EFFECT OF EXTRACTIVES ON SHRINKAGE AND OTHER HYGROSCOPIC PROPERTIES OF TEN SOUTHERN PINE WOODS

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ABSTRACT

The significance of extraction treatment on the ten woods of the southern pines was studied. Additional data were obtained on fiber saturation point and equilibrium moisture content. The hygroscopic properties of these woods vary widely with extractive content. Extraction of wood with hot-water and organic solvents greatly improved the volumetric shrinkage—specific gravity relationship. The variation of shrinkage anisotropy with specific gravity was discussed.

INTRODUCTION

Hygroscopicity is an important property of wood. Differences in hygroscopicity, as reflected by variations in moisture equilibrium, shrinkage, and fiber saturation point, are the results of variations in the amount of wood substance, the hygroscopic potential of wood, and the chemical composition of wood. Vorreiter (1963) found that the fiber saturation point decreases considerably with an increase in density. However, the fiber saturation point is not a function of density alone. A cell wall with a high percentage of amorphous regions and a large number of polar sites on the surface of the cellulose crystallites has a high potential for adsorbing water. Furthermore, not all wood has the same chemical composition. The significance of this has been reported by Christensen and Kelsey (1959), who found that the sorption behavior is highest in hemicellulose, less in cellulose, and least in lignin. Nearn (1955) found that the equilibrium moisture content and shrinkage of wood were affected by removal of water-soluble extractives. Recent work by Wangaard and Granados (1967) showed that the principal effect of extractives is to depress the sigmoid isotherm in the upper range of relative humidity.

When the cell walls lose water, they shrink in external dimension in proportion to the apparent volume of moisture loss. Hence, the dimensional change property of wood is dependent on the amount of cell wall substance. A relationship of volumetric shrinkage of different woods with specific gravity has been obtained by a number of investigators. Newlin and Wilson (1919) found a straight line relationship with a slope of 28 which goes to the origin for 117 domestic species. Hence Stamm (1935) postulated a simple relationship describing average percentage of external volumetric shrinkage ($\overline{S}_v$) to the average volumetric fiber saturation point ($\overline{M}_F$) and the average specific gravity based on green volume ($\overline{G}$) as follows:

$$\overline{S}_v = (\overline{M}_F)(\overline{G}) = (\overline{M}'_F)(\overline{G})/1.115 \quad (1)$$

where $\overline{M}'_F$ is defined as gravimetric saturation, which is the slope of the line and the apparent fiber saturation point based on a percentage volume of water per unit weight of dry wood. Theoretically, $\overline{M}'_F$ deviates from the average fiber saturation point, expressed as the weight of water per unit weight of dry wood, by a factor equal to the average specific gravity of the adsorbed water, namely, 1.115 (Stamm 1964).

The total shrinkage of the gross wood (S_v) consists of the shrinkage of the cell wall and the shrinkage of the cell cavities, according to the percentage of green volume (V_g) of the gross wood:

$$S_v = \frac{100(V_w)}{V_g} + \frac{\int_{M_F}^{0} \left(\frac{dV}{dM}\right) dM}{V_g} \quad (2)$$

where V_w is volume of water sorbed in the cell wall, V is volume of the cell cavities, M is moisture content, and M_F is maximum moisture in the cell wall or fiber saturation point. The second term of Equation (2) vanishes if it is assumed that the cell

TABLE 1. *Species of southern pine used in the study and their sources*

Species	Source
Major species	
Slash pine (*P. elliottii* Engelm.)	LSU Forest, Bogalusa, La.
Longleaf pine (*P. palustris* Mill.)	LSU Forest, Bogalusa, La.
Shortleaf pine (*P. echinata* Mill.)	LSU Forest, Bogalusa, La.
Loblolly pine (*P. taeda* L.)	LSU Forest, Bogalusa, La.
Minor species	
Spruce pine (*P. glabra* Walt.)	Reimers-Schneider Mill, Natalbany, La.
Pond pine (*P. serotina* Michx.)	So. For. Exp. Sta. (Olustee, Fla.)
Pitch pine (*P. rigida* Mill.)	So. For. Exp. Sta. (New Lisbon, N. J.)
Virginia pine (*P. virginiana* Mill.)	So. For. Exp. Sta. (Blacksburg, Va.)
Sand pine (*P. clausa* Vasey)	So. For. Exp. Sta. (Ocala, Fla.)
Table-mountain pine (*P. pungens* Lamb.)	So. For. Exp. Sta. (Blacksburg, Va.)

cavities remain constant during shrinkage; therefore Equation (2) can easily be converted to Equation (1).

Stamm and Loughborough (1942) used the above Equation (1) and reported that the apparent fiber saturation point of 52 softwoods is 26% and of 106 hardwoods is 27%. Other investigators have reported different equations from that proposed by Stamm. Kelsey (1956) gave an equation of $\overline{S_v/M'_F} = 0.238 + 0.467$ (G) with an r^2 of 0.57 for 130 Australian species; whereas Sekhar and Rajput (1967) showed an equation of $S_v = 6.2 + 2.8(G)$ for 150 Indian woods. The departure of the regression coefficient from unity in Kelsey's equation has been explained as due largely to a change in the size of the cell cavities during drying.

The southern pines consist of a number of closely related species. However, there are considerable variations in specific gravity and extractive content within and among species. Hence this study was undertaken to determine the effect of extractives on the hygroscopic properties of these woods.

EXPERIMENTAL PROCEDURE

Ten southern pine species were chosen for this study, as listed in Table 1. For the four major southern pine species, selected trees having wide variations in specific gravity at DBH were felled, then taken to a mill where a number of cants were cut from the corewood (5–15 years) and maturewood (25–40 years) section. From each cant, two representative end-matched samples were prepared, which measured 1 × 1 inch in cross-section and ¼ inch in the fiber direction. For each of the six minor southern pine species, cross-sectional wedges were obtained from different positions in a log. From each wedge, two end-matched samples having the same 1 × 1 inch cross-sectional size were prepared from each of several radial locations.

All the prepared samples were first dipped in water and then placed in a sealed desiccator over water for one week. The samples were then transferred to controlled conditions either in desiccators over saturated salt solutions, in the oven, or in a drying chamber to undergo desorption and later adsorption in the following sequence: zinc sulfate (85% nominal R.H.), drying chamber (60% R.H.), potassium carbonate (43% R.H.), drying oven (0% R.H.), and zinc sulfate.

To ensure equilibrium, each sample was weighed to the nearest 0.001 gram at least three times. The radial and tangential dimensions of each sample were measured twice with a caliper to the nearest 0.001 inch. After the final sorption run, each sample was soaked in water for 24 hr, then taken out and any excess surface moisture was carefully removed with blotters. The volume was determined by mercury displacement method with an Amsler volumeter, which is accurate to 0.01 cc.

After sorption runs, all samples underwent two extraction treatments in a soxhlet apparatus. The first treatment consisted of hot-water extraction for 60 hr, with changes

TABLE 2. *Hygroscopicity of unextracted southern pines*

Species and wood type	No. samples	Sp. grav. (G) Mean	Sp. grav. (G) Range	Total shrinkage $\overline{S}_v$ (%)	Total shrinkage $\overline{S}_r/\overline{S}_t$	Total shrinkage r^2 (S_r/S_t on G)	Fiber saturation pt. Int. pt. Mean (%)	Fiber saturation pt. Int. pt. Range (%)	Fiber saturation pt. $1.115\overline{S}_v / \overline{G}$	Fiber saturation pt. r^2 (S_v on G)	E.M.C. at 85% RH Ads. (%)	E.M.C. at 85% RH Des. (%)	E.M.C. at 85% RH Ratio
Slash pine													
Corewood	50	.520	(.35–.70)	8.42	.810	.00(NS)[a]	26.0	(20.5–33.1)	18.1	.00(NS)	11.8	16.1	.73
Maturewood	20	.596	(.53–.63)	16.02	.893	.27	28.9	(27.2–31.6)	30.0	.41	14.0	17.5	.80
Longleaf pine													
Corewood	48	.544	(.46–.72)	11.65	.731	.03(NS)	29.0	(23.3–37.8)	23.8	.51	12.8	16.7	.77
Maturewood	30	.585	(.51–.69)	13.08	.773	.58	27.4	(23.0–30.0)	24.5	.56	13.0	17.0	.77
Shortleaf pine													
Corewood	44	.422	(.34–.62)	11.46	.632	.04(NS)	29.6	(24.2–35.2)	28.9	.62	13.8	17.7	.77
Maturewood	30	.494	(.37–.61)	13.05	.645	.49	28.9	(25.4–33.5)	29.4	.84	13.9	17.4	.80
Loblolly pine													
Corewood	36	.433	(.35–.54)	12.12	.639	.12(NS)	31.8	(26.4–37.8)	31.2	.29	13.8	17.9	.77
Maturewood	30	.500	(.40–.66)	13.24	.723	.42	28.1	(24.0–31.5)	32.4	.67	13.3	17.5	.77
Spruce pine	26	.412	(.35–.48)	8.88	.521	.08(NS)	26.0	(20.0–33.8)	24.1	.06(NS)	13.7	15.5	.88
Pond pine	24	.466	(.42–.59)	11.96	.656	.12(NS)	27.2	(23.7–30.8)	28.5	.12(NS)	13.7	15.7	.87
Pitch pine	22	.537	(.44–.64)	11.20	.625	.04(NS)	26.9	(24.0–34.2)	23.3	.01(NS)	14.4	17.6	.82
Virginia pine	14	.458	(.45–.53)	11.23	.651	.05(NS)	28.8	(24.0–32.4)	27.3	.21	14.2	16.5	.86
Sand pine	24	.451	(.30–.58)	10.27	.627	.32	27.8	(24.8–32.8)	25.4	.04(NS)	14.0	17.3	.81
Table-mtn. pine	8	.414	(.39–.43)	11.25	.609	.02(NS)	29.0	(25.0–34.4)	30.0	.02(NS)	14.2	15.5	.92

[a] (NS)—Not significant at 5% level of probability.
Symbols used: G = specific gravity based on green volume; S_r = radial shrinkage; S_t = tangential shrinkage; S_v = volumetric shrinkage ($S_r + S_t$); r^2 = coefficient of determination of a regression equation.

of water every 12 hr. The second extraction treatment was with consecutive acetone for 24 hr, and 2:1 benzene-methanol for 46 hr, followed by soaking in running water for about one week in order to displace the organic solvents in the wood. After hot-water, and again after chemical extraction, the samples were slowly air-dried for several days, then placed in a drying oven at 215 F for 48 hr, and their dimensions measured once more.

The determination of apparent fiber saturation point by the intersection point method has been described by Kelsey (1956) and Nearn (1955). This consists essentially of plotting the usual linear pattern of shrinkage against moisture content and extrapolating this line to zero shrinkage.

The experimental shrinkage value, either radial or tangential, was calculated by dividing the difference between green dimension and dimension at a certain humidity condition by the green dimension. The apparent total volumetric shrinkage (S_v), as determined from the summation of the radial shrinkage (S_r) and tangential shrinkage (S_t), is:

$$S_v \cong S_r + S_t \qquad (3)$$

which should give a very close approximation of the value obtained from

$$S_v = S_r + S_t + S_l - [(S_r)(S_t)(S_l)/100] \quad (4)$$

The value of S_v obtained from Equation (3) will have a deviation of less than 0.75% shrinkage from that obtained with Equation (4), if the normal longitudinal shrinkage (S_l) is assumed to vary between 0.00 and 0.75%. Koehler (1931) showed that this is the approximate range of values for southern pines.

RESULTS AND DISCUSSION

Averages obtained from experimental data for a number of unextracted samples are presented in Table 2, and for extracted samples in Tables 3 and 4.

Shrinkage

The average unextracted volumetric shrinkage of each of the four major species was lower in the corewood than in the maturewood (Table 2). The difference, especially in slash pine, was much too large to be attributable to the lower specific gravity of the corewood. Extraction of these woods by either hot-water treatment (Table 3) or by combined hot-water and chemical treatment (Table 4) resulted in

TABLE 3. *Hygroscopicity of hot-water extracted southern pines*

Species and wood type	Sp. grav. (G)	Total shrinkage: $\bar{S}_v$ (%)	Total shrinkage: Per cent increase in $\bar{S}_v$[a] (%)	Total shrinkage: $\bar{S}_r/\bar{S}_t$	Total shrinkage: r^2 (S_r/S_t on G)	Fiber saturation pt.: $\frac{1.115\bar{S}_v}{\bar{G}}$	Fiber saturation pt.: r^2 (S_v on G)	Extractives removed (%)	Extractives in cell wall (estimated) (%)
Slash pine									
Corewood	.495	9.72	15.4	.810	.00(NS)[b]	21.8	.02(NS)	5.3	5.2
Maturewood	.585	17.17	7.0	.864	.39	33.0	.75	1.9	2.3
Longleaf pine									
Corewood	.517	12.97	11.2	.767	.00(NS)	28.0	.34	4.4	3.8
Maturewood	.570	13.78	5.4	.760	.55	27.0	.65	2.6	1.8
Shortleaf pine									
Corewood	.425	12.34	7.7	.667	.00(NS)	32.3	.57	2.6	2.6
Maturewood	.489	14.06	7.7	.692	.69	32.1	.88	2.2	2.6
Loblolly pine									
Corewood	.420	13.55	11.7	.661	.10(NS)	35.9	.30	3.1	3.9
Maturewood	.486	14.26	7.7	.729	.53	32.8	.70	2.6	2.6
Spruce pine	.406	10.35	16.5	.544	—	28.4	—	3.0	5.5
Pond pine	.481	12.30	2.8	.664	—	28.5	—	2.2	1.0
Pitch pine	.534	11.57	3.3	.613	—	24.2	—	2.0	1.1
Virginia pine	.452	12.28	9.3	.691	—	30.2	—	2.4	3.1
Sand pine	.443	10.65	3.7	.669	—	26.8	—	2.6	1.2
Table-mtn. pine	.432	12.10	7.5	.605	—	31.2	—	2.1	2.5
			8.4			29.4		2.8	2.8

[a] Based on unextracted value.
[b] (NS)—Not significant at 5% level of probability.

a substantial increase in shrinkage. The amount of extractives removed was greater in the corewood, especially in slash and longleaf pine, than in the maturewood of the major species and the mixed-wood of the minor species.

The variations in untreated volumetric shrinkage within the minor species are shown in Fig. 1. There appeared to be no definite trend with height in the tree, although there was a consistent trend with radial position. The volumetric shrinkage was lowest near the pith (corewood) and increased progressively toward the bark. In some woods, this increase was quite substantial. Boutelje (1958) found a similar relationship between maximum swelling and distance from the pith in Swedish pine. Thus, there seems to be some inverse correlation between shrinkage and the amount of extractives in wood. Kurth (1933) found that the extractive content of a young longleaf and shortleaf pine tree increased from bark to the pith. Others (Anderson 1962; Stanley 1968) also showed that the heartwood of pines contained much more extractives than the sapwood.

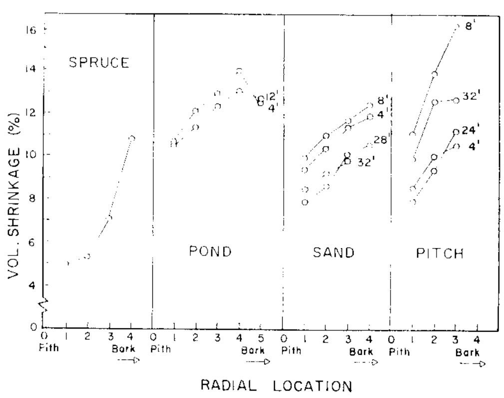

FIG. 1. Variation of volumetric shrinkage with height and radial location in the tree stem for various minor species of southern pine.

The low shrinkage of extractive-rich wood has been attributed to the bulking action of water-soluble extractives in the cell wall (Nearn 1955; Stamm 1964), which reduces the space available for water adsorption. This water-soluble extractive ef-

TABLE 4. *Hygroscopicity of hot-water and chemical (acetone and benzene-methanol mixture) extracted southern pines*

Species and wood type	Sp. grav. (G)	Total shrinkage $\bar{S}_v$ (%)	Per cent increase in $\bar{S}_v$[a]	$\bar{S}_r/\bar{S}_t$	r^2 (S_r/S_t on G)	Fiber saturation pt. $\frac{1.115\bar{S}_v}{\bar{G}}$	r^2 (S_v on G)	Extractives removed	Extractives in cell wall (estimated) (%)
Slash pine									
Corewood	.410	10.79	28.2	.847	.00(NS)[b]	29.3	.20	19.0	9.5
Maturewood	.575	18.01	12.2	.921	.29	34.4	.76	3.2	4.1
Longleaf pine									
Corewood	.454	13.25	13.6	.737	.26	32.6	.65	13.3	4.6
Maturewood	.560	14.32	9.5	.777	.72	28.5	.70	4.4	3.2
Shortleaf pine									
Corewood	.415	13.21	15.3	.651	.04(NS)	35.4	.73	4.8	5.1
Maturewood	.482	14.36	10.0	.656	.71	33.4	.85	3.5	3.4
Loblolly pine									
Corewood	.410	13.72	13.2	.678	.32	37.3	.42	5.3	4.4
Maturewood	.470	15.04	13.6	.737	.53	35.6	.78	4.5	4.5
Spruce pine	.390	10.77	21.3	.524	—	30.7	—	5.0	7.1
Pond pine	.464	12.75	8.3	.671	—	31.1	—	4.5	2.8
Pitch pine	.513	12.41	10.8	.801	—	27.0	—	3.3	3.6
Virginia pine	.446	12.61	12.3	.702	—	31.0	—	3.4	4.1
Sand pine	.426	11.32	10.2	.650	—	29.0	—	4.0	3.4
Table-mtn. pine	.424	12.30	9.3	.631	—	32.3	—	4.4	3.1
			13.4			32.0		5.9	4.5

[a] Based on unextracted value.
[b] (NS)—Not significant at 5% level of probability.

fect is borne out by the fact that most of the increase in shrinkage in this study was accomplished after hot-water treatment. Chemical extraction caused an additional increase in shrinkage, probably by removing more of the water-soluble extractives and also the water-insoluble ones from the cell wall. The effect of residual organic solvent on shrinkage should have been negligible (Stamm and Harris 1953), especially since most of the organic solvent should have been replaced by water through pre-soaking treatment before shrinkage was determined.

The amount of extractives in the cell wall can be estimated from shrinkage data. Table 3 shows that the average increase in shrinkage was 8.4% after hot-water treatment. Assuming that the fiber saturation point (based on volume of water per unit dry weight of wood) is 28.0% and the specific gravity of the water-soluble extractives is 1.2, then the weight of the extractives per unit weight of dry wood would be: (volume of extractives) × (specific gravity) = (0.28 × 0.084) × 1.2 = 0.028 or 2.8%. The average per cent of extractives removed was also 2.8%. This may suggest that all the water-soluble extractives were in the cell wall. By similar reasoning, the amount of extractives in the cell wall after hot-water and chemical treatment was found to be 4.5%. This was less than the total amount of extractives removed (5.9%), indicating that some of the extractives must have been confined to the coarse capillaries and therefore were not effective in reducing shrinkage. The removal of these extractives would merely influence the hygroscopicity of wood by decreasing the inert weight of wood substance.

The coefficient of shrinkage anisotropy, which is the ratio of radial to tangential shrinkage of wood, in general, is close to 0.60 (Kollman and Côté 1968). This ratio was found to be well correlated ($r^2 = 0.66$)

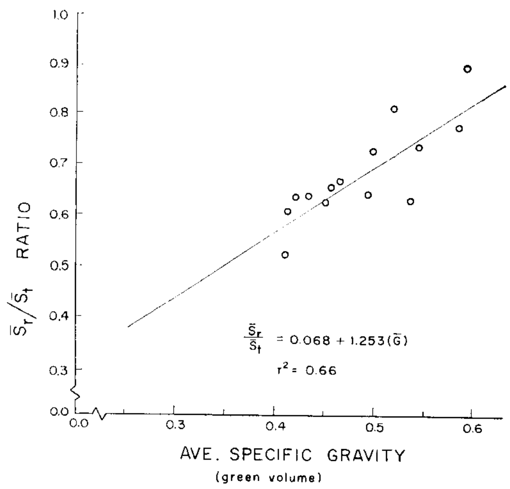

FIG. 2. Linear relationship between average ratio of radial to tangential shrinkage and average specific gravity for the 14 species and wood type combinations tested.

with specific gravity as shown in Fig. 2; but it held only for the maturewood of the major southern pine species (Table 5). The high regression coefficient for radial shrinkage indicates that the variation of volumetric shrinkage due to specific gravity is largely controlled by shrinkage in the radial direction. Nakato (1958), who worked with isolated springwood and summerwood of several Japanese species, also found that the ratio of radial to tangential shrinkage increases with density. Accordingly, tangential shrinkage should be less dependent on specific gravity.

The causes of shrinkage anisotropy have been explained by a number of authors (Boutelje 1962; Kelsey 1956). A significant negative correlation between the ratio of tangential to radial shrinkage and density has been established by Mörath (1932). His hypothesis predicts greater tangential than radial shrinkage in gross wood of conifers by virtue of the denser summerwood shrinking more than the springwood. This theory was confirmed by the results of Vintilla (1939), Pentoney (1953), and Boutelje (1962), for several conifers. All of them found that the tangential shrinkage of the summerwood was always larger than that of the springwood. The ratio of tangential to radial shrinkage for summerwood was near unity, whereas the ratio for springwood was more than 2. Since Mörath's mechanism is dependent on the volume of summerwood and springwood, its importance would increase as the relative volume of springwood increases and the specific gravity of wood decreases.

TABLE 5. *Regression equations of several shrinkage properties on specific gravity (G) based on green volume for various groups of southern pine species and various extraction treatments*

Shrinkage property	Major southern pines				Minor southern pines	
	Corewood		Maturewood			
	Unextracted					
S_r	(NS)[a]	(.00)[b]	−2.6 + 15.7 G	(.62)	(NS)	(.19)
S_t	(NS)	(.00)	4.0 + 6.9 G	(.35)	(NS)	(.06)
S_v	(NS)	(.03)	1.2 + 22.7 G	(.58)	(NS)	(.13)
S_r/S_t	(NS)	(.08)	0.01 + 1.33G	(.51)	(NS)	(.17)
	Extracted with Hot Water					
S_r	(NS)	(.08)	−2.4 + 16.5 G	(.62)	—	
S_t	(NS)	(.01)	4.0 + 8.1 G	(.38)	—	
S_v	(NS)	(.03)	1.5 + 24.7 G	(.56)	—	
S_r/S_t	(NS)	(.08)	0.09 + 1.25G	(.59)	—	
	Extracted with Hot Water and Chemicals					
S_r	1.0 + 10.0G	(.40)	−1.9 + 16.4 G	(.55)	—	
S_t	1.4 + 14.0G	(.31)	4.5 + 8.8 G	(.28)	—	
S_v	2.4 + 24.1G	(.41)	2.6 + 25.2 G	(.49)	—	
S_r/S_t	(NS)	(.01)	0.03 + 1.52G	(.59)	—	

[a] (NS)—Not significant at 5% level of probability.
[b] Number in parenthesis refers to r^2 value.

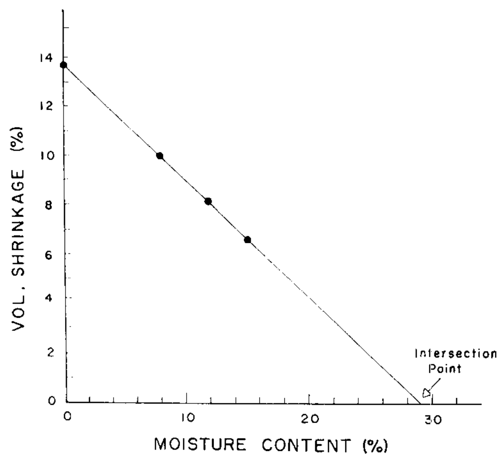

FIG. 3. Typical linear relationship between volumetric shrinkage and moisture content to determine the shrinkage intersection point.

If the cell cavities shrink in the same proportion as the cell walls, then the shrinkage of the gross wood would be proportional to the weight and not the volume of the moisture sorbed, and therefore would be independent of cell wall thickness or density of wood. The evidence (Ellwood and Wilcox 1962; Nearn 1955) is that shrinkage of cell cavities may be expected to be greater tangentially than radially and, consequently, tangential shrinkage may be less dependent on specific gravity than radial shrinkage. This effect would also explain, at least in part, why a correlation of radial to tangential shrinkage ratio with specific gravity occurs only in maturewood which contains little extractives and therefore is less susceptible to abnormally low shrinkage.

Fiber Saturation Point

Fig. 3 illustrates a typical shrinkage—moisture content curve used to determine the intersection point as an indicator of fiber saturation point of wood. Since a straight line could be fitted graphically in most cases, no mathematical treatment was made to fit the curve. Results from erratic samples were discarded. The samples were considered "stress-free" because they were thin enough to insure against compression set during drying. The intersection points were found to vary considerably within and between species. The range and average values for each species and wood type combination are shown in Table 2.

The average unextracted apparent fiber saturation point predicted from Equation (1) (i.e. $1.115\overline{S}_v/\overline{G}$ ratio) tends to be somewhat lower than the corresponding average value obtained from the shrinkage intersection point method. From this it may be assumed that the cell cavities are enlarging on shrinkage rather than remaining constant in value. No correlation between these values was found for the various species tested. However, the ratio increased after hot-water and chemical treatment and corresponded closely to the unextracted intersection point value. The resultant correlation was 0.73. The effect of extractives on the intersection point was not determined in this study; but Nearn (1955) found that the removal of extractives led to an increase in intersection point. In a few species, including the southern pines, Nearn reported that the intersection point either showed slight increase or continued low value following hot-water extraction.

Spruce pine and the corewood of slash and longleaf pine show the greatest increase in the average shrinkage—specific gravity ratio as a result of extraction treatment. This is brought about by a substantial increase in shrinkage and, in slash pine, by a substantial decrease in weight due to the removal of extractives. The loss in weight is most pronounced after hot-water and chemical treatment, since a large portion of the water-insoluble extractives were removed. The effect of extraction on the volumetric shrinkage—specific gravity relationship is shown in Fig. 4. For unextracted wood, the points are widely scattered ($r^2 = 0.21$), and the shrinkage for slash pine corewood is far lower than the others. Hot-water extraction improved this relationship slightly ($r^2 = 0.31$); whereas combined hot-water and chemical treatment improved it considerably ($r^2 = 0.59$), partly because of its effect on specific gravity. In extractive-rich wood, specific gravity is not a reliable indication of the amount of wood sub-

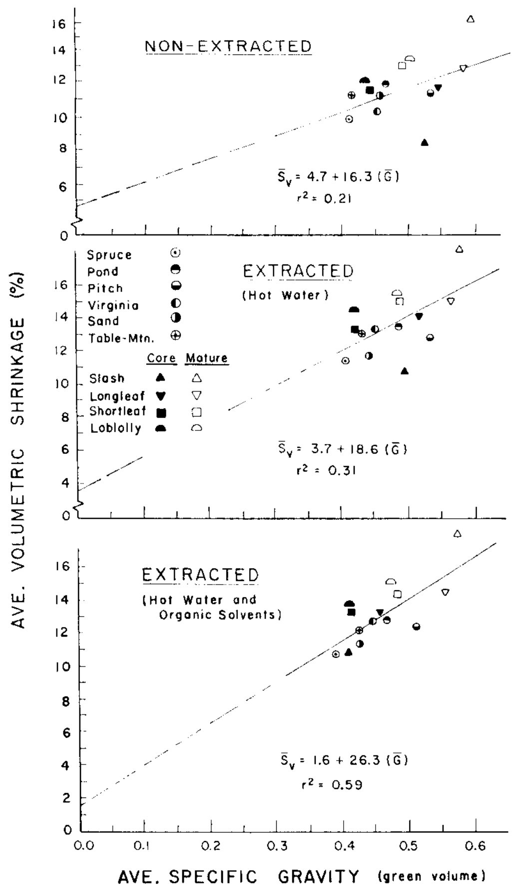

FIG. 4. Relationship of average volumetric shrinkage and average specific gravity for unextracted and extracted wood.

stance. Unless the extractives are removed from the wood, specific gravity cannot be used satisfactorily to predict shrinkage or fiber saturation point from Stamm's relationship (Equation (1)). Further evidence of this is found in Table 5. The corewood of the major species shows no significant correlation between shrinkage and specific gravity until hot-water and chemical extraction treatment has removed most of the extractives. The maturewood, on the other hand, having much lower extractives content, shows good correlation, and extraction merely changed the slope of the regression equation slightly.

In some woods, the ratio of shrinkage to specific gravity is still low even after extensive extraction treatment. This is the case for pitch pine. There must be other causes besides the presence of extractives for such low shrinkage values. Boutelje (1958) reported that the maximum swelling—density ratio is much larger for sapwood than for heartwood, but that is not caused solely by the greater percentage of resin in the heartwood, since extraction of resin did not seem to affect the hygroscopic changes in volume of the heartwood. Stamm and Loughborough (1942) indicated that a change in dimension of the cell cavity, resulting either from mechanical restraint or from internally imposed drying stresses, can cause low shrinkage. In such a case, the shrinkage of the wood is less than the volume of water sorbed, so that much of the shrinkage is internal. Since different parts of the cell wall have different sorption tendencies and different stress patterns during drying, their shrinkage behavior may be different. It is possible then for the bulking extractives in the cell wall to contribute some restraining influence during pre-drying, causing abnormal shrinkage by tension set. Further studies using previously undried wood are necessary to ascertain the relations between shrinkage and stress formation during mild drying.

Equilibrium Moisture Content

The unextracted equilibrium moisture contents for various southern pine species are shown in Table 2. Differences among species were found to be statistically significant ($P = 0.05$). For the same sorption and humidity condition, those species with higher extractive content generally had lower moisture content values at equilibrium, clearly showing the bulking effect of the extractive substance in wood. The average hysteresis constant at 85% relative humidity was close to 0.80, which agrees well with published values (Wangaard and Granados 1967). No sorption runs were made on extracted samples because Nearn (1955), Anderson (1961), and recently Wangaard and Granados (1967) have already demonstrated that the equilibrium moisture content values for extracted wood are always higher than unextracted values at higher ranges of humidity.

CONCLUSIONS

From shrinkage measurements of unextracted and extracted samples of 10 southern pine woods, the following conclusions were drawn:

1. The individual hygroscopic properties of wood can be attributed largely to the components of wood. The water-soluble extractives bulk the cell wall and cause low shrinkage. The water-insoluble extractives which are confined largely to the gross capillaries add weight to the wood, and therefore affect its specific gravity. Accordingly, the relationship between volumetric shrinkage and specific gravity can be used to predict fiber saturation point if the wood has low extractive content and the volume of the cell cavities remains constant.

2. Larger percentages of extractives may be removed from the corewood than from the maturewood, but the amount also differs among species. The corewood of slash pine and longleaf pine has considerably more extractives than other species.

3. The ratio of radial to tangential shrinkage increases with an increase in specific gravity, probably because of density difference within the annual ring and greater tangential shrinkage in the cell cavities.

4. The average unextracted shrinkage—specific gravity ratio is much lower than the extracted ratio.

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