SHRINKING AND SWELLING DIFFERENCES BETWEEN HARDWOODS AND SOFTWOODS

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ABSTRACT

Using existing data in the Wood Handbook as a basis for calculations, it is shown that at similar specific gravities hardwoods shrink, and presumably swell, more than softwoods. A possible explanation to account for this difference in behavior is presented, in which the lower lignin content of hardwoods, resulting in a reduced restraint to dimensional change, is considered. Evidence is also presented indicating that at least for hardwoods, the relationship between specific gravity and volumetric shrinkage is not completely linear.

INTRODUCTION

The shrinking and swelling of wood and related wood-liquid relationships affect many of the physical properties and the economic utilization of wood. The changes in dimension and volume of wood with changing moisture content have been observed and studied by numerous individuals, and this phenomenon is discussed in most recent textbooks of wood science and technology (Kollmann and Côté 1968; Stamm 1964; Brown, Panshin, and Forsaith 1952; Browning 1963). Of the various aspects of wood in relation to moisture, the interdependence among moisture content below the fiber saturation point, dimensional changes, and specific gravity of the wood have been studied extensively.

Newlin and Wilson (1919) were the first to show graphically a direct linear relationship between volumetric shrinkage of different wood species and specific gravity. The shrinkage was from green to oven-dry condition and the specific gravity based on oven-dry weight and green volume. A total of 164 species, both hardwoods and softwoods, were evaluated together. The plotted points, although showing considerable deviation, fit a straight line through the origin. The ratio of per cent volumetric shrinkage to specific gravity was 28.

Stamm and Loughborough (1942; Stamm 1964) using the data of Markwardt and Wilson (1935) plotted total volumetric shrinkage of green wood versus specific gravity for 52 softwoods and 106 hardwoods separately. The relationship was considered linear, and the ratio of per cent shrinkage to specific gravity was 26 for the softwoods and 27 for the hardwoods. The slightly higher ratio value for hardwoods could be considered due to a 1–2% higher fiber saturation point for hardwoods than for softwoods (Stamm and Loughborough 1942), probably because of a higher hemicellulose content of hardwood species.

Similar results were obtained by other researchers (Kollmann and Côté 1968; Stamm 1964), with Greenhill (1940) observing values from 170 Australian wood species giving a ratio of 27. Although there was considerable individual species variation, a linear relationship between volumetric shrinkage and specific gravity seemed reasonable without differentiating between hardwoods and softwoods.

For those species showing abnormally low volumetric shrinkage, such as redwood, eastern red cedar, honey locust and black locust, a high extractive content of the wood is responsible. Stamm and Loughborough (1942) considered the extractives as a bulking agent replacing a portion of the water that normally would be absorbed. It was shown conclusively by Wangaard and Granados (1967) that the principal effect of extractives is to depress the sigmoid isotherm in the upper range of wood moisture content consistent with the theory of bulking action whereby the extractive substance within the cell wall precludes moisture from occupying the same space.

Some species such as basswood and balsa (Kollmann and Côté 1968) show unusually large volumetric shrinking and swelling, which is not as easily explained as abnormally low shrinkage. Considerable changes in the size of the lumina of these woods during shrinking and swelling are assumed to occur. Another possible explanation is that these species, usually of a low specific gravity, have an abnormally high fiber saturation point (Vorreiter 1963; Feist and Tarkow 1967; Kellogg and Wangaard 1969), resulting in greater shrinking and swelling from greater changes in moisture content.

Other facets of shrinking and swelling phenomena have been thoroughly studied also, including the effect of specific gravity on the ratio of tangential shrinkage to radial shrinkage or swelling (Kollmann and Côté 1968; Brown, Panshin, and Forsaith 1952). In all of these studies hardwoods and softwoods were considered similar in behavior, and differences are often ascribed to differences in specific gravity, a measure of the amount of cell-wall material present in the wood. That hardwoods generally shrink and swell more than softwoods is considered due to many hardwood species having a specific gravity higher than that of most softwoods. In none of these previous studies have hardwoods and softwoods been segregated into discrete specific gravity classes and then viewed independently.

DATA AND CALCULATIONS

All of the data upon which the calculations are based were obtained from the Wood Handbook (U. S. Forest Products Laboratory 1955). Specific gravity and volumetric shrinkage values are from Table 12, p. 70 and Table 39, p. 315, respectively, of the Wood Handbook. All wood species listed in both of these tables, 52 hardwoods and 36 softwoods, were used, regardless of whether some species were known to exhibit abnormal shrinkage characteristics. Specific gravity is based on green volume and oven-dry weight, and volumetric shrinkage is the total change from green volume to oven-dry volume.

The coefficient of volumetric shrinkage was determined by subtracting the volumetric shrinkage to 20% moisture content from the volumetric shrinkage to 6% moisture content and dividing by the per cent moisture difference, which is 14. The specific coefficient is simply the volumetric coefficient of shrinkage divided by the specific gravity of the wood species. The results are given in Table 1, listed in order of increasing specific gravity.

The specific gravities of the individual wood species were arbitrarily grouped into classes, such that at least three species were present in each specific gravity class. Averaged shrinkage values for hardwoods and softwoods segregated according to specific gravity classes are given in Table 2.

RESULTS AND DISCUSSION

Two discrepancies are noted in the data presented in Table 2. The lowest specific gravity hardwoods have a higher than normal shrinkage even for hardwoods. Those species known to exhibit abnormally large shrinking and swelling are usually very light hardwoods (Kollmann and Côté 1968) and one of these species, basswood, is included in this evaluation. Collectively, the six softwoods in the specific gravity range 0.41–0.45 exhibit a lower than expected shrinkage. Some of the species in that range, such as eastern red cedar, have lower than usual shrinkage because of a high extractive content. Rather than bias the evaluation, all data available in the Wood Handbook (U. S. Forest Products Laboratory 1955) were used.

In comparing the overall shrinkage values presented in Table 2, however, it becomes readily apparent that at similar specific gravities hardwoods shrink more than softwoods. The average hardwood shrinks 2.1 % more than softwood when drying from

TABLE 1. *Specific gravity and shrinkage values of different wood species*

Wood species	Specific[a] gravity	Volumetric[a] shrinkage %	Coefficient[b] of volumetric shrinkage	Specific coefficient[c] of volumetric shrinkage
		Hardwoods (52 species)		
Black cottonwood	0.32	12.4	0.41	1.28
American basswood	0.32	15.8	0.52	1.63
Quaking aspen	0.35	11.5	0.38	1.09
Butternut	0.36	10.6	0.36	1.00
Red alder	0.37	12.6	0.42	1.14
Eastern cottonwood	0.37	14.1	0.47	1.27
Yellow-poplar	0.40	12.3	0.41	1.03
Bigleaf maple	0.44	11.6	0.39	0.89
Silver maple	0.44	12.0	0.40	0.91
Cucumber tree	0.44	13.6	0.46	1.05
Black ash	0.45	15.2	0.51	1.13
Southern magnolia	0.46	12.3	0.41	0.89
Water tupelo	0.46	12.5	0.41	0.89
Black tupelo	0.46	13.9	0.46	1.00
American sycamore	0.46	14.2	0.48	1.04
American elm	0.46	14.6	0.49	1.07
Sweetgum	0.46	15.0	0.50	1.09
Black cherry	0.47	11.5	0.39	0.83
Slippery elm	0.48	13.8	0.46	0.96
Paper birch	0.48	16.2	0.56	1.17
Red maple	0.49	13.1	0.44	0.90
Hackberry	0.49	16.9	0.56	1.14
Oregon ash	0.50	13.2	0.44	0.88
Black walnut	0.51	12.8	0.42	0.82
Black maple	0.52	14.0	0.46	0.88
Southern red oak	0.52	16.3	0.54	1.04
Green ash	0.53	12.5	0.41	0.77
White ash	0.55	13.4	0.44	0.80
Yellow birch	0.55	16.7	0.56	1.02
Northern red oak	0.56	13.5	0.45	0.80
Black oak	0.56	14.2	0.48	0.86
Sugar maple	0.56	14.9	0.49	0.88
American beech	0.56	16.3	0.54	0.96
Water oak	0.56	16.4	0.54	0.96
Willow oak	0.56	18.9	0.63	1.12
Laurel oak	0.56	19.0	0.64	1.14
Rock elm	0.57	14.1	0.47	0.82
Chestnut oak	0.57	16.7	0.56	0.98
Bur oak	0.58	12.7	0.43	0.75
Pin oak	0.58	14.5	0.49	0.84
Honey locust	0.60	10.8	0.36	0.60
Pecan hickory	0.60	13.6	0.46	0.77
Scarlet oak	0.60	13.8	0.46	0.77
Sweet birch	0.60	15.6	0.52	0.87
White oak	0.60	15.8	0.52	0.87
Post oak	0.60	16.2	0.54	0.90
Swamp chestnut oak	0.60	16.4	0.54	0.90
Shellbark hickory	0.62	19.2	0.64	1.03
Shagbark hickory	0.64	16.7	0.56	0.88
Mockernut hickory	0.64	17.9	0.59	0.92
Black locust	0.66	10.2	0.34	0.52
Pignut hickory	0.66	17.9	0.59	0.89

[a] Specific gravity and volumetric shrinkage values obtained from Table 12, p. 70 and Table 39, p. 315, respectively, of the Wood Handbook (1955). Values are based on green volume and oven-dry weight or volume.
[b] Coefficient calculated using data in Table 39, p. 315, Wood Handbook (1955). Volumetric shrinkage to 6% moisture content minus volumetric shrinkage to 20% content divided by per cent moisture content difference, 14.
[c] Column 3 divided by column 1.

TABLE 1. Continued

Wood species	Specific[a] gravity	Volumetric[a] shrinkage %	Coefficient[b] of volumetric shrinkage	Specific coefficient[c] of volumetric shrinkage
	Softwoods (36 species)			
Northern white cedar	0.29	7.2	0.24	0.83
Western red cedar	0.31	6.8	0.22	0.71
Atlantic white cedar	0.31	8.8	0.29	0.94
Engelmann spruce	0.32	10.4	0.34	1.06
Eastern white pine	0.34	8.2	0.28	0.82
Balsam fir	0.34	11.2	0.38	1.12
Incense cedar	0.35	7.6	0.26	0.74
Sugar pine	0.35	7.9	0.26	0.74
White fir	0.35	9.8	0.32	0.91
Pacific silver fir	0.35	13.8	0.46	1.31
Noble fir	0.35	13.8	0.46	1.31
Western white pine	0.36	11.8	0.39	1.08
Grand fir	0.37	11.0	0.36	0.97
Sitka spruce	0.37	11.5	0.39	1.05
California red fir	0.37	12.2	0.41	1.11
Redwood, old-growth	0.38	6.8	0.22	0.58
Ponderosa pine	0.38	9.6	0.32	0.84
Eastern hemlock	0.38	9.7	0.33	0.86
Black spruce	0.38	11.3	0.37	0.97
Lodgepole pine	0.38	11.5	0.39	1.03
Red spruce	0.38	11.8	0.39	1.03
Western hemlock	0.38	11.9	0.39	1.03
Port-Orford cedar	0.40	10.1	0.34	0.85
Douglas-fir, Rocky Mts.	0.40	10.6	0.36	0.90
Douglas-fir, intermediate	0.41	10.9	0.36	0.88
Red pine	0.41	11.5	0.39	0.95
Alaska cedar	0.42	9.2	0.31	0.74
Bald cypress	0.42	10.5	0.35	0.83
Eastern red cedar	0.44	7.8	0.26	0.59
Douglas-fir, coast	0.45	11.8	0.39	0.87
Shortleaf pine	0.46	12.3	0.41	0.89
Loblolly pine	0.47	12.3	0.41	0.87
Tamarack	0.49	13.6	0.46	0.94
Western larch	0.51	13.2	0.44	0.86
Longleaf pine	0.54	12.2	0.41	0.76
Slash pine	0.56	12.2	0.41	0.73

TABLE 2. *Shrinkage values of hardwoods and softwoods grouped according to specific gravity classes*

Specific gravity		Hardwoods				Softwoods			
Class	Range	No. of species	Avg. vol. shrinkage %	Avg. coef. of vol. shrinkage	Avg. sp. coef. of vol. shrinkage	No. of species	Avg. vol. shrinkage %	Avg. coef. of vol. shrinkage	Avg. sp. coef. of vol. shrinkage
1	0.36	3	13.2	0.44	1.33	11	9.6	0.32	0.95
2	0.36–0.40	4	12.4	0.42	1.11	13	10.8	0.36	0.95
3	0.41–0.45	4	13.1	0.44	1.00	6	10.3	0.35	0.81
4	0.46–0.50	12	13.9	0.47	0.99	3	12.7	0.43	0.90
5	0.51–0.55	6	14.3	0.47	0.89	3	12.5	0.42	0.78
6	0.56–0.60	18	15.2	0.51	0.88	*	—	—	—
7	0.60	5	16.4	0.54	0.85	0	—	—	—

* One species with specific gravity 0.56 included in prior class.

the green to oven-dry condition. This represents a 19% greater relative shrinkage for hardwoods.

Many wood-liquid relationships deviate considerably at the extremes in equilibrium moisture content. The sigmoid isotherm for moisture content of wood versus relative humidity is one example. Accurate measurements of moisture content near the fiber saturation point are also very difficult to obtain, and consequently the determination of the fiber saturation of a wood species is usually the result of extrapolation of data (Stamm 1964; Wangaard and Granados 1967; Kollmann and Côté 1968). Also, the increase in volume of wood with increasing moisture content is not a linear relationship near the extremes in equilibrium moisture content (Keylwerth 1962). Near oven-dry and near the fiber saturation point, the volumetric swelling is less per unit increase in moisture content than normal. For most wood species, however, the increase in volume between 6 and 20% moisture content is a linear relationship to moisture content. Consequently, the coefficient of volumetric shrinkage between 6 and 20% moisture content was determined. Use of this value should also minimize to some extent the effect of extractives upon shrinking and swelling, since extractives affect primarily the upper range of wood moisture content (Wangaard and Granados 1967). For similar specific gravities, the average coefficient of volumetric shrinkage of hardwoods is 0.07 higher than that of softwoods and this represents a 20% greater relative value.

The specific coefficient of volumetric shrinkage, a term not noticed in the existing literature, would indicate the effect of specific gravity upon the volume change per 1 % change in moisture content. This term should be the same for all specific gravity classes if the relationship between specific gravity and volumetric shrinkage were linear. For hardwoods this value consistently decreases with increasing specific gravity, indicating a nonlinear relationship. Also, for similar specific gravities the averaged specific coefficient of volumetric shrinkage is 0.19 higher for hardwoods than for softwoods, a 21% relative increase.

In all three of the shrinkage values determined, the hardwoods have been approximately 20% greater than the softwoods. Only 28% of the softwood species used have a specific coefficient of volumetric shrinkage greater than 1.00 at an average specific gravity of 0.36; whereas, 38% of the hardwoods have a specific coefficient of volumetric shrinkage greater than 1.00, and at a higher average specific gravity of 0.45. Hardwoods have greater shrinking, and presumably swelling, than softwoods. The cause for this difference in behavior must be due to differences in the cell wall of hardwoods and softwoods. Kellogg and Wangaard (1969) have noticed differences in both wood substance density and void volume in dry cell walls. Hardwoods have an averaged wood substance density of 1.522 and an average void volume of 3.21%; whereas, softwoods have values of 1.538 and 2.09, respectively. Except for the void volume in basswood, there is no overlap in the individual values for hardwoods and softwoods. Void volume should not affect shrinking and swelling behavior. It is difficult to visualize a causal relationship between shrinking and swelling and wood substance density unless it were due to differences in chemical composition.

Hardwoods and softwoods have about the same amount of cellulose, but they differ in the amount of lignin and hemicellulose. Hardwoods average less lignin than softwoods; the values being 22 and 28%, respectively. Conversely, hardwoods have about 5% more hemicellulose than softwoods. Hemicelluloses exhibit the highest sorptive capacity of any of the principal cell-wall constituents, followed by cellulose and lignin (Runkel and Lüthgens 1956; Christensen and Kelsey 1959). The hemicelluloses probably account for the same amount of increase in shrinking and swelling of hardwoods as they do for the increase in water absorption of hardwoods. Hardwoods have a higher fiber saturation point than softwoods of only 1–2% (Stamm and Loughborough 1942) amounting to a relative increase of approximately 5%. Hardwoods, however, have a 20% greater shrinkage than softwoods of comparable specific gravity.

Hardwoods average approximately 20% less lignin than softwoods. This lower lignin content has been determined experimentally to exist in the secondary wall of hardwood fibers (Fergus and Goring 1968; Bentum et al. 1969) and it is the secondary wall that is primarily responsible for the shrinking and swelling characteristics of wood. If it is assumed that the lignin acts as a restraint upon dimensional change of the secondary wall, this lowered lignin content should account for most of the differences in the shrinking and swelling of hardwoods and softwoods.

That the three-dimensional lignin macromolecule does indeed restrain shrinking and swelling can be seen when cotton, which contains essentially no lignin in the cell wall, is compared with wood. The cross-sectional swelling (comparable to volumetric swelling in wood) of mature cotton is 33% (Welo et al. 1952). This value compares favorably with the swelling of cotton fiber substance, 35%, thus indicating practically no changes in the lumen dimensions. This volumetric change is considerably higher than that of any wood, although the degree of crystallinity of cellulose in cotton and wood is about the same (Rydholm 1965). Viscose rayon, which has a low degree of crystallinity, swells considerably more—to 65%.

In cold soda pulping, the argument given for the ability to pulp hardwoods by this method and not softwoods is that there is less restraint to swelling in hardwoods because of a lower lignin content in the cell wall (Rydholm 1965).

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