are totally saturated, cannot be determined exactly since there is no sharp change in the MC-RH relationship at that point. Because the wood is likely to be in a stressed condition, the values for volumetric shrinkage obtained at the oven-dry condition tend to deviate from a straight line and were not used in determining shrinkage intersection points (Choong and Manwiller 1976). However, the shrinkage intersection point (IP), which measures apparent FSP, was derived by plotting the linear pattern of S_v against MC and extrapolating this line to zero shrinkage (Kelsey 1956; Wangaard 1957; Stamm 1959). The shrinkage points at 20%, 50%, 75%, and 90% RH were used in deriving regression equations and apparent FSP values.

The apparent FSP as determined from the IP ranges from 26.4% to 42.5% for never-dried woods (Table 2) and from 26.0% to 33.3% for previously-dried woods (Table 3). It has previously been proposed that wood with a large extractive content may display an abnormally low FSP (Nearn 1955; Higgins 1957; Wangaard 1957; Spalt 1958; Wangaard

TABLE 2. *Regression equations of the relationship between volumetric shrinkage (S_v) and moisture content (MC) for never-dried bottomland Louisiana hardwood species and their intersection points.*

Species/Wood-type	Scientific name	Regression of S_v on MC	r^2	Intersection point[1] (%)	FSP[2]	FSP[3]
Willow	*Salix nigra* Marsh				—	—
Sapwood		8.974–0.211 (MC)	0.67	42.5		
Heartwood		11.485–0.373 (MC)	0.96	30.7		
Cottonwood	*Populus deltoides* Bartr. ex Marsh.				—	—
Sapwood		11.259–0.404 (MC)	0.85	27.8		
Heartwood		14.527–0.426 (MC)	0.87	34.1		
Tupelogum	*Nyssa aquatica* L.				—	31.2
Sapwood		12.163–0.353 (MC)	0.95	34.4		
Heartwood		15.840–0.415 (MC)	0.88	38.2		
Sweetgum	*Liquidambar styraciflua* L.				30.9	32.6
Sapwood		14.975–0.370 (MC)	0.92	40.4		
Heartwood		16.167–0.439 (MC)	0.83	36.8		
Yellow-poplar	*Liriodendron tulipifera* L.				29.0	27.7
Sapwood		15.463–0.497 (MC)	0.84	31.1		
Heartwood		12.402–0.405 (MC)	0.82	30.6		
Sycamore	*Platanus occidentalis* L.				—	—
Sapwood		12.107–0.421 (MC)	0.84	28.8		
Heartwood		14.729–0.429 (MC)	0.66	34.3		
American elm	*Ulmus americana* L.				26.7	30.7
Sapwood		13.107–0.382 (MC)	0.92	34.3		
Heartwood		14.122–0.424 (MC)	0.95	33.3		
Soft maple	*Acer saccharinum* L.				26.3[4]	28.9[4]
Sapwood		10.954–0.347 (MC)	0.93	31.6		
Heartwood		12.450–0.393 (MC)	0.81	31.7		
White ash	*Fraxinus americana* L.				27.9	29.0
Sapwood		11.919–0.377 (MC)	0.81	31.6		
Heartwood		14.804–0.581 (MC)	0.99	26.4		
Mean			SW[5] = 0.86 HW[6] = 0.86	SW[5] = 33.6 HW[6] = 32.9		

[1] This intersection point is equivalent to the apparent fiber saturation point.
[2] FSP determined from average of adsorption and desorption data from stemwood of 6-in. trees (Okoh 1976).
[3] Average FSP determined from shrinkage data of 6-in. stemwood (Choong and Manwiller 1976).
[4] Values represent red maple (*Acer rubrum* L.).
[5] SW = sapwood.
[6] HW = heartwood.

TABLE 3. *Regression equations of the relationship between volumetric shrinkage (S_v) and moisture content (MC) for previously-dried bottomland Louisiana hardwood species and their intersection points.*

Species/Wood-type	Regression of S_v on MC	r^2	Intersection point[1] (%)	t-test[2]
Willow				
Sapwood	8.695–0.282 (MC)	0.88	30.8	**
Heartwood	11.924–0.399 (MC)	0.98	29.9	NS
Cottonwood				
Sapwood	10.896–0.386 (MC)	0.84	28.2	NS
Heartwood	14.337–0.430 (MC)	0.91	33.3	NS
Tupelogum				
Sapwood	11.909–0.426 (MC)	0.96	27.9	*
Heartwood	15.294–0.482 (MC)	0.95	31.7	*
Sweetgum				
Sapwood	13.648–0.453 (MC)	0.94	30.1	**
Heartwood	15.320–0.465 (MC)	0.95	32.9	*
Yellow-poplar				
Sapwood	15.288–0.517 (MC)	0.86	29.6	NS
Heartwood	12.277–0.429 (MC)	0.94	28.6	NS
Sycamore				
Sapwood	11.783–0.447 (MC)	0.80	26.3	NS
Heartwood	14.670–0.504 (MC)	0.73	29.1	NS
American elm				
Sapwood	12.384–0.468 (MC)	0.92	26.1	**
Heartwood	13.983–0.459 (MC)	0.96	32.9	NS
Soft maple				
Sapwood	10.770–0.380 (MC)	0.87	28.3	NS
Heartwood	12.219–0.398 (MC)	0.84	30.7	NS
White ash				
Sapwood	10.837–0.409 (MC)	0.91	26.4	**
Heartwood	14.546–0.560 (MC)	0.99	26.0	NS
Mean		sapwood = 0.89 heartwood = 0.92	sapwood = 28.2 heartwood = 30.6	

[1] This intersection point is equivalent to the apparent fiber saturation point.
[2] t-test was conducted to compare volumetric shrinkage of never-dried and previously-dried wood.
* Denotes significance at alpha = 0.05.
** Denotes significance at alpha = 0.01.

and Granados 1967; Feist and Tarkow 1967; Choong 1969b; Shupe et al. 1996). In this study, we found never-dried specimens to have an average apparent FSP of 33.3%, (33.6% for sapwood and 32.9% for heartwood), and previously-dried specimens to have an average apparent FSP of 29.4% (28.2% for sapwood and 30.6% for heartwood).

Table 2 also presents FSP values from previous research projects by Okoh (1976) and Choong and Manwiller (1976) on stemwood of 6-in. trees. Our FSP values are consistently higher than those reported by the other researchers. We determined FSP using wood specimens obtained from sawlogs. Okoh (1976) determined FSP from adsorption and desorption data, and Choong and Manwiller (used) derived FSP from shrinkage data.

Moreover, it is known that FSP values may also vary according to the experimental procedure used by Koch (1985).

The slope of the shrinkage-MC curve can be considered an indicator of dimensional stability. A wood that exhibits a low slope (e.g., 0.211 for never-dried willow sapwood) would have high stability, whereas a steep slope (e.g., 0.581 for never-dried white ash heartwood) would indicate less dimensional stability.

If the slope of the shrinkage-MC curve indicates a degree of dimensional stability, then species that have similar slopes for sapwood and heartwood should indicate good lumber stability (i.e., less bow, cup, twist, etc.). For example, previously-dried sweetgum (slope = 0.453 and 0.465 for sapwood and heartwood, respectively) and American elm (slope = 0.468 and 0.459 for sapwood and heartwood, respectively (Table 3). After kiln-drying, we would expect these species to show good stability with minimal warp. Shrinkage performance does not always correlate well with wood density if large fibril angles, aspirated pits, or high extractive concentrations are present (Kollman and Côté 1968).

In contrast, soft maple (slope = 0.380 and 0.398 for sapwood and heartwood, respectively) is dimensionally stable but has low slope. Therefore, it will display less shrinkage per unit MC change. It should not be mixed with sweetgum and American elm because these two species have higher rates of dimensional changes than soft maple.

CONCLUSIONS

This research has shown that there is a strong relationship between S_v and MC of heartwood and sapwood of southern hardwoods for both never-dried and previously-dried specimens. The average apparent FSP as determined from the IP was 33.3% (33.6% for sapwood and 32.9% for heartwood) for never-dried specimens and 29.4% (28.2% for sapwood and 30.6% for heartwood) for previously-dried specimens. An average of 86.0% of the variability in S_v of never-dried specimens can be attributed to MC, and 90.5% of the variability in S_v of previously-dried specimens can be attributed to MC. Significant differences in EMC for both never-dried and previously-dried wood species were found to exist at RH conditions of both 90% and 75%.

REFERENCES

CHOONG, E. T. 1969a. Moisture and the wood of the southern pines. Forest Prod. J. 19(2):30–36.

———. 1969b. Effect of extractives on shrinkage and other hygroscopic properties of ten southern pine woods. Wood Fiber 1:124–133.

———, AND F. G. MANWILLER. 1976. Dimensional and relative hygroscopic properties of hardwoods from southern pine sites. Wood Sci. 9(1):39–43.

———, P. J. FOGG, AND C. B. POLLOCK. 1989. Variation in shrinkage properties of second-growth baldcypress and tupelogum. Wood Fiber Sci. 21(1):17–29.

FEIST, W. C., AND H. TARKOW. 1967. Polymer exclusion in wood substance: A new procedure for measuring fiber saturation points. Forest Prod. J. 17(10):65–68.

HIGGINS, N. C. 1957. The equilibrium moisture content—Relative humidity relationship of selected native and foreign woods. Forest Prod. J. 7:371–377.

KELSEY, K. E. 1956. The shrinkage intersection point—Its significance and the method of its determination. Forest Prod. J. 6(10):411–417.

KOCH, P. 1985. Utilization of hardwoods growing on southern pine sites. USDA Forest Serv. Agric. Handb. 605, vol. 1. U.S. Govt. Print. Off., Washington. DC. 1418 pp.

KOLLMANN, F. F. P., AND W. A. CÔTÉ, JR. 1968. Principles of wood science and technology, vol. 1. Solid wood. Springer-Verlag, New York, NY. 592 pp.

NEARN, W. T. 1955. Effect of water soluble extractives on the volumetric shrinkage and equilibrium moisture content of eleven tropical and domestic woods. Penn. Agric. Exp. Stat. Bull. 598. 38 pp.

OKOH, I. K. A. 1976. Moisture sorption and electrical resistivity of some woods and barks. Ph.D. thesis, State Univ. of New York, Coll. of Environ. Sci. and For., Syracuse, NY. 183 pp.

SAS INSTITUTE, INC. 1989. SAS/STAT User's guide, version 6, 4th ed., vol. 2. Cary, NC. 846 pp.

SHUPE, T. F., E. T. CHOONG, AND M. D. GIBSON. 1995a. Differences in moisture content and shrinkage between innerwood and outerwood of a single cottonwood tree. Forest Prod. J. 45(10):89–92.

———, ———, AND ———. 1995b. Differences in moisture content and shrinkage between outerwood, middlewood, and corewood of two yellow-poplar trees. Forest Prod. J. 45(9):85–90.

———, ———, AND ———. 1996. The effects of previous drying and extractives on shrinkage of outerwood, middlewood, and corewood of two sweetgum trees. Forest Prod. J. 46(9):94–97.

SPALT, H. A. 1958. The fundamentals of water vapor sorption by wood. Forest Prod. J. 8(10):288–295.

STAMM, A. J. 1959. Method for estimating vapor sorption at fiber saturation point of wood and paper. Holz Roh-Werkst. 17(5):203–205.

———. 1964. Wood and cellulose science. Ronald Press Co., New York, NY. 549 pp.

STEEL, R. G. D., AND J. H. TORRIE. 1980. Principles and procedures of statistics; A biometrical approach, 2nd ed. McGraw-Hill, Inc., New York, NY. 633 pp.

WANGAARD, F. F. 1957. A new approach to the determination of fiber saturation point from mechanical tests. Forest Prod. J. 7(11):410–416.

———, AND L. A. GRANADOS. 1967. The effect of extractives on water vapor sorption by wood. Wood Sci. Technol. 1:253–277.